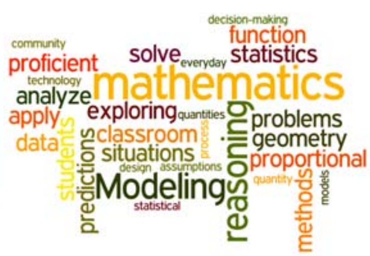
The Evolution of Mathematical Models for Animal Nutrition —what to expect next?

Luis Tedeschi, Texas A&M University
NANP-NRSP-9 Modeling Committee

The National Animal Nutrition Program

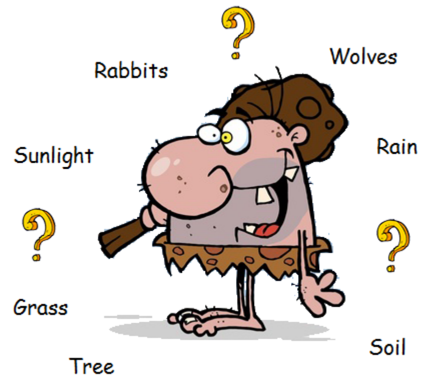
TEXAS A&M UNIVERSITY

TEXAS A&M AGRILIFE RESEARCH



Why Mathematical Modeling?

The Logical Process of Modeling



DATA

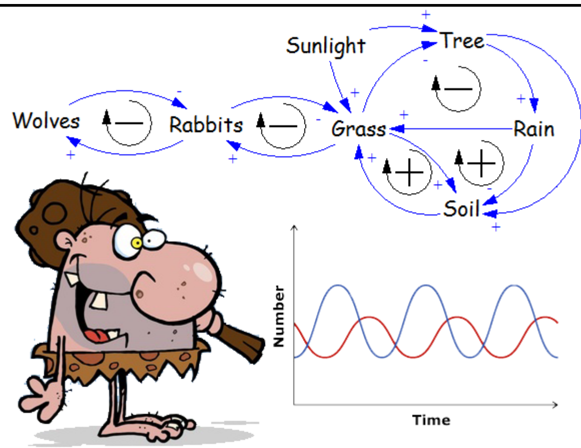
Data is the set of individual facts, figures, sensory impressions, etc. that is regarded as essentially meaningless, although it is the raw material from which meaning is derived.

INFORMATION

Information is **data** which has undergone some kind of organization. Datasets may be divided into categories according to some criteria; individual data items may be linked together according to some salient feature.

KNOWLEDGE

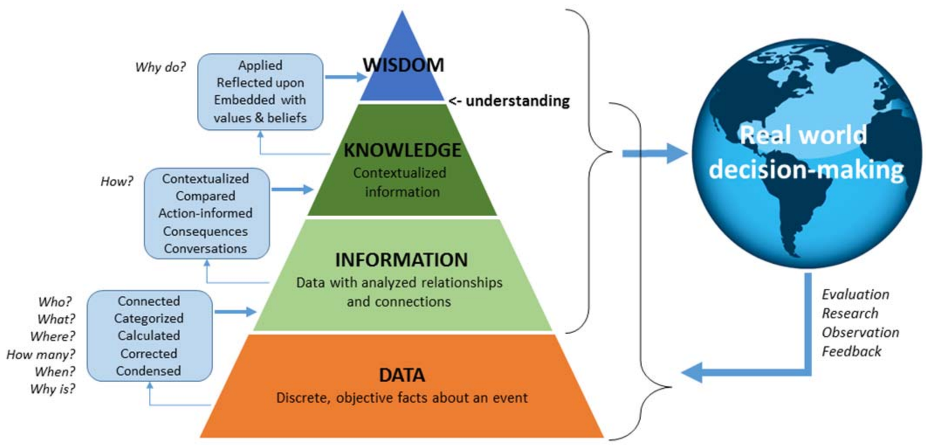
Knowledge is the **information** that has been internalized by the person such that they might put it to use. An important feature of knowledge is that, whereas information and data may reside in texts, objects, and events, knowledge acquisition, ownership, and transfer can only be effected by human agents.



WISDOM

Wisdom is the possession of **knowledge** such that one is able not only to observe *patterns* of information within data and make intelligent connections between different patterns, but also to feel the *principles* (i.e., *structure*) which underlie the patterns themselves. Wisdom allows one to see these various *patterns* in their contexts and to be able to remain independent of immersion in that context oneself. The observer may transpose *patterns* to different *contexts* but keeping the same *principles*

DIKW x Real World Problems



https://www.climate-eval.org/blog/answer-42-data-information-and-knowledge

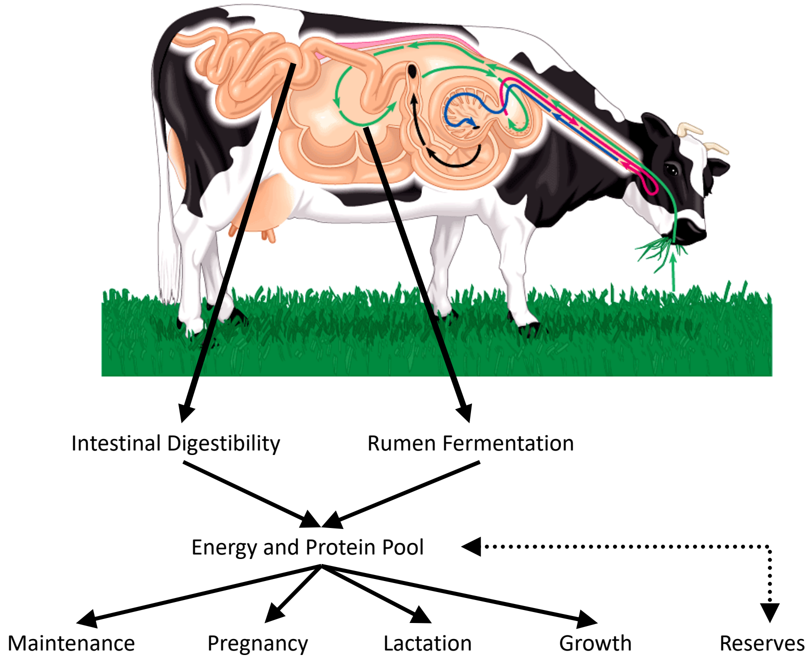
The Elephant in the Room…

- Simulation modeling is a potentially valuable approach to facilitate agricultural research, but it is <u>consistently underutilized</u>, most likely because its potential users are **(1)** not aware of its capabilities, and **(2)** believe that model development is complex and difficult (Tedeschi and Fox, 2018)

