Improving Energetic and Nitrogen Efficiency when Formulating for Amino Acids – a more Holistic Approach

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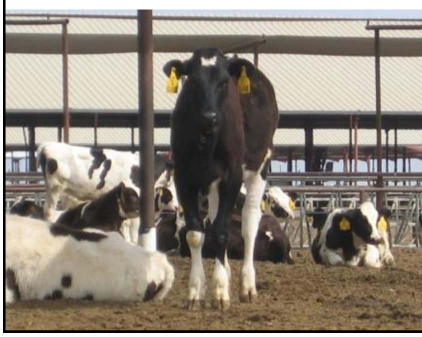

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Today's Talk

- Cows are changing and we need to be conscious of this
- **Protein synthesis** is required for lactose synthesis, fatty acid synthesis and milk protein synthesis
- The concept of N efficiency is energy dependent and, in a ruminant, might be related more to urinary N excretion than intake to milk N
- Thus, the concept of N efficiency is not just related to milk protein output, it is related to energy corrected milk as all components require N

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Efficiency of Use of Intake Nitrogen

- This is a tough metric for ruminants since they require non-protein N for rumen function
- When this is described for non-ruminants the N-currency is amino acids
- On farm N efficiencies (milk N:feed N) range from 20 to 32%
- Theoretical efficiency limit 40 to 45% in lactating dairy cattle (Van Vuuren and Meijs, 1987; Hvelplund and Madsen, 1995)
- Practical limit is ~38 to 40% (high cow groups are achieving this)
- Although it is an ambiguous metric, it can be useful if extended to whole body N metabolism

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Table 1 *Characteristics of the upper and lower quartile based on efficiency of N utilization (ENU) and milk yield*

	ENU (g milk N/100 g N intake)		3.5% Fat corrected milk (kg/day)	
	Low	High	Low	High
EU data set				
ENU (%)	21.0	32.0	24.8	28.7
3.5% FCM (l/day)	26.8	31.2	22.2	35.3
Forage (%)	66.5	56.9	67.4	52.6
Forage CP (%)	20.0	14.8	16.1	14.7
Forage NDF (%)	48.9	59.4	50.5	50.5
DMI (kg/day)	17.9	18.9	15.3	21.1
US data set				
ENU (%)	22.0	32.8	25.5	29.8
3.5% FCM (l/day)	31.8	38.2	27.0	41.6
Forage (%)	53.4	52.6	56.2	51.9
CP (%)	17.9	15.4	15.6	17.4
NFC (%)	31.8	38.2	39.2	42.8
DMI (kg/day)	23.2	23.8	21.0	24.3

FCM = fat corrected milk; DMI = dry matter intake; NFC = non-fibre carbohydrates.

Calsamiglia et al., 2010

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There are cows within groups achieving the theoretical limits of N efficiency

Hardie Family Farm, Lansing NY

High group average production: 120 ± 35 lb/d

Average DMI: 60.2 lb/d, 15.8% CP

Average N efficiency: 38% (productive N:intake N)

Cows at high end of production: ~168 lb/d milk

At estimated intake, N efficiency: 41%

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Efforts to reduce excessive protein feeding

Energetic value of overfeeding nitrogen or nitrogen excretion in urine – impacts on ME allowable milk:

- Reed et al. (2017) determined that overfeeding N increased heat expenditure in cattle, reducing energy for productive function
- In their data metabolizing RDP had a greater impact on heat production than RUP ~ 1.10 Mcal/kg vs 0.78 Mcal/kg
- Overfeeding rumen available protein will reduce the amount of energy available for milk and milk component synthesis
  - Disposal of excessive NH_3 can have a larger impact than RUP/AA

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Efforts to reduce excessive protein feeding

Morris et al., (2021) demonstrated that increasing urinary nitrogen (UN) excretion decreased metabolizable energy content of the diet as calculated from digestible energy:

- Urinary energy (UE) output was 1,390 to 3,160 kcal and UN was 85-220 g/d (20 to 60% of nitrogen intake)
- The best fitting equation was UE =14.6 ± 0.32 x UN (UE is kcals/g and UN is g/d)
- Urinary nitrogen needs to be accounted for when refining the calculation of dietary ME and lower nitrogen intake

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Efforts to reduce excessive protein feeding

- Nichols et al. (2022) review on urea recycling capabilities in ruminants:
  - Levels of rumen degradable protein should be optimized to capture ruminally recycled nitrogen → Improvements in nitrogen use efficiency
  - Excessive dietary urea feeding (>1% DM) elicits deleterious effects on animal (hypophagic effects, ammonia toxicity) and may lead to sequestered urea recycling
  - Increases in post-ruminal protein supply should help improve endogenous urea supply through hepatic production


Contents lists available at ScienceDirect

Animal

The international journal of animal biosciences

Review: Unlocking the limitations of urea supply in ruminant diets by considering the natural mechanism of endogenous urea secretion

K. Nichols *, I.P.C. de Carvalho, R. Rauch, J. Martín-Tereso

Trouw Nutrition R&D, P.O. Box 299, 3800 AG Amersfoort, the Netherlands

Formulating closer to nitrogen and amino acid requirements, reducing urinary N excretion, and reliance on endogenous urea recycling leads to improvements in energetic and nitrogen efficiency

