CNCPS v7: What Nutritionists Need to Know*

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1

Outline for Today

- Model guided research approach
  - Some chemistry updates, some biology updates
- How the chemistry is used in the model and what it means to both digestible AA
- New chemistry for fiber digestibility and what it means for predicting rumen fill and feed intake
- New chemistry for amino acids and what it means for limiting AA
- Studies evaluating the model
- Summary

2

What's new with this thing?

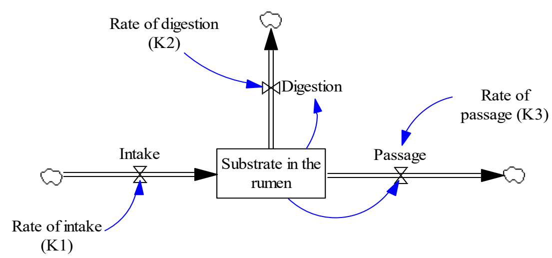
- Revised dynamic structure for the entire gastrointestinal model- feed and microbial digestion is determined on a nitrogen and AA basis
  - Reconstructed back to protein digestion if needed as an output
  - Dynamic structure allows for illustration of relationships from changing meal patterns
- Disaggregation of potentially digestible NDF into 'fast' and 'slow' degrading NDF (Raffrenato et al., 2019)
  - Utilization of Norfor (2011) passage rates for NDF
- Inclusion of protozoa metabolism in the microbial sub-model
- Mechanistic sub-model for estimation of nitrogen recycling
- Inclusion of endogenous nitrogen transactions along the gastrointestinal tract
- Expansion of the post-rumen model to include a separate small and mechanistic large intestinal model
- Incorporation of revised nitrogen digestibility of non-forage feeds using in vitro estimates (Ross et al., 2013;)
- Revised post-absorptive efficiencies of EAA towards productive use

3

Cornell Net Carbohydrate and Protein System (CNCPS)

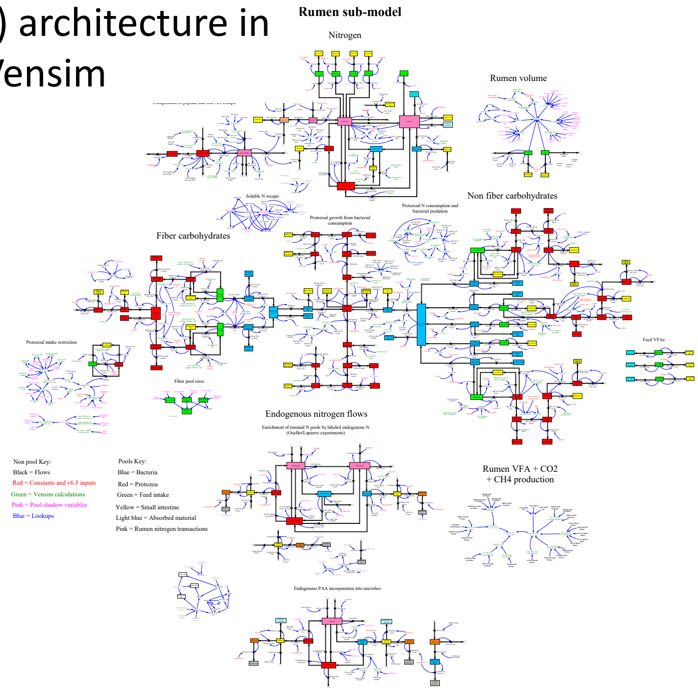
Currently existing model structure:

- **Digestibility = kd/(kd+kp)**
  - **Rate of degradation (kd): intrinsic to the feed**
  - **Rate of passage (kp): intrinsic to the animal**
- **Equation used to calculate disappearance of given substrate**
  - **Microbial growth rate is calculated directly from CHO kd**
- **Metabolizable Energy (ME): Calculated from digested nutrients**
- **Metabolizable Protein (MP): Microbial protein & undegraded feed protein**



4

CNCPS (v7) architecture in Vensim



5

CNCPS v.7 general structure

Rumen Overview:

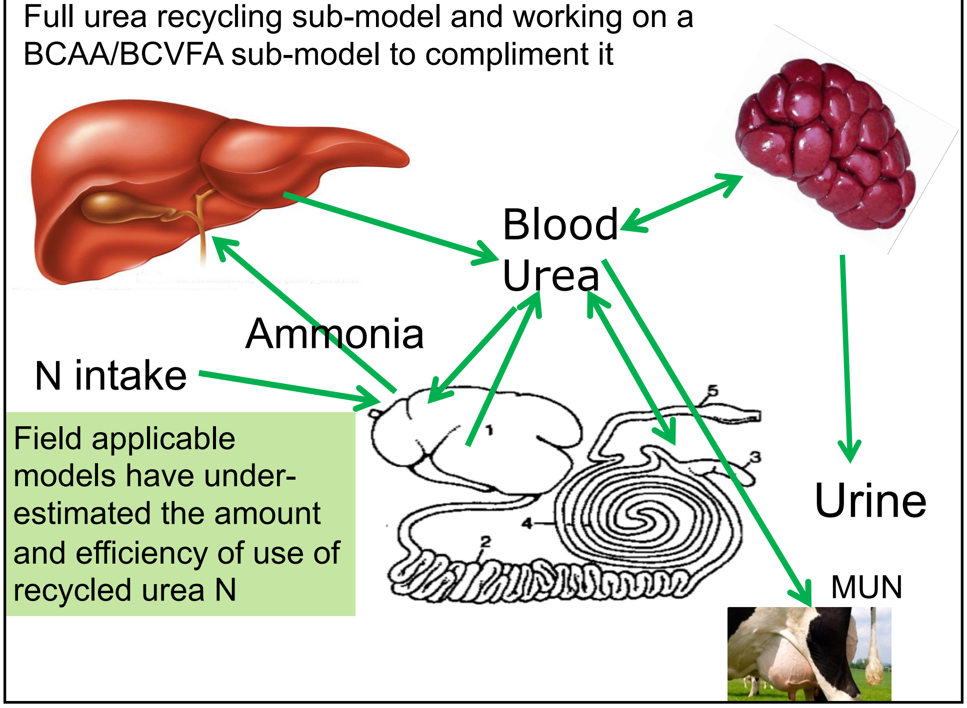
- Rumen volume
- Nitrogen transactions
  - Soluble N escape
  - Peptide & free AA (PAA) escape
  - Endogenous N flows
    - Microbial incorporation of PAA
    - Supply at duodenum and ileum
- Fiber carbohydrate digestion
- Non-fiber carbohydrate digestion
- Protozoal metabolism
  - Nitrogen and bacterial consumption
  - Growth and nutrient excretion
- VFA, CO_2 and CH_4 production

Post-Rumen Overview:

- Nitrogen feed fraction digestion
  - Urea recycling
  - Nitrogen excretion
- Fiber carbohydrate digestion
- Non-fiber carbohydrate digestion
- Microbial organic matter digestion
- VFA, CO_2 and CH_4 production
- Metabolizable energy calculations
- Metabolizable protein calculations

6

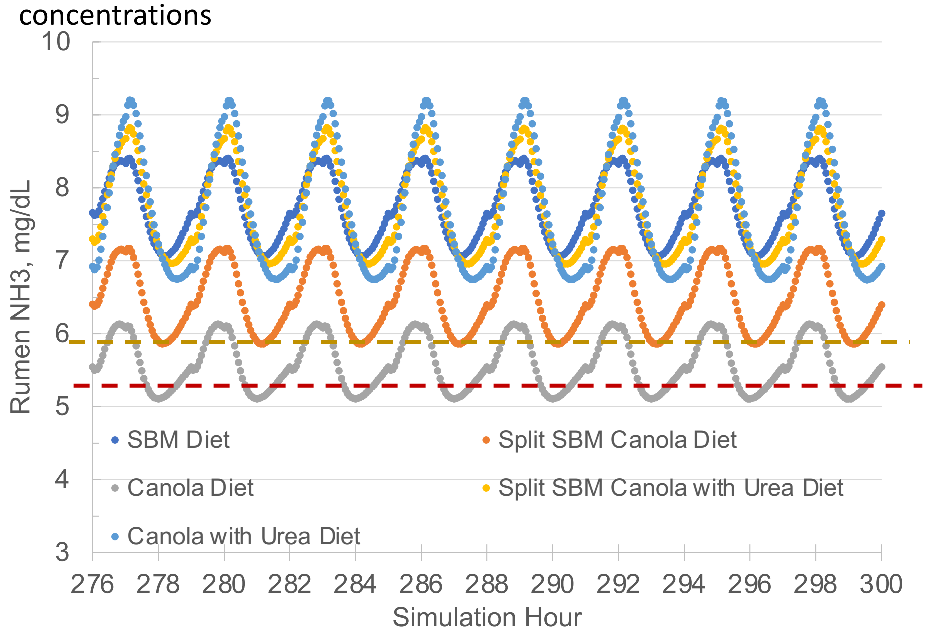
Full urea recycling sub-model and working on a BCAA/BCVFA sub-model to compliment it



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

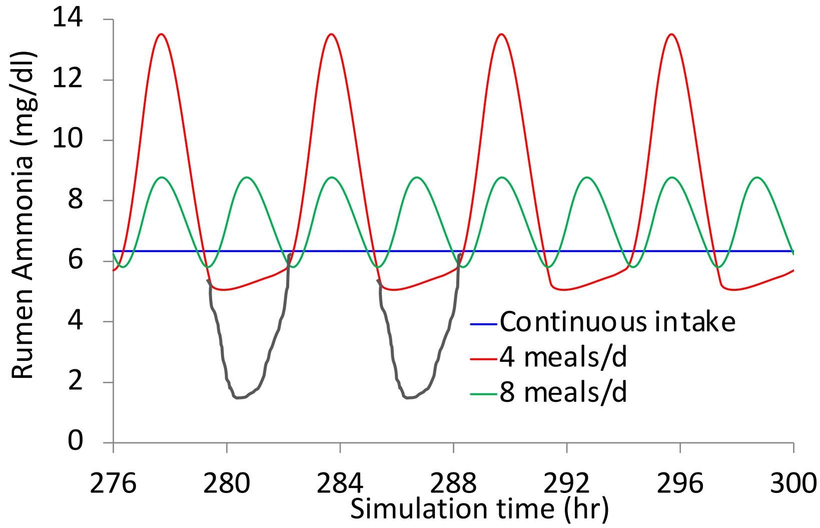
7

Full urea recycling in CNCPS v7 to predict rumen ammonia concentrations



8

Incorporation Urea Recycling to Calculate Rumen Ammonia And Meal Pattern in CNCPS v7



Higgs, 2014

9

Endogenous N Flows; Contributions to supply

Diet	Endogenous N (% duodenal flow)	Bacterial N from endogenous AA (% N flow)
High fiber	15%	11%
Low fiber	15%	10%
Hay	26%	30%
Formic-acid silage	23%	29%
Inoculated silage	25%	31%
Low MP	18%	20%
Medium MP	16%	18%
High MP	14%	17%

Source: Ouellet et al., 2007

10

Amino Acid Profiles Of The Components Of Duodenal Flow (% EAA)

	Maize silage	Soybean meal	Bacteria	Protozoa	Rumen epithelia	Abomasal juice	Pancreatic juice	Cow bile
Arg	5.8	16.4	9.9	9.3	14.9	11.1	8.5	6.4
His	6.0	6.7	4.7	4.4	5.2	8.1	7.1	10.6
Ile	12.4	11.1	13.2	13.7	9.7	10.6	11.0	10.6
Leu	26.2	16.8	16.4	15.7	19.6	10.9	18.5	19.1
Lys	5.8	13.7	15.8	20.1	15.9	16.6	12.9	10.6
Met	5.3	3.2	4.9	4.6	4.4	3.4	3.3	4.3
Phe	12.4	11.6	10.8	10.6	9.3	10.6	9.0	8.5
Thr	9.8	8.8	10.8	10.1	9.3	14.9	13.8	12.8
Val	16.2	11.8	13.4	11.4	11.7	13.8	15.8	17.0

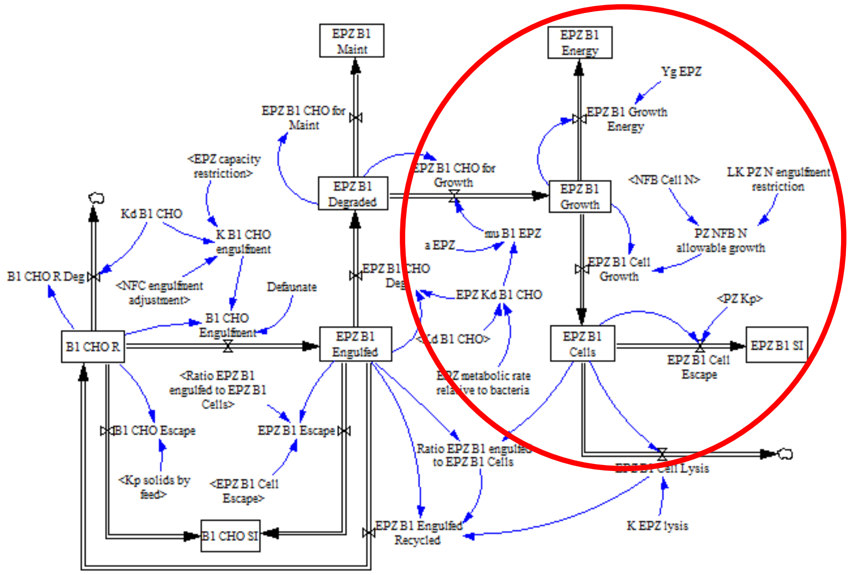
(Jensen et al., 2006)