Modeling

- What level of detail?
  - Descriptive vs. Predictive
  - Empirical vs. Mechanistic
  - Deterministic vs. Stochastic
  - Static vs. Dynamic
  - Continuous vs. Discrete
  - Spatially homogeneous vs. heterogeneous
  - Basic vs. Applied
  - Problem- vs. System-driven
  - Data- vs. Concept-driven
  - Teleonomic vs. Teleologic
- Objectives (Baldwin, 1995)
  - Appraise feed biological and nutritive values
  - Describe nutrients/substrates in the organs/tissues and their relationships with animal's physiological stage
  - Determine feed requirement to meet animal production
  - Estimate animal performance given ration composition and intake

Ruminant Models

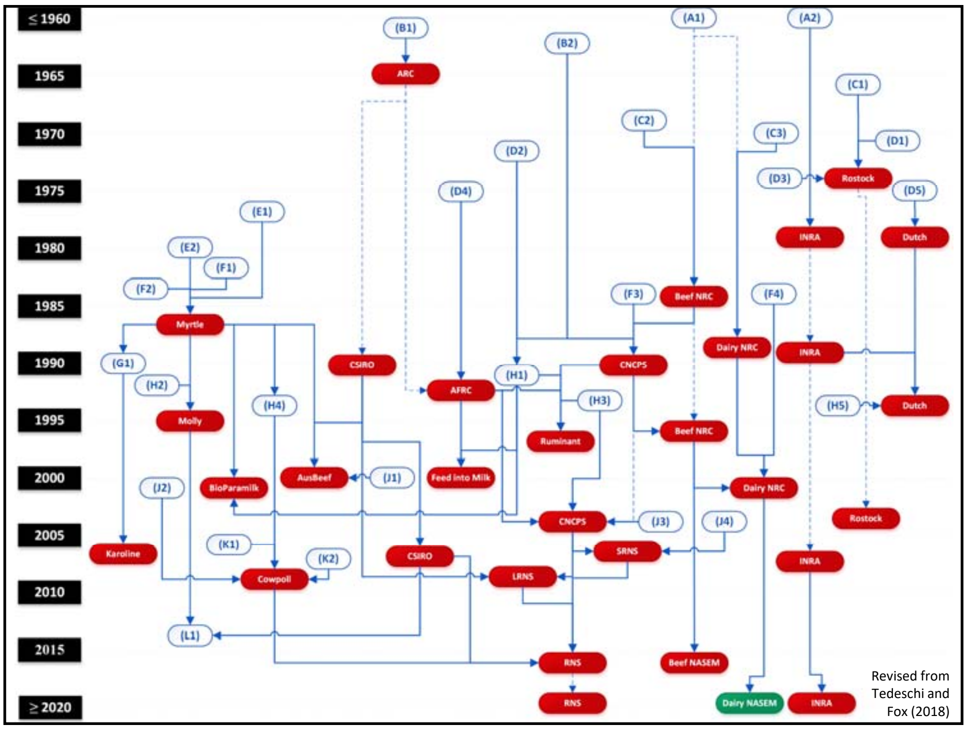


Different Schools of Thoughts ➔ Many Models

- **American models**
  - Applied: NRC, CNCPS, LRNS, BR-Corte, RNS
  - Research: Baldwin's Molly
- **British models**
  - Applied: AFRC, CSIRO, FiM, Bioparamilk, Ruminant
  - Research: France and Thornley, Illius and Gordon, AusBeef
- **French models**
  - Applied: InRation
  - Research: INRA
- **Dutch and Scandinavian models**
  - Applied: NorFor, DVE/OEB
  - Research: Dijkstra's, Karoline

Chronological Evolution of Models

- 1940s: National Research Council (NRC)
- 1960s: Agriculture Research Council (ARC)
- 1970s: Rostock, INRA, Dutch
- 1980s: Beef/Dairy NRC
- 1990s: CSIRO, AFRC, CNCPS, Molly
- 2000s: AusBeef, FiM, Ruminant, BioParamilk
- 2010s: Karoline, Cowpoll, LRNS, SRNS, RNS



Revised from Tedeschi and Fox (2018)

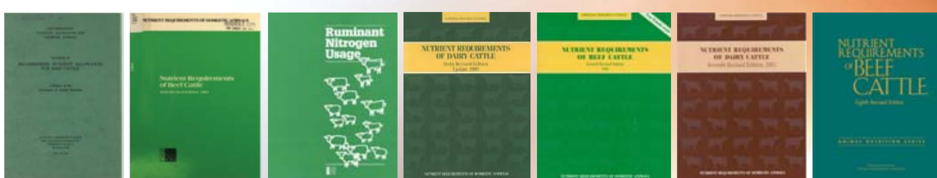
American Models

History

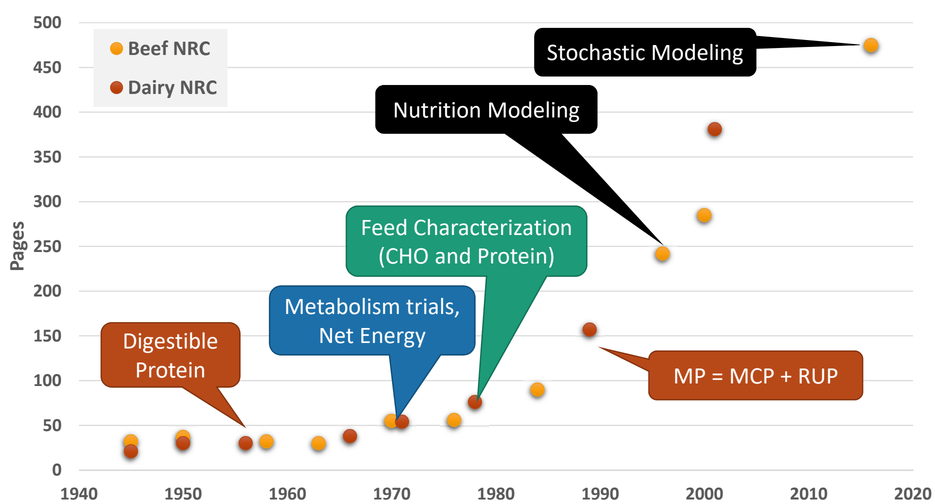
- 1908 – Inception of protein requirements by Henry P. Armsby (Chairman of the Committee on Organization of the American Society of Animal Nutrition) (Forbes, 1924)
- 1910 – Armsby presented "A Scheme for Cooperative Experiments upon the Optimum Protein Supply of Fattening Cattle" (Christensen, 1932)
- 1917 – Armsby formulated "Cooperative Experiments upon the Protein Requirements for the Growth of Cattle" and sponsored by the National Research Council with the participation of several stations from 1918 to 1923 (Christensen, 1932)
- 1924 – A report by the Subcommittee on Animal Nutrition, chaired by Dr. E. B. Forbes provided the guidelines for future experimentation on protein requirements of cattle (Forbes, 1924)
- 1929 – A detailed report by the Subcommittee on Animal Nutrition, chaired by Dr. H. H. Mitchell provided the guidelines for minimum protein requirements of cattle (Mitchell, 1929)