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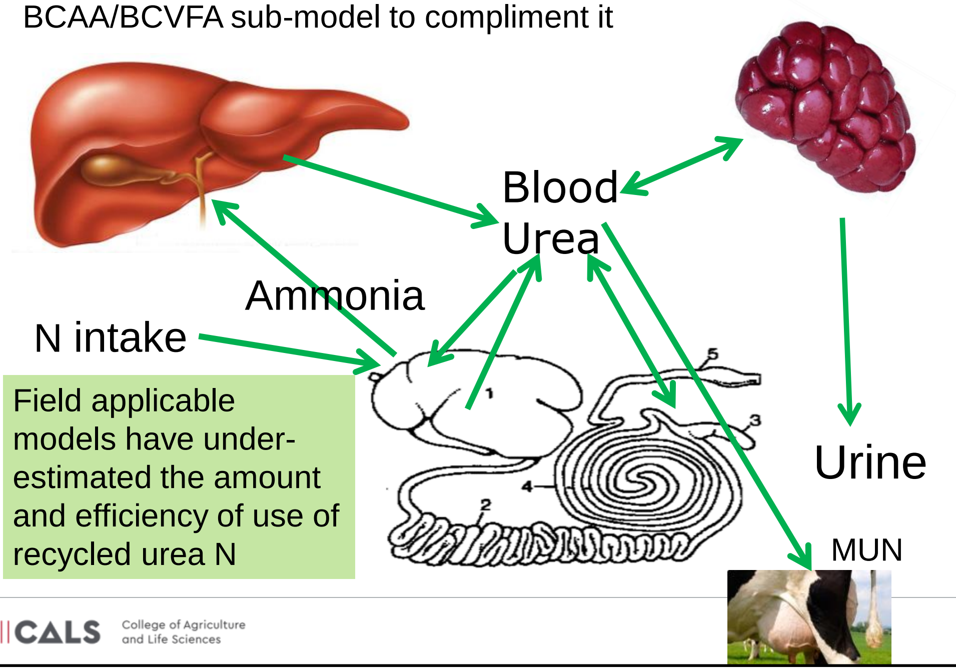
Full urea recycling sub-model and working on a BCAA/BCVFA sub-model to compliment it



Field applicable models have under-estimated the amount and efficiency of use of recycled urea N

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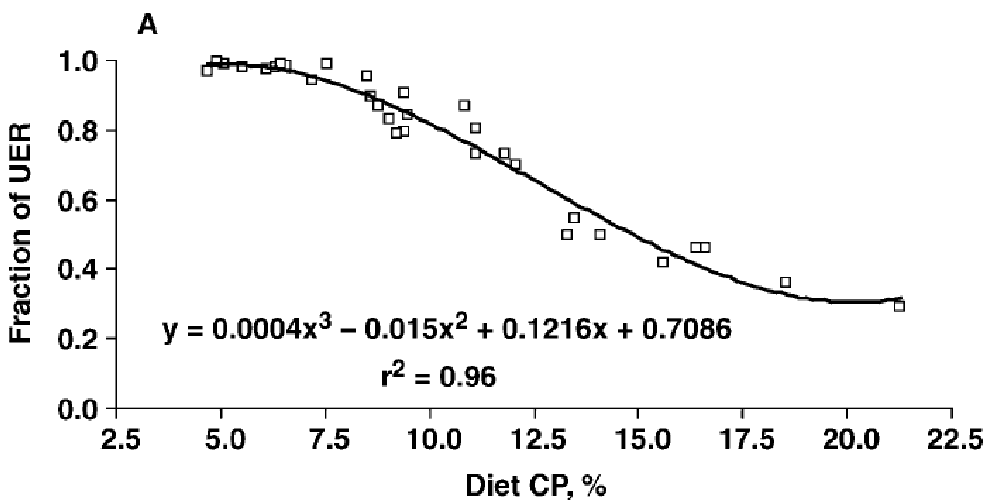
Urea entry rate to GIT



Reynolds and Kristensen, 2008

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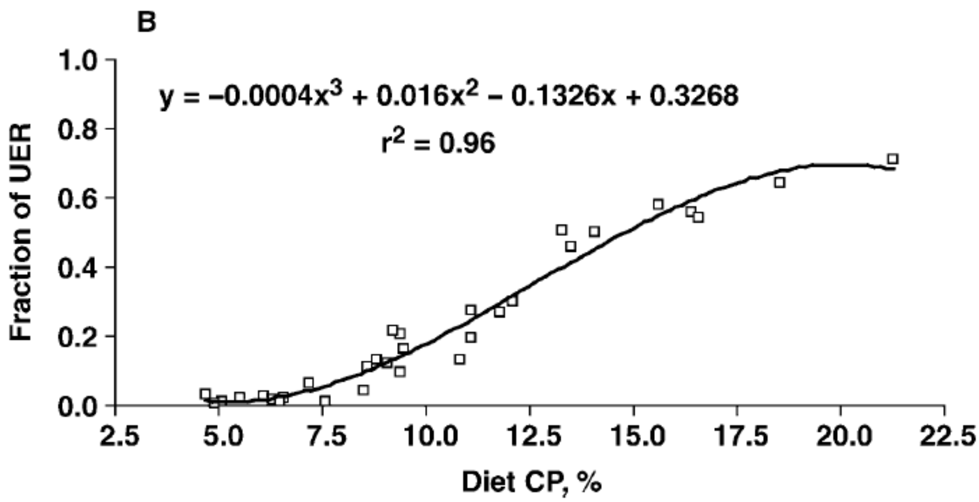
Urea entry rate that is excreted in urine/feces



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Reynolds and Kristensen, 2008

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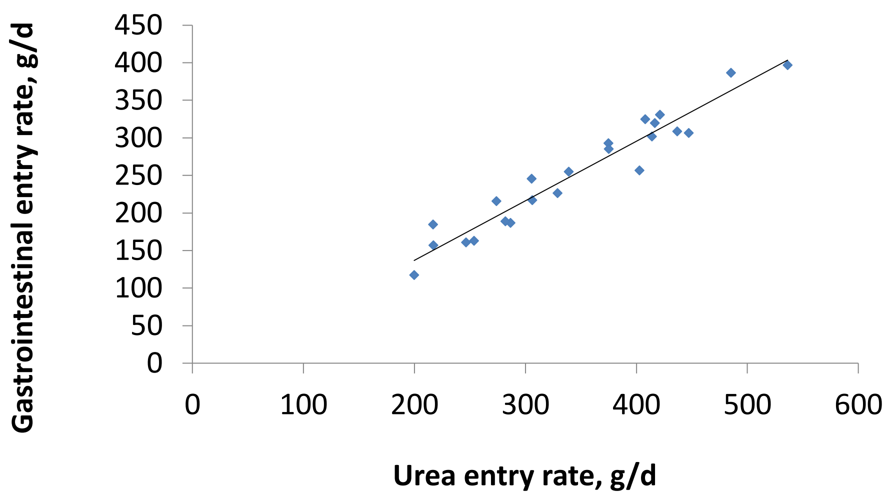
Urea-N entry rate and gastrointestinal urea-N entry rate for each experimental unit across all dietary treatments differing in dietary CP (15.3% and 16.7%), starch, and Rumensin inclusion fed to dairy cattle and continuously infused with $^{15}N^{15}N$ urea-N.