11

Protozoa

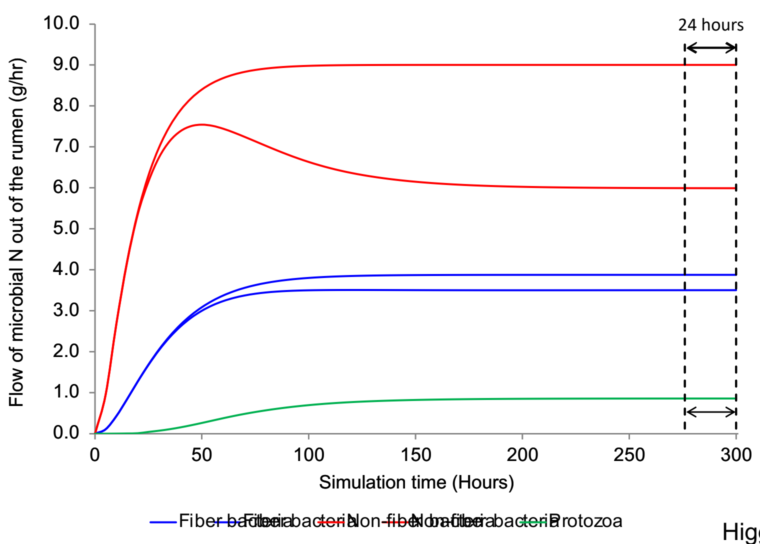
12

CNCPS v7 Protozoal sub-model – working out a passage calculation correction before release



13

Microbial N Flow Out of the Rumen (grams / hour)



Higgs, 2014

14

Contribution of Protozoa – Irish Pasture Example from Dineen et al., 2020 JDS

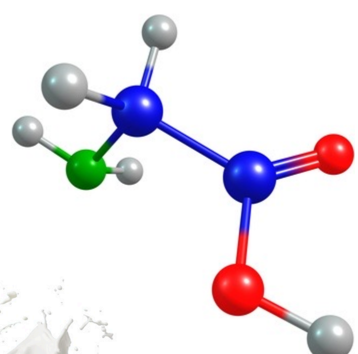
Item	Treatment[2] G	Treatment[2] G+RB	SEM	P-value
N intake, g/d	429	424	11	0.53
Flow at omasal canal				
Total N, g/d	394	436	18	<0.01
Ammonia N, g/d	21	14	1	<0.01
NAN				
g/d	373	422	18	<0.01
% of N intake	90.9	99.3	2.8	<0.05
NANMN[3]				
g/d	49.1	47.7	4.1	0.78
% of N intake	11.6	11.0	0.9	0.65
Microbial NAN				
g/d	324	374	15	<0.01
% of total NAN	87.1	88.8	0.8	0.17
Bacterial NAN				
g/d	248	298	18	<0.01
% of microbial NAN flow	76.5	80.1	3.2	0.24
Protozoa NAN				
g/d	79	73	11	0.55
% of microbial NAN flow	23.5	20.0	3.2	0.24
Microbial N, g/kg of OTDR[4]	24.4	26.6	0.7	<0.05
True ruminal N digestibility, %	88.4	89.0	0.9	0.65

G = grass only

G+RB = grass plus rolled barley

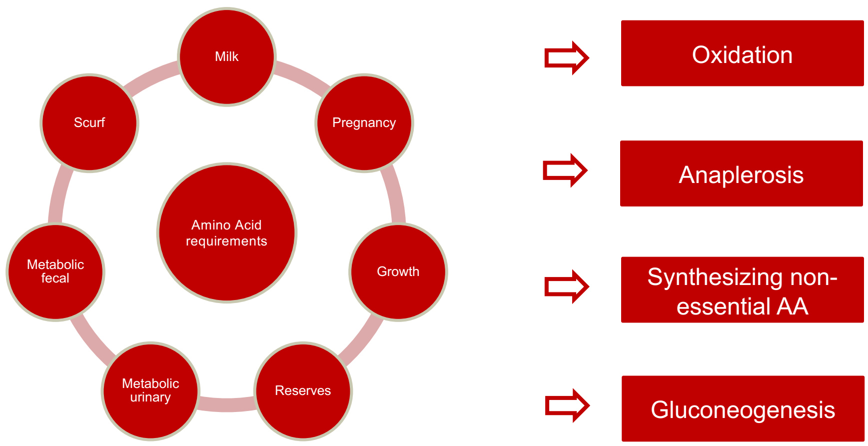
15

What Is The Optimum Supply Of Amino Acids For A Dairy Cow?



16

‘Efficiency’ Of AA Use (Additional Requirement)



17

What Is The Optimum Additional Requirement?

Studies from the literature that infused AA post-ruminally were run through the CNCPS:

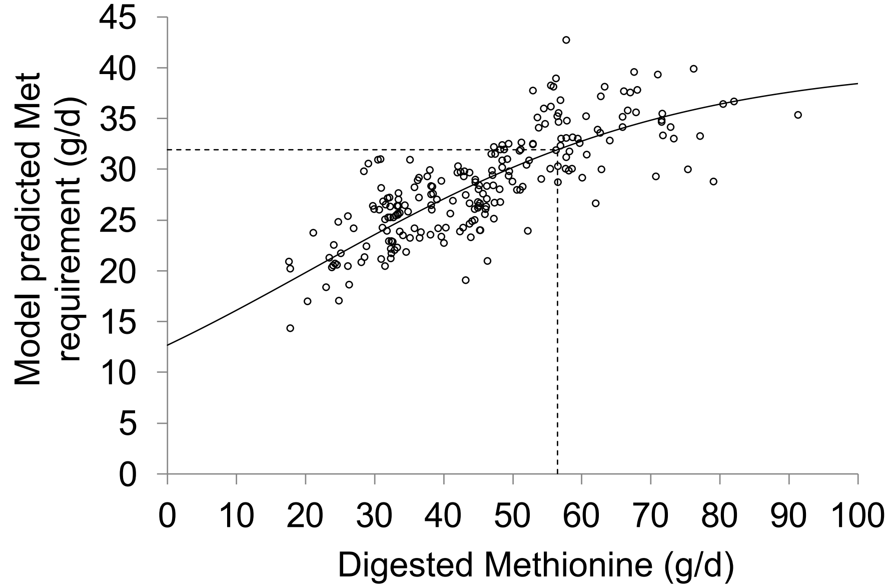
- 41 publications
- 51 experiments
- 218 treatments