National Research Council (NRC)

- 1945 – Recommended nutrient allowances for cattle
- 1956 – Nutrient requirements of dairy cattle
- 1958 – Nutrient requirements of beef cattle
- Serve as the basis for most applied models used in the US
- Beef NRC (1996, 2000) introduced "levels of solution"
- Two methods to compute EE (comparative slaughter, respiration chambers)



Evolution of NRC's "Knowledge"



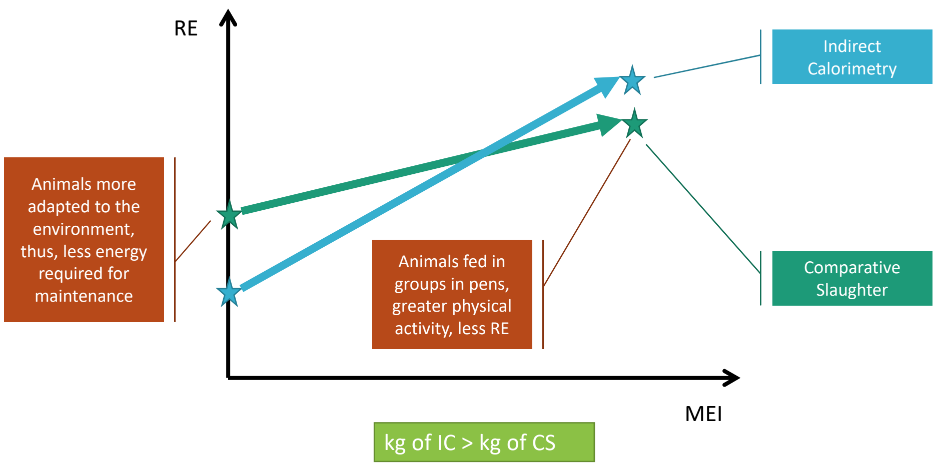
USDA ARS United States Department Of Agriculture Agricultural Research Service

Calorimetry Chambers in Beltsville, MD

Feedlot at UC, Davis, CA

Comparative Slaughter Technique

Indirect calorimetry x comparative slaughter



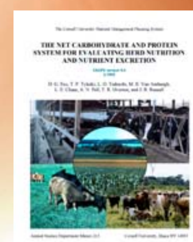
Cornell Net Carbohydrate and Protein System—Based Nutrition Models

- 1980
  - Net protein (*Fox et al., 1981*) and rumen (Van Soest et al., 1981)
  - Requirements (*Fox and Black, 1984*)
  - Protein supply (*Sniffen et al., 1987*)
  - Environment adjustments (*Fox et al., 1988*)
- 1991 (version 1)
  - Cornell Net Carbohydrate and Protein System (CNCPS) never released to the public
- 1993 (version 2)
  - *Fox et al. (1990) – Search Ag. report*

Chalupa and Boston (2003)

CNCPS-based Models Evolution

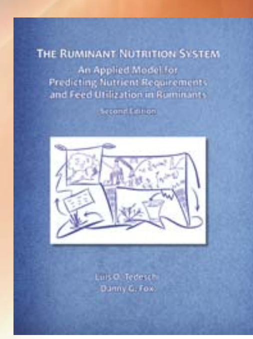
- 1994 (version 3)
  - Excel spreadsheet
  - Beef NRC (1996) is based on this version
- 2000 (version 4)
  - Microsoft Visual Basic 6.0
  - Dairy NRC (2001) has some components
- 2003 (version 5)
  - Microsoft Visual Basic .NET
  - *Fox et al. (2004)*
  - CPM Dairy



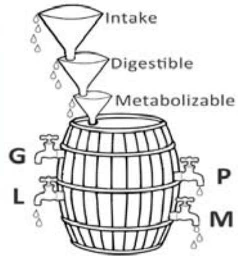
Chalupa and Boston (2003)

CNCPS-based Models Evolution

- 2004
  - *Cannas et al. (2004)*
  - CNCPS Sheep (CNCPS-S)
- 2005
  - Small Ruminant Nutrition System (SRNS)
    - sheep and goats
- 2016
  - *Tedeschi and Fox (2016, 2018)*
  - Ruminant Nutrition System (RNS)
    - cattle (beef and dairy), sheep, and goats



Tedeschi and Fox (2018)



Ruminant Nutrition System (RNS)

Level of Solution 1 (Empirical)

$$tTDN_{1x} = \begin{cases} 2.25 \times dEE & \text{Fat supplements} \\ dNFC + dCP + 2.25 \times dEE & \text{Animal protein meals} \\ dNFC + dCP + 2.25 \times dEE + dNDF & \text{Other feedstuffs} \end{cases} \quad [7.7]$$

$$dEE = \begin{cases} EED \times EE & \text{Fat supplements} \\ (1 - 0.0314 \times (EE - 1)) \times (EE - 1) & \text{Nonfat supplements, EE} > 1 \\ EE & \text{Nonfat supplements, EE} < 1 \end{cases} \quad [7.8]$$

$$dNFC = \begin{cases} 0.98 \times (100 - CP - Ash - EE) & \text{Animal protein meals} \\ 0.98 \times PAF \times (100 - NDF_N - (CP - IADIP) - Ash - EE) & \text{Other feedstuffs} \end{cases} \quad [7.9]$$

$$dCP = \begin{cases} CPD \times CP & \text{Animal protein meals} \\ CP \times e^{-0.012 \times (100 \times ADIP/CP)} & \text{Forage-based feedstuffs} \\ CP \times (1 - 0.004 \times (100 \times ADIP/CP)) & \text{Concentrate-based feedstuffs} \end{cases} \quad [7.10]$$