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Recktenwald et al. 2014

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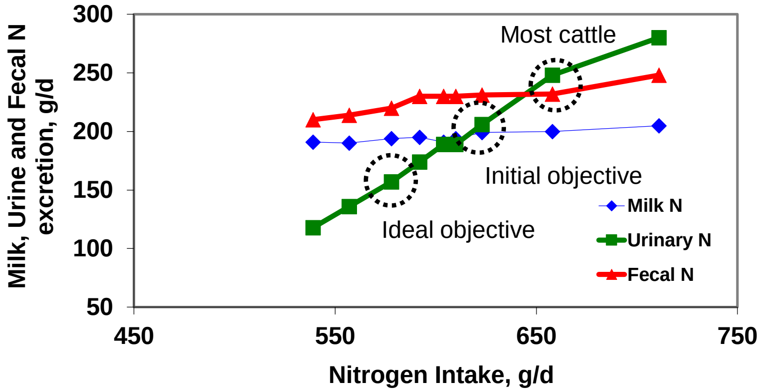
Nitrogen excretion in diets varying in dietary nitrogen



Milk Nitrogen: ~200 g or 1.28 kg (2.81 lb) protein

Urinary N:
- Most Cattle: ~250 g
- Initial Objective: ~200 g
- Ideal Objective : ~150 g

Milk N:Urinary N
- Most Cattle: 0.8
- Initial Objective: 1.0
- Ideal Objective : 1.3

Metrics can be used as a proxy for improvements of Productive N:Urinary N

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Van Amburgh et al. 2015 J. Dairy Sci

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Improving energetic efficiency through nitrogen reduction

- Moving from “most cattle” from 0.7:1.0 on productive N:urinary N to a 1:1 ratio results in a 660 g- 610 g = 50 g reduction in intake N and a proportional reduction in urinary N (1.5 lb soybean meal equivalent)
- Using the equation from Morris et al. 2021, reducing N excretion by 50 g would result in a retention of energy of 0.73 Mcals
  - Could be partitioned to milk or milk components
  - Reduce the environmental impact of milk production
  - Reduce feed costs improving IOFC
  - Results in an improvement in energetic efficiency of cattle

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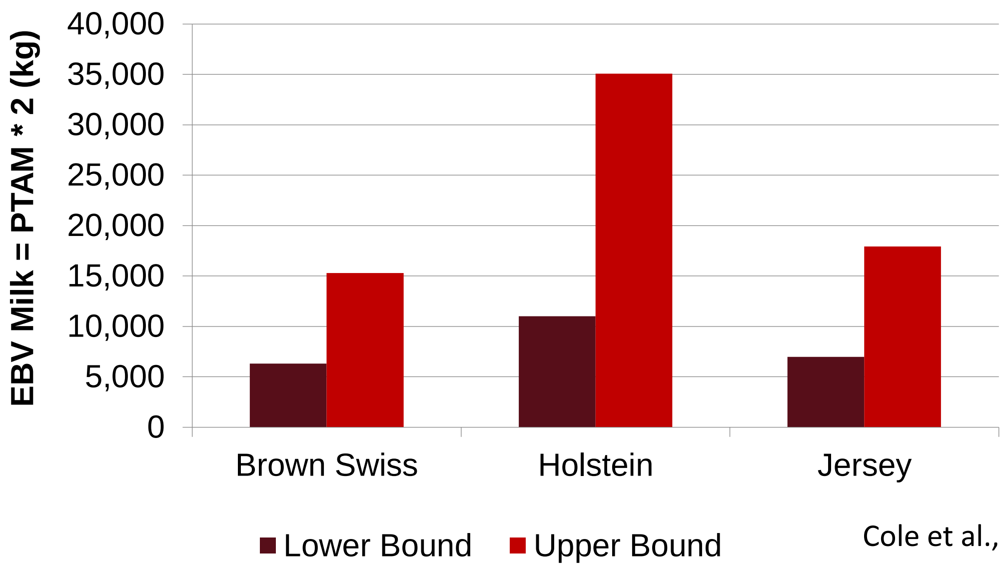
Genetic Potential: upper and lower bounds for Brown Swiss, Holstein and Jersey cattle



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Cole et al., 2010

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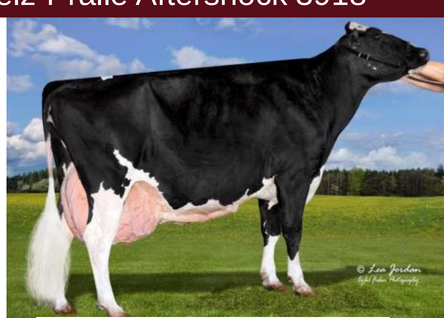
What are the limits? Two world record holders as examples

Selz-Pralle Aftershock 3918	Ever-Green-View My Gold - ET



PTA Milk = 228 kg
EBV Milk = 456 kg

35,467 kg + 34,601 kg=**70,068 kg**
Lower bound = **46,003 kg**

PTA Milk = 216 kg
EBV Milk = 431 kg

35,154 kg + 34,627 kg = **69,781 kg**
Lower bound = **46,170 kg**

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Chad Dechow, 2019

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Perspective

- Based on evaluations by J. Cole and C. Dechow, the genetic capacity for milk yield for Holsteins is approximately 75,000 lb
  - There are cows on commercial farms in Central NY in high performing herds that are peaking in milk yield between 186 to 214 lb/d (>44,0000 lb/lactation)
- My perspective is that many cows in a herd have this capacity.
- Leads to the question, what are we doing, and when, that either detracts from or fails to "turn on" that ability and when is that communicated to the animal?