Model predicted AA requirement was compared to AA supply

Similar dataset to Doepel et al. 2004 and Lapierre 2007

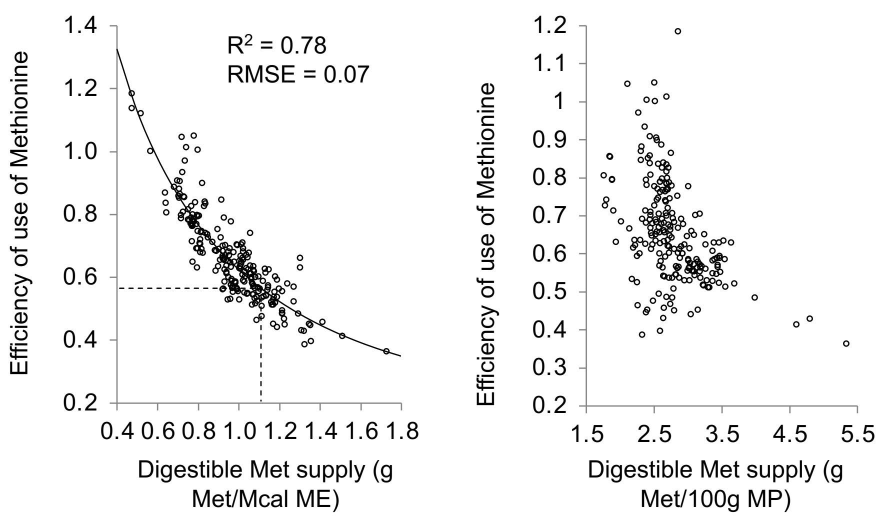
18

Predicted methionine requirements to methionine supply



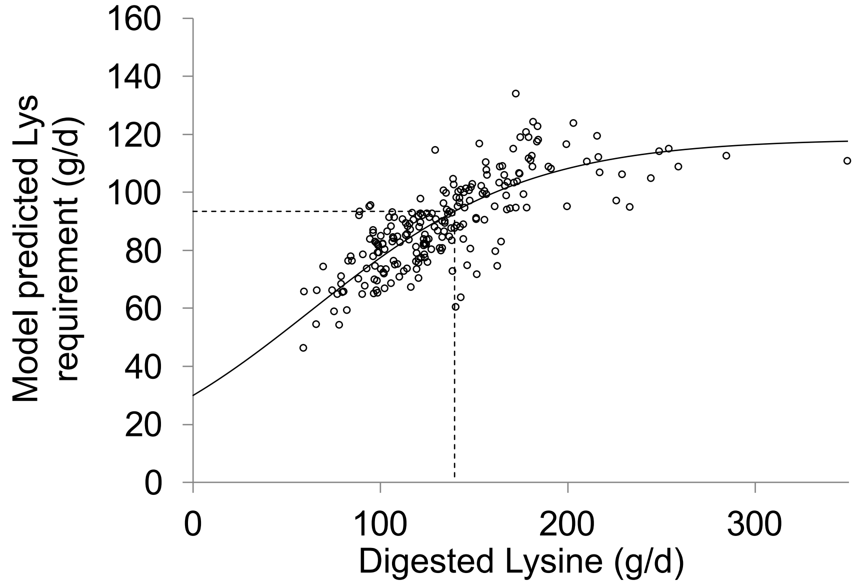
19

Methionine use relative to metabolizable energy or protein



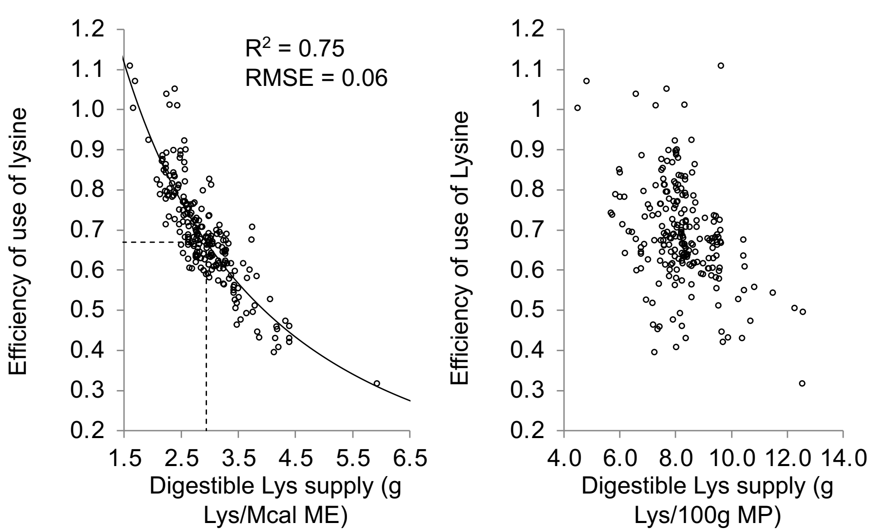
20

Predicted lysine requirements to lysine supply



21

Lysine use relative to metabolizable energy or protein



22

Optimum Supply Of Each EAA Relative To Metabolizable Energy – CNCPS v7.0

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

23

CNCPS v.7 predicted vs observed microbial N flows at the omasum

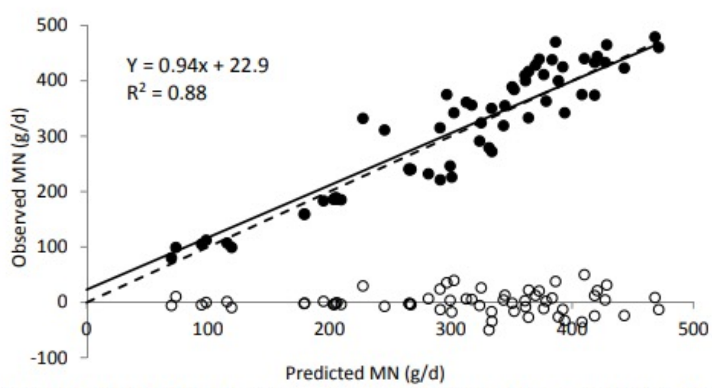
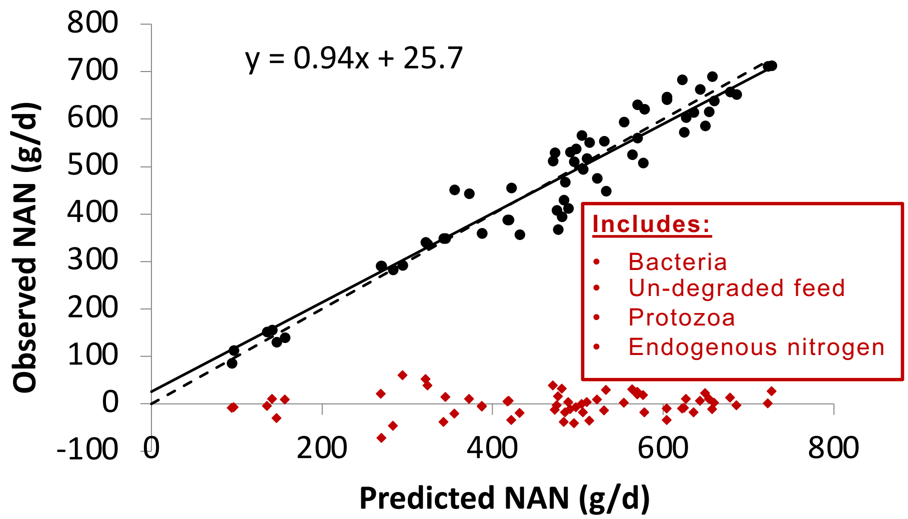


Figure 8. Predicted and observed microbial N (MN) flows at the omasum (●) and residual error (○) from the mixed model regression analysis. The solid line (—) represents the linear regression and the dashed line (- - -) is the unity line.