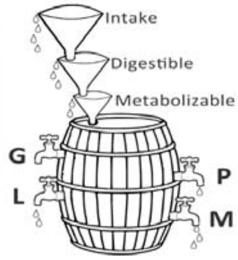
$$dNDF = 0.75 \times (NDF_N - Lignin) \times \left(1 - \phi \times (Lignin/NDF_N)^{2/3}\right) \quad [7.11]$$

$$NDF_N = NDF - NDIP + IADIP \quad [7.12]$$

$$IADIP = \begin{cases} 0.7 \times ADIP & \text{Forage-based feedstuffs} \\ 0.4 \times ADIP & \text{Concentrate-based feedstuffs} \end{cases} \quad [7.13]$$

$$aTDN_{1x} = \begin{cases} tTDN_{1x} - 1.4 & \text{Fat supplements} \\ tTDN_{1x} - 4.13 & \text{Animal protein meals} \\ tTDN_{1x} - 7 & \text{Other feedstuffs} \end{cases} \quad [7.14]$$

Where *ADIP* is acid-detergent insoluble (crude) protein, % DM; $aTDN_{1x}$ is apparent total digestible nutrients at maintenance level of intake, % DM; *CP* is crude protein, % DM; *CPD* is CP digestibility, g/g; *dCP* is digestible crude protein, % DM; *dEE* is digestible ether extract, % DM; *dNDF* is digestible neutral detergent fiber (NDF), % DM; *dNFC* is digestible nonfiber carbohydrate, % DM; *e* is the Napierian number (i.e., Napier's constant, 2.718, for exponential function), dimensionless; *EE* is ether extract, % DM; *IADIP* is indigestible acid-detergent insoluble (crude) protein, % DM; *NDF* is neutral detergent fiber, % DM; NDF_N is NDF corrected for NDIP and IADIP, % DM; *NDIP* is neutral-detergent insoluble (crude) protein, % DM; *PAF* is processing adjustment factor, g/g; *tTDN* is true total digestible nutrients at maintenance level of intake, % DM; and φ is a coefficient to adjust the weights of lignin and NDF as an approximation to their volumes in using the surface law.



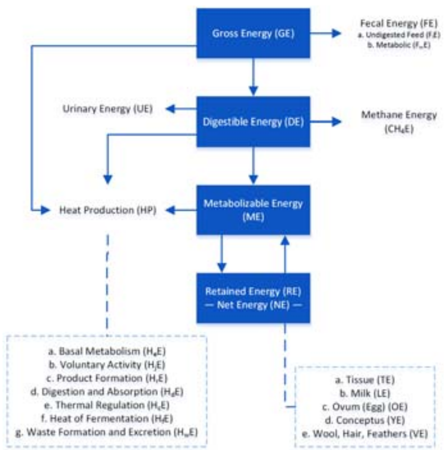
Ruminant Nutrition System (RNS)

Level of Solution 2 (Mechanistic)

Mechanistic Modeling

- Nutrient fractionation
  - Carbohydrate
  - Protein
- Bacteria submodel
  - Deficiency of N or Branched-Chain AA
- Ruminal degradation and passage fractional rates
- Ruminal pH submodel
- Intestinal digestibility
  - Midgut (small intestine)
  - Hindgut (large intestine)
- Fecal matter
- Digestibility and TDN

Two Critical Concepts

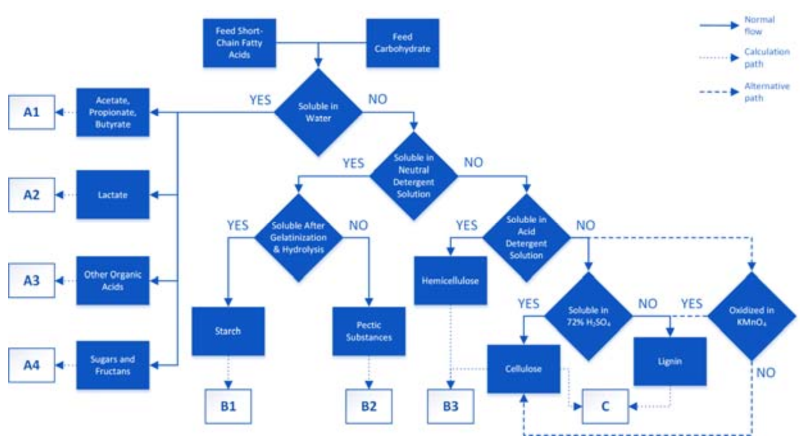


Energy Partitioning

First Limiting Factor Concept
(Sprengel-Liebig Law of the Minimum)

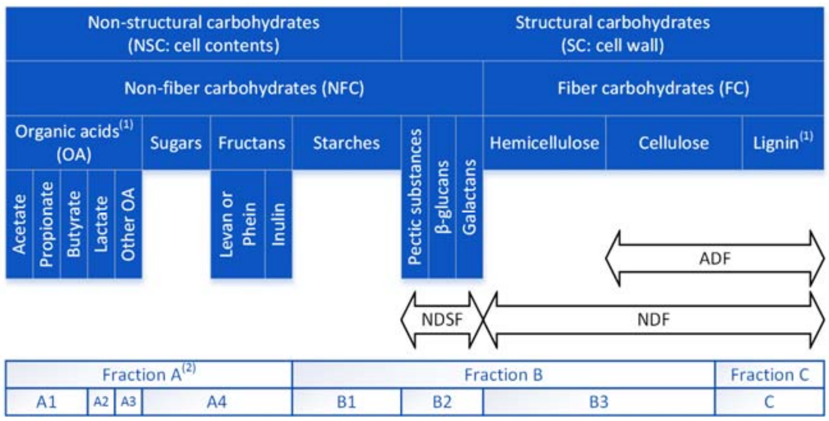
Tedeschi and Fox (2018)