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Cow 6028 4th lactation record

- 41,150 lb milk, 1,739 lb fat, 1,370 lb protein in 367 days of lactation
- She averaged 103 lb/d for the lactation

PEN	4	CALF1	7980	SID	11H11665	DID	5252
MILK	89	PCTF	4.0	PCTP	3.3	RELV	131

L#	AGE	FDAT	CDAT	DDAT	TOTM	TOTF	TOTP	305ME	RELV	DOPN	DIM	DDRY
1	1-10	9/17/18	11/15/18	6/21/19	21030	892	698	31530	101	59	277	56
2	2-9	8/16/19	10/10/19	5/29/20	29990	1166	952	37990	122	55	287	44
3	3-8	7/12/20	10/16/20	5/28/21	34190	1415	1146	37840	117	96	320	53
4	4-8	7/20/21	12/09/21	7/22/22	41150	1739	1370	38760	120	142	367	53
5	5-10	9/13/22	2/09/23	-	41570	1669	1285	41890	131	149	340	0
TOT					167930	6881	5451					

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Cow 5973 3rd lactation record

- 41,849 lb milk, 1,724 lb fat, 1,338 lb protein in 356 days of lactation
- Averaged 117.4 lb milk per day

PEN	3	CALF1	0	SID	11H11437	DID	5155
MILK	109	PCTF	3.9	PCTP	3.4	RELV	132

L#	AGE	FDAT	CDAT	DDAT	TOTM	TOTF	TOTP	305ME	RELV	DOPN	DIM	DDRY
1	2-0	10/01/18	4/06/19	11/08/19	38730	1423	1192	37330	116	187	403	69
2	3-4	1/16/20	6/25/20	2/05/21	44470	1498	1343	40940	126	161	386	43
3	4-6	3/20/21	7/28/21	3/11/22	41850	1725	1338	37710	119	130	356	54
4	5-7	5/04/22	-	-	56140	2079	1723	41990	132	472	472	0
TOT					181190	6725	5596					

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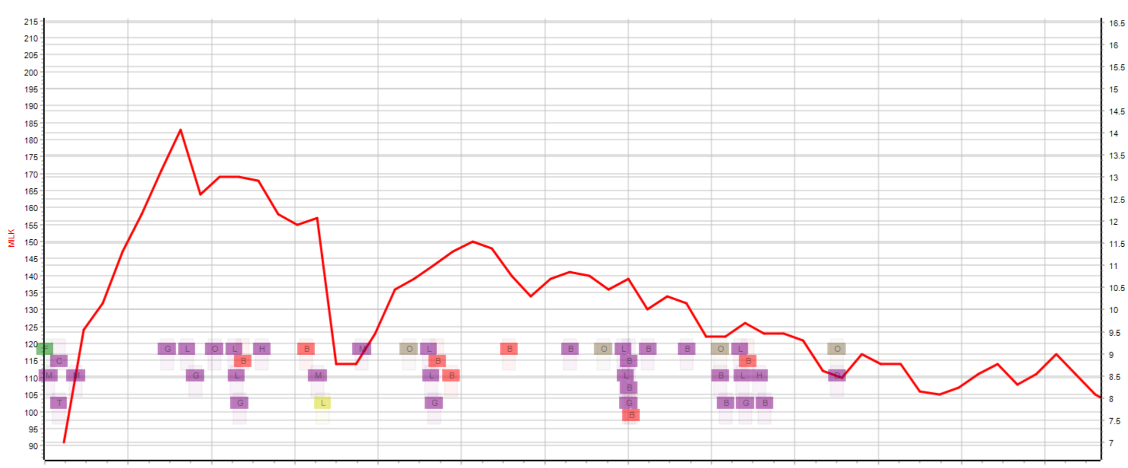
Cow 5973

- Peaked at 183 lb milk per day



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Cow 6389 3rd lactation

- 47,060 lb milk, 2,144 lb fat, 1,653 lb protein
- Averaged 117 lb/d   404-day lactation

PEN	3	CALF1	7962	SID	11H11815	DID	5582
MILK	130	PCTF	5.4	PCTP	3.5	RELV	119

L#	AGE	FDAT	CDAT	DDAT	TOTM	TOTF	TOTP	305ME	RELV	DOPN	DIM	DDRY
1	1-10	7/04/19	10/03/19	5/08/20	30570	1318	997	42570	136	91	309	56
2	2-10	7/03/20	10/23/20	6/04/21	39100	1747	1322	43940	136	112	336	51
3	3-11	7/25/21	2/13/22	9/02/22	47060	2144	1653	41870	127	203	404	78
4	5-2	11/19/22	-	-	31580	1325	1015	38090	119	273	273	0
TOT					148310	6534	4987					

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Cow 4291 3rd lactation

- 51,600 lb milk, 2,063 lb fat, 1,668 lb protein
- 124 lb milk per day – 4% Fat, 3.23% protein
- 417 day lactation

PEN	3	CALF1	0	SID	11H11462	DID	5281
MILK	120	PCTF	4.5	PCTP	3.4	RELV	126

L#	AGE	FDAT	CDAT	DDAT	TOTM	TOTF	TOTP	305ME	RELV	DOPN	DIM	DDRY
1	1-11	11/02/18	2/19/19	9/27/19	34690	1181	1062	41900	134	109	329	61
2	2-11	11/27/19	4/25/20	12/04/20	42150	1536	1303	40830	125	150	373	59
3	4-1	2/01/21	8/29/21	3/25/22	51600	2062	1669	42410	134	209	417	64