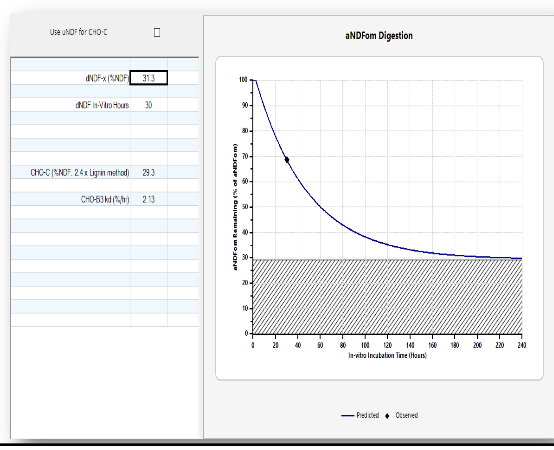
24

CNCPS v7 predicted and observed total non-ammonia N flows at the omasum



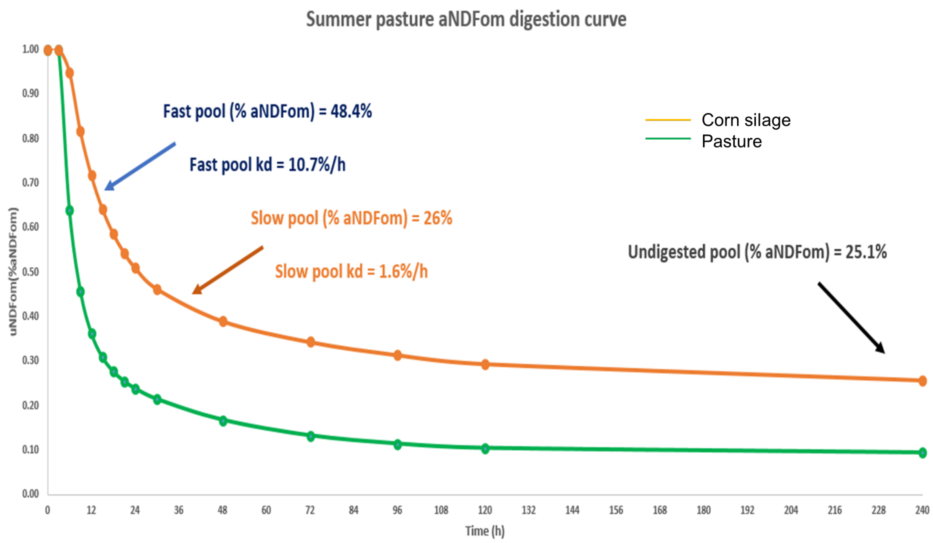
25

Describing aNDFom digestibility in multiple pools: Learning how to make use of the information in diet formulation



26

Irish Pasture aNDFom digestion curve vs corn silage



27

Formulation values – Standard diet for this comparison

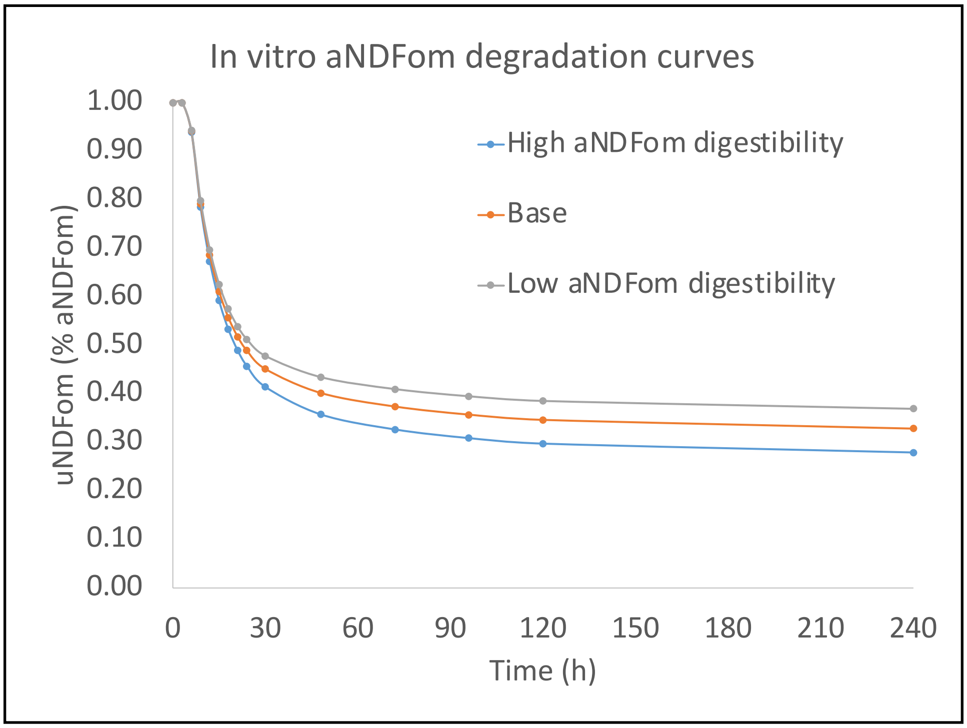
- 1,653 lb (750 kg) producing 90 lb milk consuming 54 lb (24.5 kg) DMI which is 32% aNDFom
- 17.28 lb aNDFom intake (7.84 kg)
  – 7,840 g aNDFom intake
  – 1 % body weight
  – 2017 Agronomic factors created high uNDF pools making it difficult to meet typical corn silage intakes