Determining Feed Carbohydrate



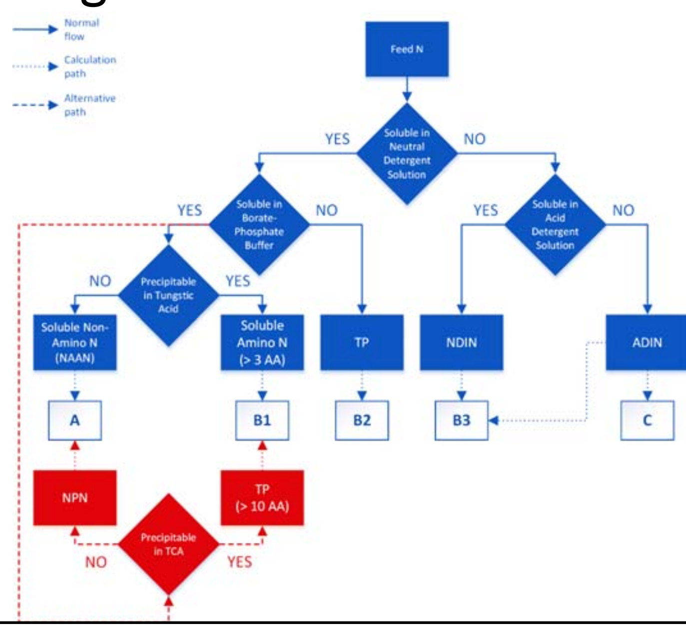
Tedeschi and Fox (2018)

Carbohydrate Fractionation



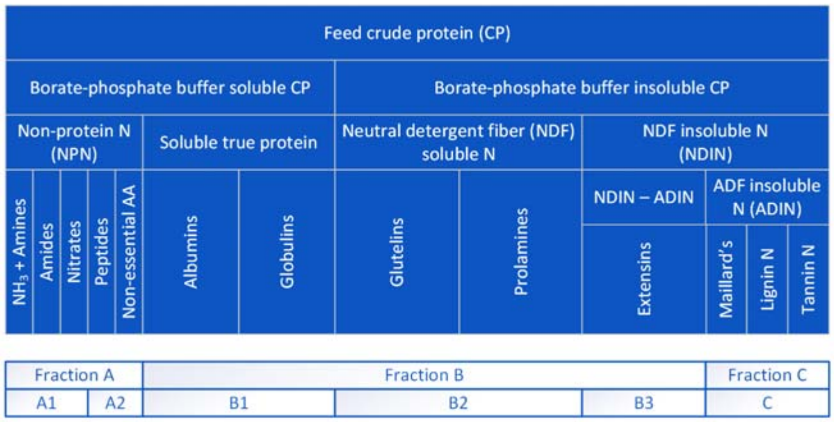
Sniffen et al. (1992); Tedeschi and Fox (2018)

Determining Feed Protein



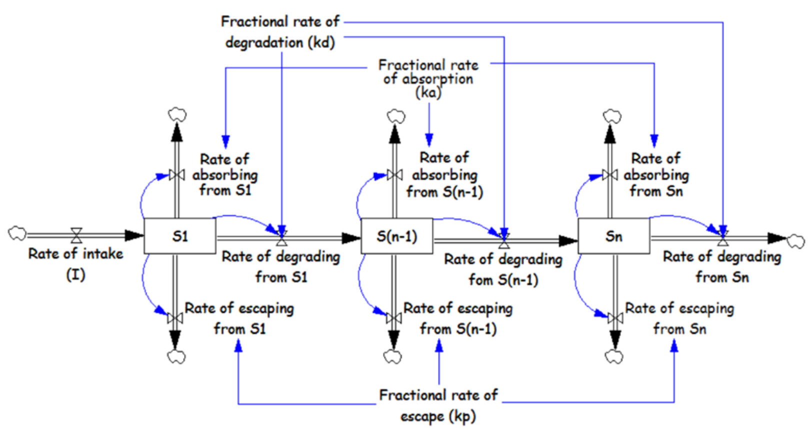
Tedeschi and Fox (2018)

Protein Fractionation



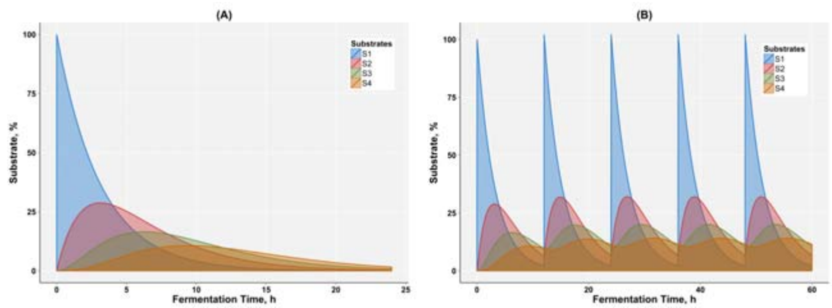
Sniffen et al. (1992); Tedeschi and Fox (2018)

Fundamental Ruminal Dynamics



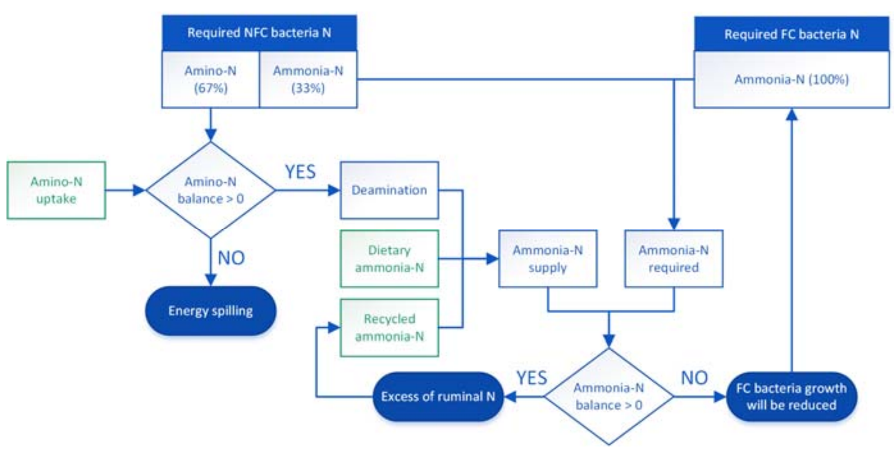
Tedeschi and Fox (2018)

Ruminal Degradation Rate (single Feeding Event)