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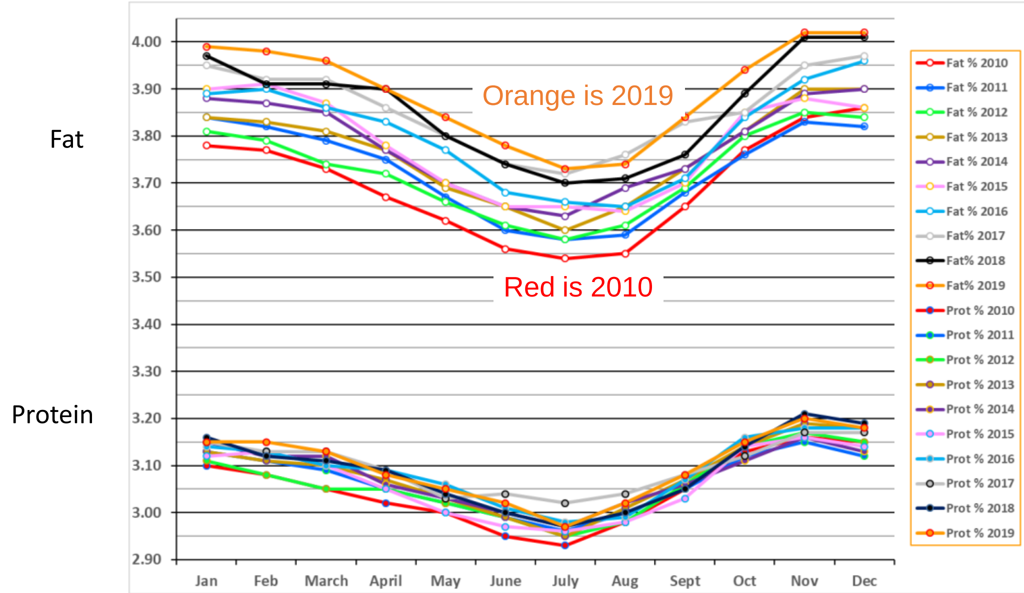
Northeast U.S. FMMO 1 Milk Fat and Protein % -- 2010 to 2019



Slide courtesy of Clay Zimmerman

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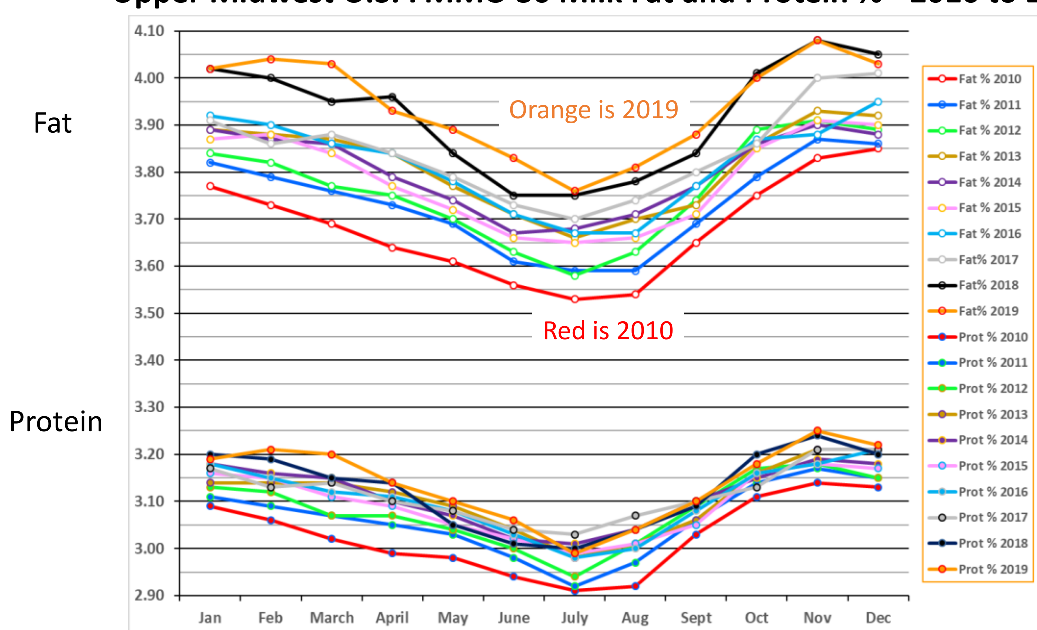
Upper Midwest U.S. FMMO 30 Milk Fat and Protein % - 2010 to 2019



Source: Zimmerman, Balchem Corporation - 2020

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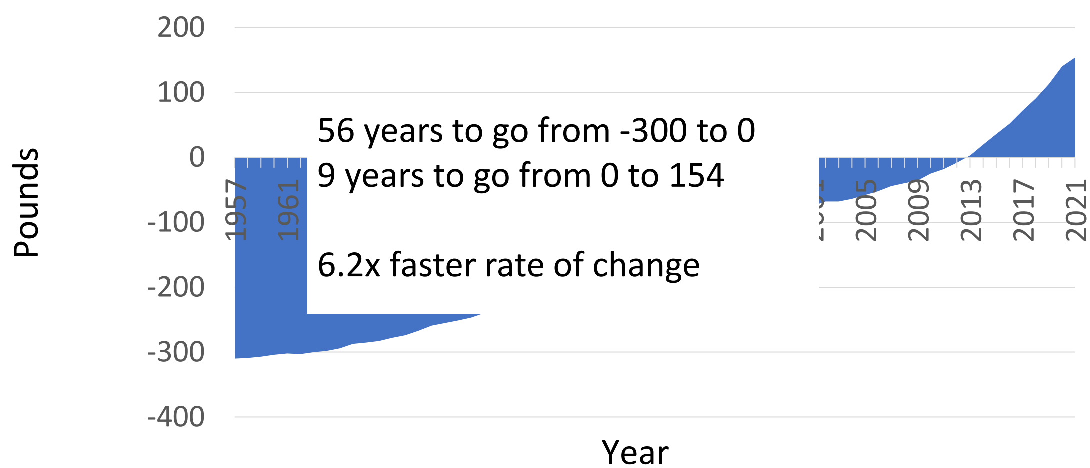
US Sire Breeding Value for Fat 1957-2021