Dineen et al., Cornell Nutrition Conf. 2019

28

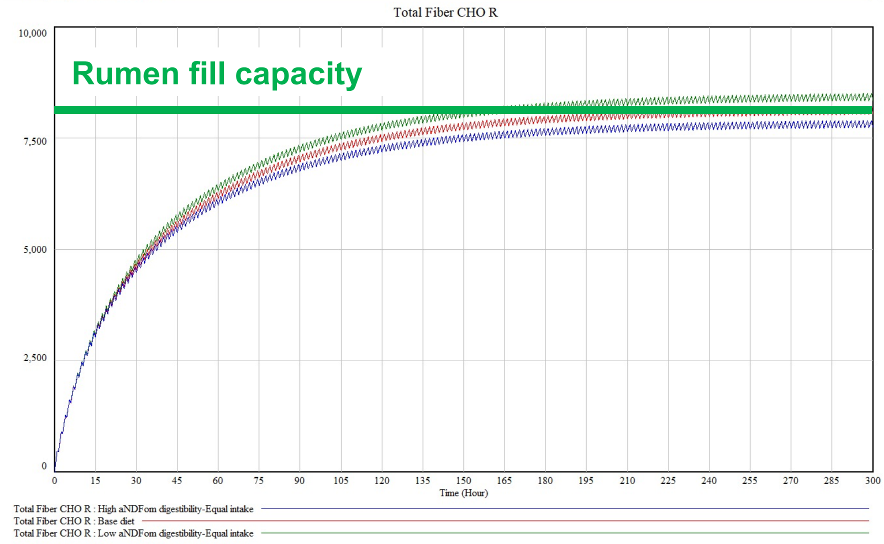
Chemical composition	Low aNDFom digestibility	Base	High aNDFom digestibility
CP (% DM)	7.0	7.5	8.1
aNDFom (% DM)	37.7	37.3	37.8
Starch (% DM)	36.0	37.1	32.1
uNDFom30 (% aNDFom)	47.8	45.1	41.4
uNDFom120 (% aNDFom)	38.6	34.7	29.8
uNDFom240 (% aNDFom)	36.7	32.6	27.7
Fast pool aNDFom (% aNDFom)	49.5	51.8	55.4
Slow pool aNDFom (% aNDFom)	13.0	15.0	16.0
uNDFom pool (% aNDFom)	36.7	32.6	27.7
Fast kd (%/h)	12.4	12.1	11.6
Slow kd (%/h)	1.8	1.8	1.8
Integrated kd (%/h)	6.3	5.9	5.9

29



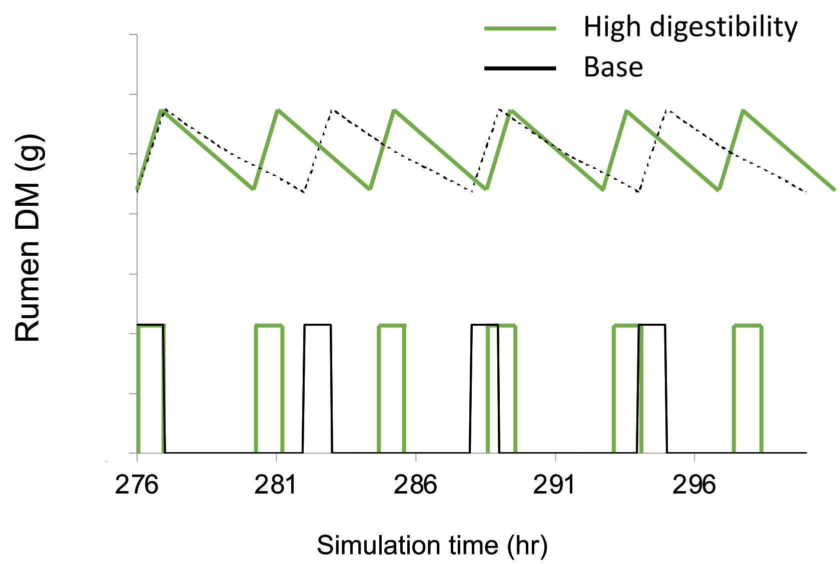
30

CNCPS v7 Rumen Fill aNDFom at Equal DMI



31

CNCPS v7 – Meal pattern and fill/flux of DM



32

CNCPS v7 Model Output – Rumen Pool Sizes and DMI			
	Low aNDFom digestibility	**Standard**	**High aNDFom digestibility**
B3 Fast CHO	1588	1632	1698
B3 Slow CHO	1588	1655	1715
C CHO	5239	4819 (0.64% BW)	4395
Total rumen NDF	8415	8106 (1.10% BW)	7809
DMI	24.5	24.5	24.5

33

CNCPS v.7 Model Output – estimated DMI based on first limiting for fill – aNDFom or uNDF			
	Low aNDFom digestibility	**Standard aNDFom digestibility**	**High aNDFom digestibility**
B3 Fast CHO, g	1464	1632	1763
B3 Slow CHO, g	1462	1655	1780
C CHO, g	4819	4819	4563
Total rumen NDF, g	7745	8106	8106
DMI, kg (lb)	22.5 (49.6)	24.5 (54)	25.4 (56)
Allowable milk, kg (lb)			
Metabolizable energy	35.8 (79)	40.9 (90)	43.3 (95)
Metabolizable protein	36.4 (80)	40.9 (90)	43.3 (95)

34

Rumen Fill and Rumen Function

- The low digestibility will overfill – thus intake drops
- The high digestibility will under fill – thus opportunity for greater DMI
- What happens to the high digestibility diet when time budgets are off, feed availability is reduced, or inventories are tight?
- What if aNDFom was formulated at 28% DM instead of 30%

35

What Does The Cow Think of All of These Changes?

?

36

Experimental Design

- 64 cows randomly allocated to 1 of 4 treatments
  - Base = limited in Met, MP and rumen N
  - Base+M = adequate in Met, limited MP and rumen N
  - Base+MU = adequate in Met and rumen N, but limited MP
  - Positive = adequate in MP, rumen N and balanced for all EAA
- Experimental period was 100 days
- Measurements:
  - Milk
  - Milk composition
  - Intake
  - Blood
  - Fecal collection for NDF digestion

37

Diets Ingredients And Composition

Ingredient, % DM	Base	Base+M	Base+MU	Positive
Corn Silage	46.98	46.49	46.75	46.13
Grass Hay	8.53	8.53	8.42	8.46
Corn grain ground fine	15.73	15.84	15.66	15.12
Corn gluten feed	8.69	8.75	8.66	7.07
Soybean meal	6.21	6.25	6.18	7.89
Soyhulls	2.07	2.08	2.06	2.10
Rumen stable soy product	2.07	2.08	2.06	4.11
Molasses Dried	2.07	2.08	2.06	1.20
NutraCor	1.90	1.92	1.90	1.64
Urea	0.08	0.08	0.52	0.12
Rumen protected lysine	0.10	0.10	0.09	0.00
Rumen protected methionine	0.00	0.08	0.08	0.09
Blood meal	1.66	1.67	1.65	2.18
Minerals and vitamins	3.92	4.05	3.91	3.88
Chemical components				
CP	13.5	13.6	14.6	15.6
SP, % CP	38.8	38.6	38.8	37.8
Starch	31.9	31.9	31.5	30.9
NDF	29.7	29.6	29.3	29.3
Ash	7.3	7.4	7.3	7.3
EE	4.7	4.7	4.6	4.4