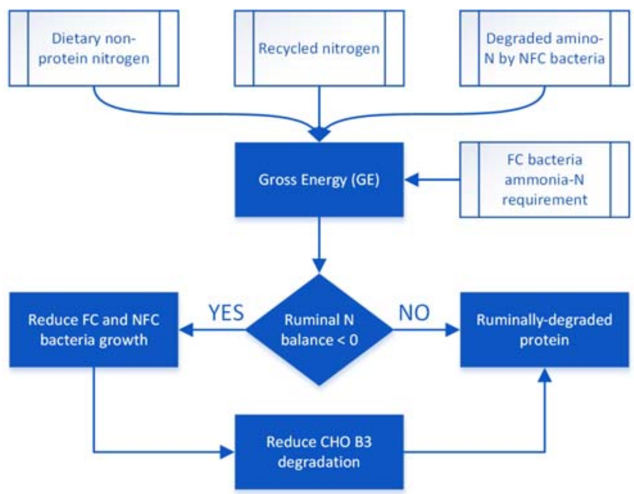
Tedeschi and Fox (2018)

Bacteria Submodel



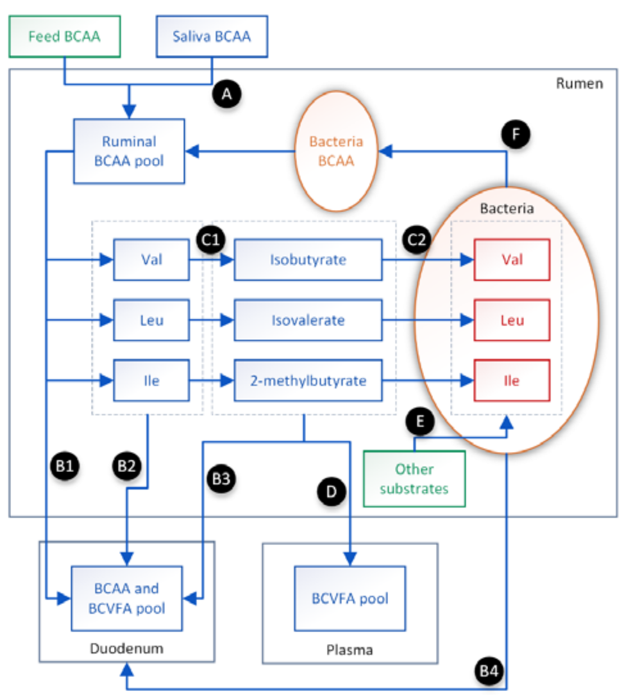
Russell et al. (1992); Tedeschi and Fox (2018)

Deficiency of Ruminal N



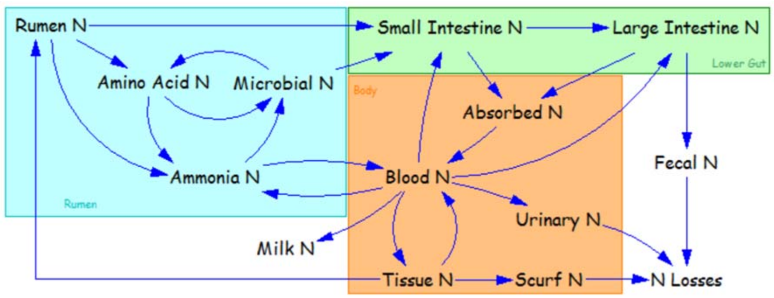
Tedeschi et al. (2000); Tedeschi and Fox (2018)

Ruminal BCAA Metabolism



Tedeschi et al. (2000); Tedeschi and Fox (2018)

The Intricate flow of Nitrogen

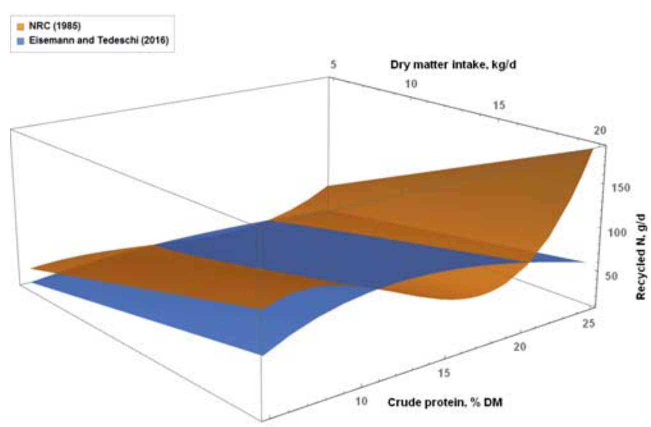


The amount of N recycled in the gastrointestinal tract (GIT) is neither a supply (inflow) nor a requirement (outflow) to the animal system; it is simply the amount of different forms of N (e.g., urea, ammonia) that circulates among the different organs of the animal. It is an abstraction of a transient N state that will eventually be allocated to a "real" N pool (e.g., faeces, urine, scurf plus hair, milk or tissue)

Tedeschi and Fox (2018) after Nolan and Leng (1972) and Mazanov and Nolan (1976)

Meta-Regression to Predict UUA:

$(-0.1113+0.966\times\exp(-0.0616\times CP))\times(1.192\times CP\times DMI-11.98)$



Eisemann and Tedeschi (2016); Tedeschi and Fox (2018)

Ruminant Nutrition System (RNS)

Requirement

Animal Requirements

- Maintenance
  - Computed using basal metabolism adjusted for different breeds, cold/Hot stress, physical activity, urea cost
- Lactation
  - Estimated from milk composition and milk yield observed for dairy and predicted for beef
- Pregnancy
  - Estimated from days pregnant
- Growth
  - Adjusted for equivalent body weight at a known % EBF
- Body reserves
  - Fluxes of fat and protein in the body

Ransom Leland Baldwin
Univ. of California, Davis
National Acad. Sci.