Dechow, 2023; https://webconnect.uscdcb.com/#/summary-stats/genetic-trend

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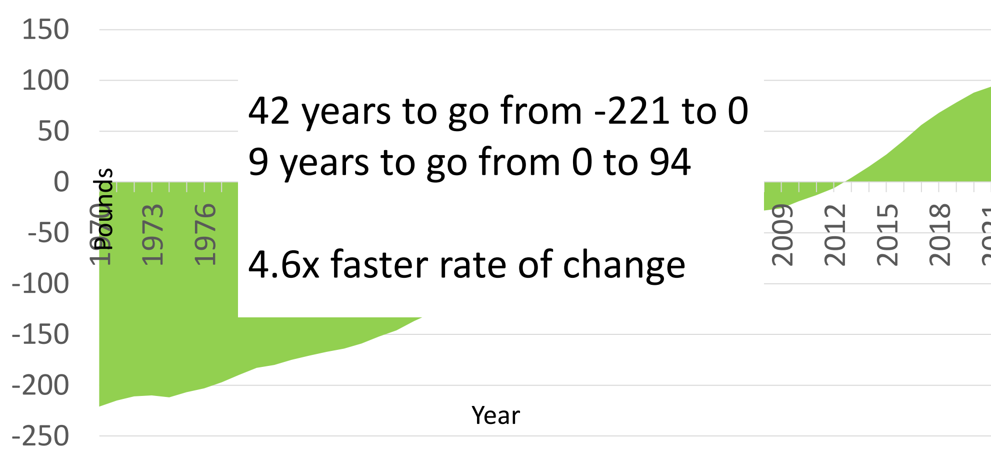
US Sire Protein Breeding Values over 51 years



Dechow, 2023; https://webconnect.uscdcb.com/#/summary-stats/genetic-trend

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Swine Requirements: Lysine as a function of Energy and Other Essential AA as function of Lysine

Table 1. Minimum standardized ileal digestible lysine and amino acid to lysine ratio for growing pigs and sows

	Growing pigs weight range, lb						Sows[4]	
SID amino acids[1]	15 to 25	25 to 55	55 to 130	130 to 175	175 to 220	220 to 285	Gestating	Lactating
Lysine, %[2]	1.35	1.25	1.08	0.88	0.78	0.70	0.60	1.05
Amino acid to lysine ratio, %[3]								
Methionine	28	28	28	28	28	28	28-29	28-29
Methionine + Cysteine	56	56	56	56	57	58	68-70	53-54
Threonine	62	62	62	62	63	64	74-76	63-64
Tryptophan	19	19	18	18	18	18	19-21	19-21
Isoleucine	52	52	52	52	52	52	58	56
Valine	67	67	68	68	68	68	71-76	64-70

[1]Minimum levels based on the NRC (2012) ingredient loading values.
[2]Minimum lysine levels considering a diet with 1,150 kcal NE/lb for growing pigs, 1,130 kcal NE/lb for gestating sows, and 1,160 kcal NE/lb for lactating sows.
[3]Minimum ratios to achieve approximately 95% of maximum growth performance. Minimum ratios of threonine, tryptophan, isoleucine, and valine can be greater depending on diet formulation.
[4]Data on amino acid requirements for contemporary sows is limited.

- These are adjusted based on genotype thus the relationship between Lysine and energy changes with increased capacity for growth
- What about cows and their increased capacity for components?

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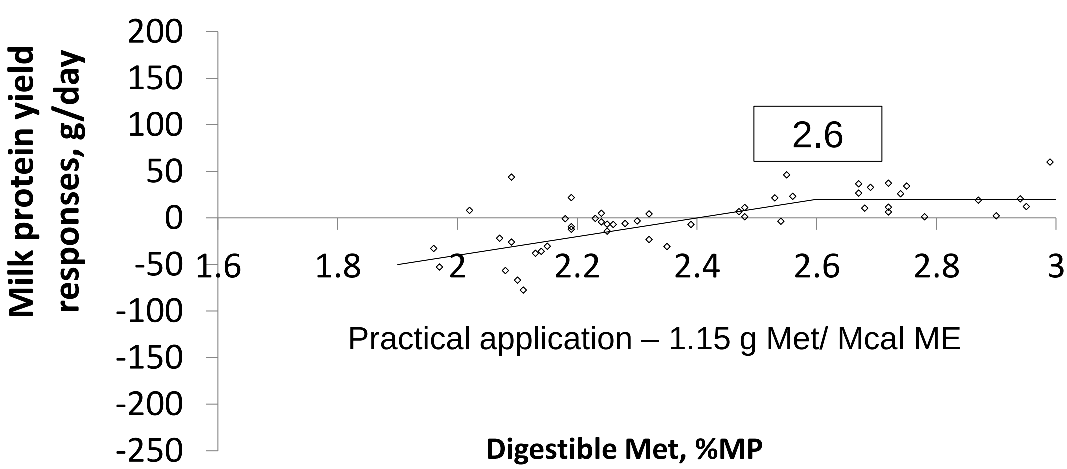
Balancing for met – updated aa profiles – milk protein yield CNCPS v6.55 (NDS/AMTS)



Van Amburgh et al., JDS 2015

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Optimum Supply Of Each EAA Relative To Metabolizable Energy – CNCPS v7.0 – Approach incorporates all productive functions

AA	R^2	Efficiency from our evaluation	Lapierre et al. (2007)	**g AA/ Mcal ME**	% EAA
Arg	0.81	0.61	0.58	**2.04**	10.2%
His	0.84	0.77	0.76	**0.91**	4.5%
Ile	0.74	0.67	0.67	**2.16**	10.8%
Leu	0.81	0.73	0.61	**3.42**	17.0%
Lys	0.75	0.67	0.69	**3.03**	15.1%
Met	0.79	0.57	0.66	**1.14**	5.7%
Phe	0.75	0.58	0.57	**2.15**	10.7%
Thr	0.75	0.59	0.66	**2.14**	10.7%
Trp	0.71	0.65	N/A	**0.59**	2.9%
Val	0.79	0.68	0.66	**2.48**	12.4%