38

Amino Acid Balance (grams AA/Mcal ME)					
AA	**Optimum**	**Base**	**Base+M**	**Base+MU**	**Positive**
Arg	2.04	1.85	1.86	1.96	2.15
His	0.91	1.01	1.01	1.05	1.19
Ile	2.16	1.83	1.83	1.94	2.00
Leu	3.42	3.64	3.65	3.81	4.15
Lys	3.03	2.83	2.82	2.98	3.09
Met	1.14	0.93	1.13	1.17	1.25
Phe	2.15	2.12	2.12	2.22	2.42
Thr	2.14	2.16	2.16	2.27	2.43
Trp	0.59	0.60	0.60	0.63	0.69
Val	2.48	2.33	2.33	2.45	2.62
Lys:Met	2.66	3.04	2.51	2.54	2.47

39

Milk and Component Yields

Item, lb/d	Base	Base+M	Base+MU	Positive	*P*-Value
Dry matter intake	53	54	55	54	0.717
Energy correct milk yield	84.9[a]	86.6[a]	88.2[a]	92.1[b]	0.005
Milk yield	88.1	89.5	89.7	92.1	0.288
True protein yield	2.49[a]	2.60[ab]	2.60[ab]	2.69[b]	0.009
Fat yield	2.87[a]	2.82[a]	2.95[ab]	3.11[b]	0.047
Milk composition, %					
True protein, %	2.88[a]	2.93[ab]	2.96[b]	2.98[b]	0.009
Fat, %	3.31	3.20	3.34	3.51	0.078
Lactose, %	4.84	4.85	4.85	4.86	0.799

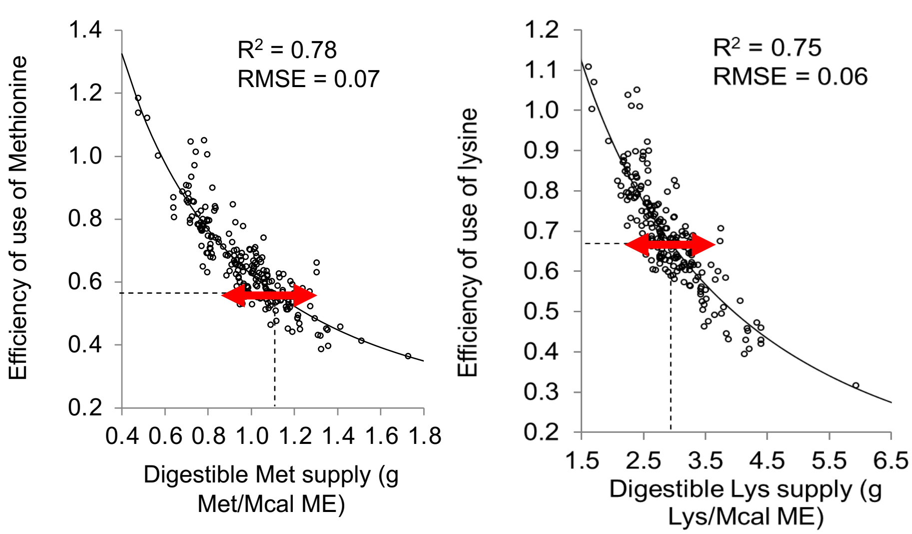
40

Nitrogen Utilization

	Base	Base+M	Base+MU	Positive	*P*-Value
N intake, mg/dl	521.6[a]	532.1[a]	581.9[b]	615.1[c]	< 0.001
MUN, mg/dl	6.9[a]	7.3[a]	9.1[b]	10.4[c]	< 0.001
PUN, mg/dl	5.9[a]	5.7[a]	8.5[b]	8.7[b]	< 0.001
N use efficiency	0.37[a]	0.38[a]	0.35[b]	0.34[b]	< 0.001
NDF digestion %	40.8[ab]	40.5[b]	42.9[a]	42.9[a]	0.008
pd NDF digestion %	56.7[ab]	55.2[b]	59.0[a]	59.2[a]	0.011
Bacterial growth depression, %	16%	17%	4%	2%	

41

Methionine use relative to metabolizable energy or protein



42

EXP 778-Experimental Design

Conducted as a pen study

- Three pens per treatment; 16 cows per pen
  (144 total cows used)
- Primi- (no more than 25% of pens) and Multiparious cows will be used
- Days in milk upon enrollment will range between 60 and 120 days
- Cows blocked by parity, body weight, previous milk production

A.LaPierre et al., 2019

43

Experimental diets

Ingredient, % DM	Negative	Neutral	Positive
Corn silage	51.49	51.49	50.40
High moisture ear corn	9.43	9.46	9.93
Triticale	7.25	7.25	7.98
Corn grain	6.38	6.42	5.95
Soybean meal	8.16	5.55	2.72
Soybean hulls	9.25	3.84	2.83
SoyPLUS	.	0.91	3.59
Canola	1.81	9.17	6.31
Urea	0.62	0.51	0.51
Smartamine M	.	0.04	0.05
Smartamine ML	.	.	0.07
Blood meal	.	.	3.08
Energy Booster	0.73	0.73	0.91
Dextrose	1.63	1.63	2.18
Minerals and Vitamins	3.26	2.90	3.15

44

Observed Chemical Composition of Diets

Chemical Component, % DM	Negative	Neutral	Positive
Dry Matter, %	44.7	44.5	44.2
Crude Protein	14.0	14.7	16.0
ADICP, % CP	5.70	5.90	5.50
NDICP, % CP	15.0	15.5	18.7
aNDFom	32.4	31.0	31.4
Lignin	2.61	3.00	2.70
Sugar	3.95	4.10	3.90
Starch	29.8	29.3	29.3
Fat	3.50	3.60	3.80
Ash	6.60	6.90	6.60
NH3	0.80	0.90	0.80
RUP, % CP	28.5	29.9	31.3
ME Mcal/kg	2.58	2.60	2.61

45

Dietary Amino Acid Supply

EAA, grams	Negative	Neutral	Positive
Arginine	143.14	161.04	164.43
Histidine	62.78	70.42	83.81
Isoleucine	147.85	162.37	160.56
Leucine	229.92	253.31	286.27
Lysine	201.70	222.12	250.07
Methionine	71.44	78.30	92.67
Phenylalanine	153.00	164.71	181.63
Threonine	144.43	161.78	171.85
Tryptophan	45.92	48.93	44.66
Valine	161.01	179.55	197.46

A.LaPierre et al., 2019

46

Animal Performance Results

DMI and Milk Yield, lb/d	Negative	Neutral	Positive	SEM
Dry matter intake	60.4	62.2	62.8	0.6
Milk yield	82.7[a]	88.4[bx]	91.2[by]	1.0
Energy correct milk yield	90.4[a]	96.3[bx]	99.4[by]	1.2
True protein yield	2.56[a]	2.78[b]	2.84[b]	0.02
Fat yield	3.39[a]	3.53[ab]	3.64[b]	0.07
Lactose yield	3.97[a]	4.23[b]	4.34[b]	0.07
Milk composition, %				
True protein	3.08[a]	3.15[b]	3.13[b]	0.02
Fat	4.14	4.08	4.09	0.06
Lactose	4.78	4.80	4.80	0.01