September 21, 1935, Meriden, CT
November 30, 2007
Education:
University of Connecticut
Michigan State University (1963)

Baldwin's Molly

A fundamental Biochemical Model

Evolution of Molly (1971 – 1987)

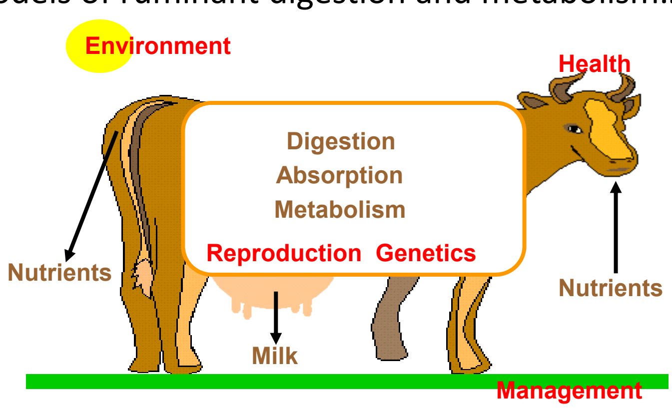
- Baldwin and Smith (1971) Modeling energetic transactions in the cow
- Reichl and Baldwin (1975) Representing microbial fermentation in the rumen
- Koong et al. (1975) Model of fetal growth
- Baldwin et al. (1976) Metabolic flux in the adipose tissue
- Baldwin et al. (1977) Integrated ruminal digestion and fermentation model
- Murphy et al. (1982) Estimating ruminal fermentation parameters
- Waghorn and Baldwin (1984) Model of metabolic flux in the mammary glands
- di Marco et al. (1987) Representing hyperplastic and hypertrophic growth
- Oltjen et al. (1986) Beef animal growth model
- Baldwin et al. (1987a,b,c) Molly cow model

Evolution of Molly (1988 – 2015)

- Argyle and Baldwin (1988) Modeling water kinetics and pH in the rumen
- Freetly et al. (1993) Model of liver metabolism in the lactating cow
- Boston and Hanigan (2000) Nonlinear optimization of diets with Molly
- Hanigan et al. (2007) Redefinition of mammary cells and activity in Molly
- Hanigan et al. (2009) Representing gestational metabolism in Molly
- Gregorini et al. (2013) Representing diurnal grazing patterns in Molly
- Hanigan et al. (2013) Revised digestive parameter estimates for Molly
- Ghimire et al. (2014) Thermodynamic effects on volatile fatty acid production in Molly
- Gregorini et al. (2015) Improved representation of ruminal digesta outflow in Molly

Baldwin (1995)

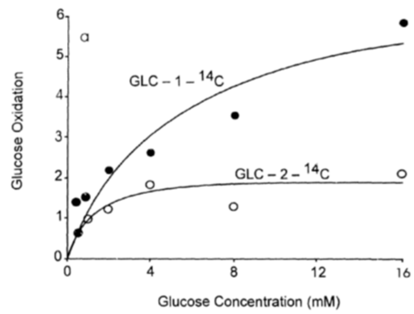
- "This is a long-term goal that will require the availability of advanced dynamic, mechanistic models of ruminant digestion and metabolism…"



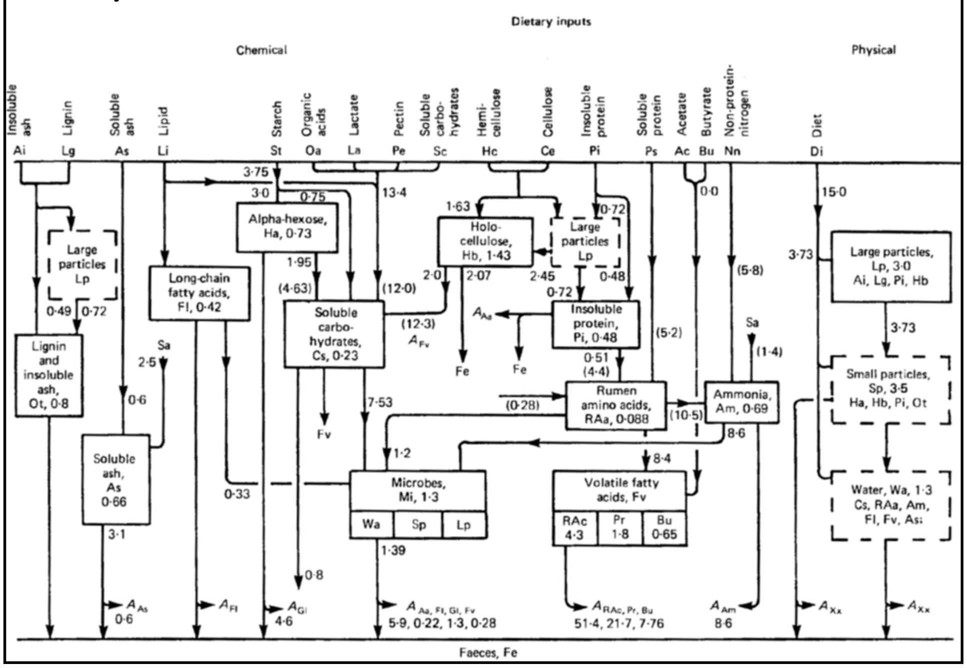
Mechanistic Modeling

$$v = \frac{V_{\max} \times [S]}{k_m + [S]}$$

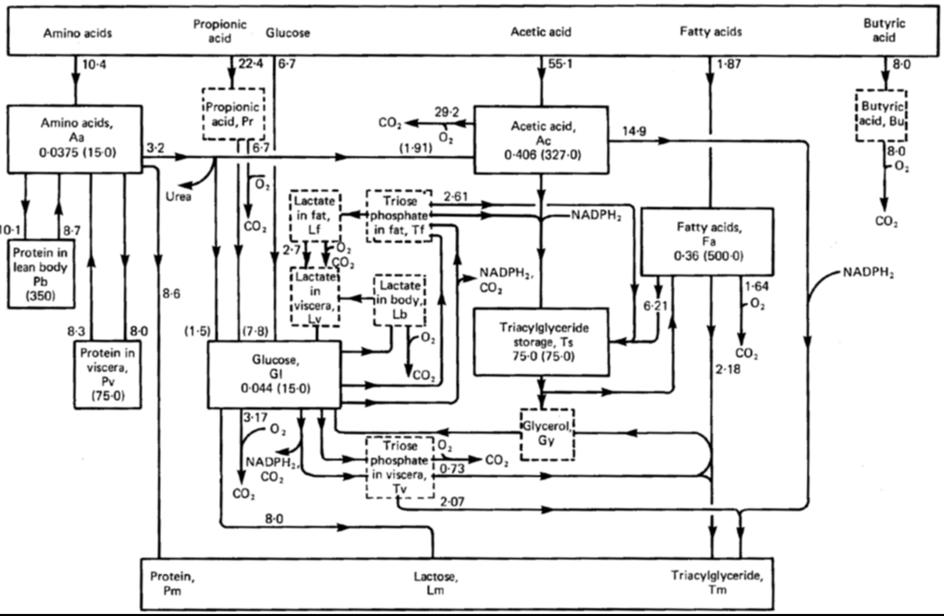
Level	Description of Level
$i+1$	herd of animals
i	animal
$i-1$	organs
$i-2$	tissues
$i-3$	cells



Molly Rumen submodel



Molly Animal submodel



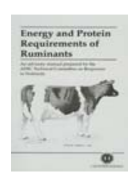
Animal Efficiencies… (Baldwin et al., 1980)

- Maximum observed efficiencies are sometimes quite comparable to theoretical efficiencies. On the other hand, observed efficiencies considerably below theoretical are also observed. This variation in observed efficiencies raises two important questions:
- (1) Could we learn to identify animals that are capable of attaining maximum efficiencies and based on genetic selection improve the average efficiency of animal production?
- (2) If we knew exactly what types of unfortunate metabolic decisions the less efficient animals were making, could we manipulate the metabolism of those animals such that their efficiencies would approach those of the best animals?