Lys and Met requirements 14.9%, 5.1% - Schwab (1996) 2.9:1

Lys and Met requirements 14.7%, 5.3% - Rulquin et al. (1993) 2.77:1

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Amino Acids and De Novo FA Synthesis

- Lys increased enzymes related to de novo FA synthesis (ACS, ACC, FAS) through upregulation of FABP and SREBP1 (Li et al., 2019)
  - Further increased when supplemented with palmitic acid and oleic acid
- Additionally, Met and Leu increase expression of SREBP1– important regulator of enzymes for milk FA synthesis (Li et al., 2019).
- Arg increased de novo and mixed FA synthesis and expression of ACC, SCD, DGAT1 (Ding et al., 2022)

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Fatty Acid Synthetase (FAS)

- FAS synthesizes de novo FA by elongating FA carbon chain
- Active sites with AA essential for function and transfer of intermediates during elongation of de novo FA
  - His, Lys, Ser, Cys (Smith et al., 2003; Wettstein-Knowles et al., 2005)
- FAS expression decreased in His- and Lys-deficient human liver cell medium (Dudek and Semenkovich, 1995)
  - This was reversible when His and Lys were reintroduced
- Expression of FAS increased by adding both NEAA and EAA compared each treatment individually (Fukuda and Iritani, 1986)
  - FAS complex likely has requirement for both types of AA

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Review of recent experiment evaluating nutrient use efficiency

Dose titration of rumen modifier – nothing to do with amino acids, except the diets were formulated using the latest information related to AA levels

192 cows were used in a replicated pen study

16 cows per pen, milked 3x per day

Prior to the experiment, the cows were producing 42 kg, 4.1% fat and 3.1% true protein

Benoit et al., JDS abstract 2022

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	DM kg
Corn silage	8.85
Haylage - MML	4.90
Corn ground fine	4.54
SBM	1.72
SoyPass	1.45
Citrus Pulp	1.13
Wheat midds	1.13
Dextrose	0.40
Blood meal	0.25
Bergafat 100	0.15
Energy Booster 100	0.15
Sodium bicarb	0.10
Smartamine M	0.03
Smartamine ML	0.03
Levucell SC	0.01
Vitamins and Minerals	0.41
Total	25.27

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Rumen modifier study diet chemistry – formulated

DM, %	45.1
CP, %	15.75
Sol CP, %CP	31.5
aNDFom, %	31.6
Sugar, %	4.92
Starch, %	26.33
EE, %	4.4
ME, mcal/kg	2.65
ME, Mcal @25.5 kg DMI	68
Forage, % DMI	54.3
Forage, %BW	0.93
Methionine, g/Mcal ME	1.19
Lysine, g/Mcal ME	3.03
Methionine, g	82
Lysine, g (methionine x 2.7)	222

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Diet/Intake related information – Methionine and Lysine levels

Cows consumed approximately **71-72 mcals** per day

Methionine @ 1.19g/Mcal = 1.19* 71.5 = **85 g**

Lysine @ 2.7 times Met = 85g * 2.7 = **229 g**

Histidine similar to Methionine

These levels are what we consider the true requirement to be based on the last 10 years of research

Meeting the requirements should improve energetic efficiency and milk component yields

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Milk, energy corrected milk, feed efficiency and body weight of cows fed four levels of rumen modifier

	Treatment					
Item	0	11g	14.5g	18g	SEM	P-Value
DMI, kg/d	26.9	26.8	26.7	27.7	0.31	0.21
Milk Yield, kg/d	39.1	39.9	39.6	39.6	0.4	0.33
ECM, kg/d,	45.9	46.9	47.1	46.8	0.51	0.11
Feed Efficiency, ECM/feed	1.71	1.74	1.76	1.70	0.02	0.93
BCS	2.9	3.1	3.0	2.9	0.2	0.7
BW, kg	693	690	693	692	2.3	0.96
PUN, mg/dL	9.13	9.23	9.19	8.88	0.16	0.36

Benoit et al., 2022

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Milk fat, protein and urea nitrogen of cows fed four levels of rumen modifier

	Treatment					
Item	0	11g	14.5g	18g	SEM	P-Value
DMI, kg/d	26.9	26.8	26.7	27.7	0.31	0.21
Milk Yield, kg/d	39.1	39.9	39.6	39.6	0.4	0.33
ECM, kg/d,	45.9	46.9	47.1	46.8	0.51	0.11
Milk fat, %	**4.60**	**4.67**	**4.72**	**4.67**	0.05	0.2
Milk fat, kg	1.79	1.83	1.85	1.83	0.02	0.02
Milk true protein, %	**3.35**	**3.38**	**3.37**	**3.39**	0.01	0.07
Milk protein, kg	1.30	1.33	1.32	1.33	0.01	0.15
MUN, mg/dL	8.92	10.20	9.65	9.56	0.12	<0.01

Benoit et al., JDS abstract 2022

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Fatty acid profile of milk from cows fed four levels of rumen modifier

	Treatment					
Item	0	11g	14.5g	18g	SEM	P-Value
De novo fatty acid, g/100g	**1.131**	**1.157**	**1.168**	**1.156**	**0.01**	**0.03**
De novo fatty acid, kg	0.44	0.45	0.46	0.46	0.005	0.32
Mixed fatty acid, g/100g	**1.856**	**1.881**	**1.918**	**1.897**	**0.02**	**0.02**
Mixed fatty acid, kg	0.73	0.74	0.75	0.75	0.009	0.39
Preformed fatty acid, g/100g	1.34	1.33	1.38	1.35	0.02	0.23
Preformed fatty acid, kg	0.52	0.52	0.54	0.53	0.007	0.29
Fatty acid chain length	14.6	14.5	14.5	14.5	0.01	0.83
Double Bonds	0.23	0.23	0.23	0.23	0.002	0.42