[a,b] Denote significant differences ($P < 0.05$) [x,y] Denote trends ($P < 0.10$)

A.LaPierre et al., 2019

47

48

Dose titration of Rumensin – nothing to do with amino acids, except the diets were formulated using the latest information on diet formulation related to AA levels from CNCPS v7 and everything we thought we knew about making a "modern diet"

Prior to this diet, the cows were producing 93 lb, 3.9% fat and 3.1% true protein at about 120 DIM

Benoit et al., ADSA abstr. 2022

49

Dietary ingredient	Dry matter inclusion, 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
Rumen protected methionine	0.03
Rumen protected lysine	0.03
Levucell SC	0.01
Vitamins and Minerals	0.41
Total	25.27

50

Formulated dietary feed chemistry

DM, %	45.1
CP, %	15.75
Sol CP, %CP	31.5
aNDFom, %	31.6
WSC/Sugar, %	4.92
Starch, %	26.33
EE, %	4.4
ME, mcal/lb	1.204
ME, Mcal @25.3 kg DMI	67.1
Forage, % DMI	54.3
Forage, %BW	0.93
Methionine, g/Mcal ME	1.19
Lysine, g/Mcal ME	3.03
Methionine, g	80
Lysine, g (methionine x 2.7)	216

51

Dose titration of Rumensin

	Treatment					
Item	0	11g	14.5g	18g	SEM	P-Value
Days in milk	190	168	193	184	7.2	----
DMI, lb/d	59.29	59.29	59.07	61.05	0.44	0.08
Milk Yield, lb/d	82.65	86.84	85.07	85.07	0.88	< 0.05
ECM, lb/d,	101.16	103.15	103.37	102.93	0.88	0.40
ECM:Feed	1.73	1.74	1.76	1.69	0.01	< 0.05
BCS	2.9	3.1	3.0	2.9	0.2	0.70
BW, lb	1521	1519	1530	1525	6	0.55
PUN, mg/dL	9.2	9.1	9.2	8.9	0.15	0.50

Benoit et al., ADSA abstr.

52

Dose titration of rumen modifier

Cows were yielding 6.96 lb components at 190 DIM

	Treatment					
Item	0	11g	14.5g	18g	SEM	P-Value
Mil						
Mil						
Mil						
Mil						
Milk lactose, %	4.62	4.65	4.63	4.62	0.01	< 0.05
Milk lactose, kg	1.80	1.86	1.83	1.83	0.02	0.17
Milk solids, %	13.8	13.8	13.9	13.8	0.04	0.39
Milk solids, kg	5.33	5.47	5.44	5.43	0.05	0.25
MUN, mg/dL	8.92	10.20	9.65	9.56	0.12	< 0.01

Benoit et al., ADSA abstr.

53

Dose titration of Rumensin

	Treatment					
Item	0	11g	14.5g	18g	SEM	P-Value
De novo, g/100g	1.131	1.157	1.168	1.156	0.01	0.03
De novo, kg	0.44	0.45	0.46	0.46	0.005	0.32
Mixed, g/100g	1.856	1.881	1.918	1.897	0.02	0.02
Mixed, kg	0.73	0.74	0.75	0.75	0.009	0.39
Preformed, g/100g	1.34	1.33	1.38	1.85	0.02	0.23
Preformed, 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 bond proportion	0.23	0.23	0.23	0.23	0.002	0.42
C16:0, %	1.81	1.80	1.85	1.84	0.02	0.17
C16:0, kg	0.70	0.71	0.72	0.72	0.009	0.37
C18:0, %	0.36	0.36	0.38	0.36	0.005	0.08
C18:0, kg	0.14	0.14	0.15	0.14	0.002	0.15
C18:1, %	0.79	0.78	0.80	0.79	0.009	0.30
C18:1, kg	0.30	0.31	0.31	0.31	0.003	0.53

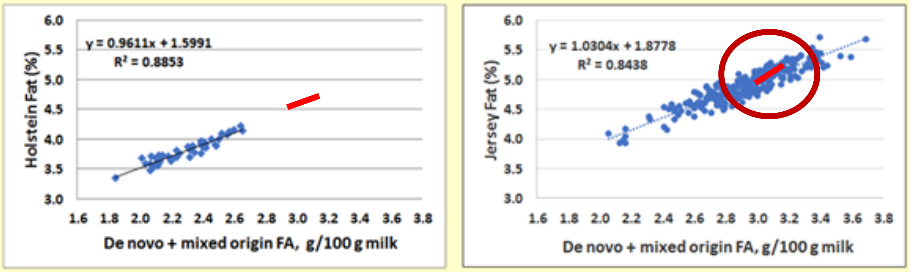
54

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

Holstein vs. Jersey Farms 2019

De novo + mixed origin fatty acids and bulk tank milk fat

Holstein | **Jersey**



Similar slope and high R^2 for the strong relationship between de novo + mixed origin fatty acid concentration and bulk tank milk fat concentration for Jersey and Holstein bulk tank milk. (herd average days in milk 150 to 200 days)

Barbano et al. Proc Cornell Nutr. Conf. 2019

55

Summary

- A new model was constructed with the goal of improving predictions of rumen function, aNDFom digestibility, EAA and N supply
- Incorporation of protozoa growth and yield, endogenous protein supply and digestibility, recycled urea N and intestinal digestibility provided new insights into AA supply and N efficiency
- New estimates of AA requirements on an energy basis were derived similar to monogastric animals
- With this approach and capability, dairy cattle were able to produce ~88-90 lb of milk on diets ~13.5% to 14.6% CP and responded positively to improved AA balance on an ME basis

56

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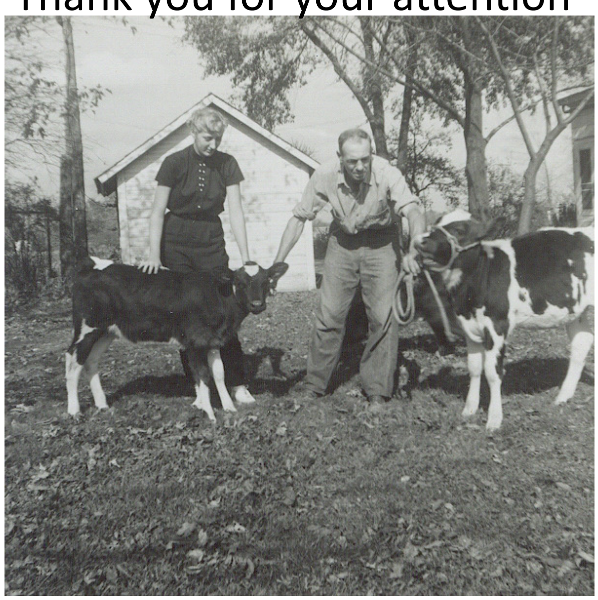
57

Thank you for your attention



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58