Benoit et al., 2022

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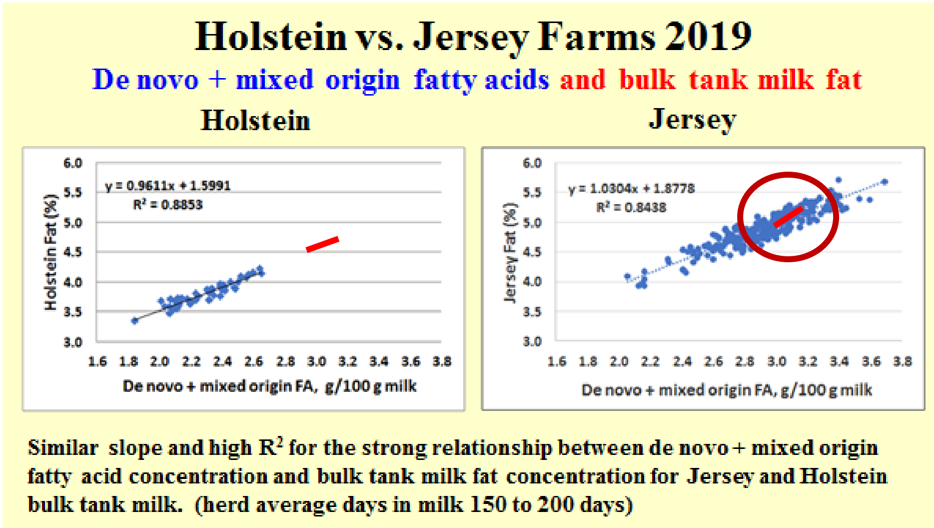
Milk de novo and mixed fatty acids from this study compared to Jersey milk components



Barbano et al. Proc Cornell Nutr. Conf. 2019

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Calculations around Nitrogen and Energetic Efficiency

Change in N efficiency was 8.1% from the initial diet to the study diet

More importantly, the change in energetic efficiency was 8.1%
(95.5 lb to 103.2 lb ECM)

	Productive N	Urinary N	Ratio
Initial diet	209	233	0.9
Treatment diet	226	215	1.05

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Effect of Rumen Protected Methionine and Lysine on Energy Corrected Milk Yield (and don't forget about Histidine…)

- 144 cows assigned to a replicated pen study
- Three levels of rumen protected Methionine
- Lysine was held constant at 3.2 g metabolizable AA per Mcal ME
- Histidine was similar to the highest Methionine level

- Methionine was fed at 0, 1.05 and 1.19 g metabolizable Met per Mcal ME

- 14-day covariate, 84-day treatment; 75% multiparous, 25% primiparous cattle per pen

Danese et al. unpublished

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144 cows, replicated pen, 16 cows/pen	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	9.8	6.8	0.35
Dry Matter Intake, kg	26.4	26.5	26.1	0.3	0.59
Milk Yield, kg	44.6	45.3	44.8	0.38	0.38
ECM, kg	48.8[a]	50.2[b]	50.4[b]	0.44	0.02
ECM to DMI	1.87	1.88	1.92	0.017	0.21
Milk True Protein, g/100g Milk	3.09[a]	3.24[b]	3.34[c]	0.010	< 0.01
Milk True Protein, kg	1.38[a]	1.46[b]	1.49[b]	0.011	< 0.01
Milk Fat, g/100g Milk	4.21[a]	4.25[a]	4.36[b]	0.026	< 0.01
Milk Fat, kg	1.88	1.92	1.94	0.023	0.16
MUN, mg/dL	11.20	11.44	11.09	0.120	0.12

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Diet, g Metabolizable Met/Mcal ME

Milk Fat, g/100g Milk	0.86	1.05	1.19	SEM	P value
De novo	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
Milk Fat, % Milk Fat					
De novo	28.79[a]	29.33[b]	29.34[b]	0.088	< 0.01
Mixed	41.83	41.61	41.56	0.148	0.40
Preformed	29.33	29.08	29.07	0.166	0.43

Danese et al. unpublished

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Diet, g Metabolizable Met/Mcal ME

	0.86	1.05	1.19	SEM	P value
N Intake, g	669	671	673	5.9	0.91
Productive N, g	235[a]	241[b]	250[c]	1.7	< 0.01
Urinary N, g	193[y]	189[xy]	181[x]	3.6	0.09
Productive:Urinary N	**1.22**	**1.28**	**1.38**		

At the 1.19 supplementation level, the difference between milk volume and ECM was 9.4 to 13 lb demonstrating a 4% increase in energetic efficiency

In this study, between the same treatments, the increase in N efficiency was 6.4%

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Observations from these studies

- Milk components can be greatly enhanced even in mid-lactation if requirements for various nutrients are met
- Data demonstrate that meeting the amino acid requirements can enhance energetic efficiency as much or more than N efficiency
- Holstein cattle can produce milk fat like Jersey cattle if fed an appropriate diet – meeting the requirements
- These cows are more environmentally efficient because they are producing more components per unit of intake reducing the intensity of greenhouse gas emissions

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Some Steps to Optimize Energetic Efficiency

- Determine the most limiting nutrient – energy or protein – do cows and model agree?
- Evaluate the rumen N balance and urinary N excretion – if high, then work to reduce the soluble protein – within CNCPS rumen NH_3 balance between 120-140%
- If grams MP is in excess, then decrease MP from feed in small increments
- Once you have ME and MP in balance and are happy with rumen N balance, focus on AA
- Met – use 1.15-1.19 g MP Met per Mcal ME (CNCPS v6.55)
- Lys – maintain a Lys:Met of ~ 2.7:1
- Pay attention to aNDFom digestibility and allocate the highest digestibility forages to the fresh and high cows
- Don't overfeed fatty acids, add some sugar and use high digestible aNDFom

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Thank you for your attention and for all the students who helped develop this work and the sponsors who keep it going.

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