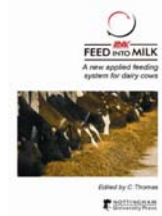
British Models

Agricultural Research Council (ARC) Ag. & Food Research Council (AFRC)

- ARC (1965, 1980) and technical reviews on energy (AFRC, 1987, 1990), protein (AFRC, 1987, 1992), mineral (AFRC, 1988, 1991), and intake (AFRC, 1991)
- Efficiency of use of energy/nutrients is a function of feed metabolizability (qm = ME/GE)
- MCP = f(Fermentable ME, Level of feeding)
  - Address the kd/kp relationship
- No recycled N

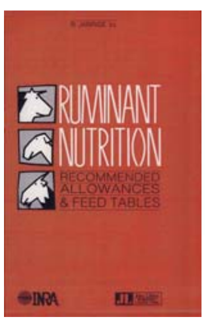


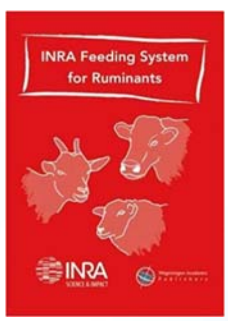
Feed into Milk (FiM, 2004)



- Why FiM?
  - Concerns about energy standards for high yielding cows
  - Dissatisfaction with parts of MP model
  - Inadequate prediction of voluntary feed intake
  - “Pressure” from industry
- MCP
  - Y_{ATP} = ATP of degraded DM from soluble, concentrate, and forage particles (ATPy)
  - MCP = $f\,(Y_{ATP})$

$$MPm = 4.1 \times BW^{0.75} + 0.3 \times BW^{0.6} + 30 \times DMI - 0.5 \times (DMTP/0.8 - DMTP) + 2.34 \times DMI,$$





French Models

Institut National de la Recherche Agronomique (INRA)

Supply

- INRA assumes 2 NE values
  - UFL → lactation: 1 UFL = NE content of 1 kg barley for milk
  - UFV → Meat: 1 UFV = NE content of 1 kg barley for meat

- Protein supply based on PDI system:
  - PDIE is energy first-limiting MP
  - PFIN is protein first-limiting MP

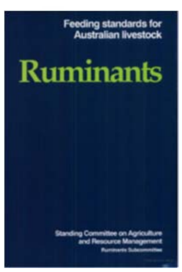
$$PDIE = PDIA + PDIME,$$

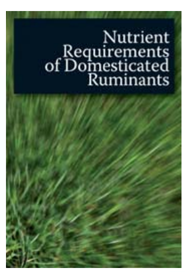
$$PDIN = PDIA + PDIMN,$$

$$PDIA = CP \times [1.11 \times (1 - a)] \times b,$$

$$PDIMN = CP \times [1.11 \times (1 - a)] \times 0.9 \times 0.8 \times 0.8,$$

$$PDIME = FOM \times 0.145 \times 0.8 \times 0.8.$$





Australian Models

Commonwealth Scientific and Industrial Research Organization (CSIRO)

Supply

- Factorial approach for protein, based on the ARC (1965, 1980) and AFRC (1993)
- RDP and UDP based on the "abc" system

$$RDP = a + b \times (1 - exp(-c \times t)),$$

$$eRDP = a + b \times c/(c + kp),$$

$$UDP = b \times kp/(c + kp) + d,$$

- Broderick (1994)

$$UDP = ADIP + (NDIP - ADIP) \times (kp/(kp + c)),$$

Table 2.1. Estimates of effective degradability of protein *in sacco* at three fractional outflow rates per h from the rumen (k), in several UK and Australian feeds

	k		
	0.02	0.05	0.08
Protein meals			
Cottonseed meal[A]	0.71	0.51	0.46
Maize gluten feed[B]	0.90	0.84	0.80
Palm kernel meal[B]	0.71	0.52	0.43
Rapeseed meal[B]	0.86	0.78	0.72
Rapeseed meal[C]	0.81	0.70	0.62
Sunflower seed meal[B]	0.88	0.80	0.74
Sunflower seed meal[C]	0.88	0.77	0.69
Soyabean meal[A]	0.76	0.57	0.46
Legume grains			
Lupins: fine meal[C]	0.95	0.93	0.92
medium meal[C]	0.85	0.72	0.64
coarse meal[C]	0.75	0.54	0.42
Cereal grains			
Barley[B]	0.90	0.85	0.81
Triticale[B]	0.93	0.90	0.87
Wheat[B]	0.93	0.90	0.87

[A] Hennessy *et al.* (1983).
[B] MAFF (1990).
[C] Freer and Dove (1984).

Microbial Crude Protein

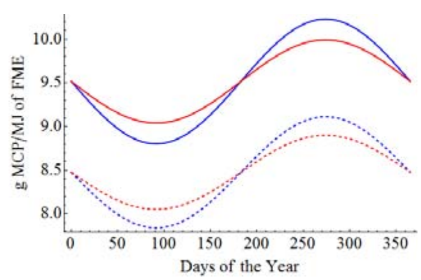
- MCP depends on fermentable ME (FME)

$$MCP = FME \times \left(7 + 6 \times (1 - exp(-0.35 \times L))\right).$$

- MCP adjusted for latitude and day of the year and for tropical pastures, the efficiency of synthesis is discounted by 1 unit

$$MCP = FME \times (7 + 6 \times (1 - exp(-0.35 \times L))) \times (1.0 + 0.1 \times (\lambda \times sin(0.0172 \times t)/40)),$$

$$MCP = FME \times (6 + 6 \times (1 - exp(-0.35 \times L))),$$



Requirements

- Maintenance:
  - Endogenous N losses uses different equation than ARC (1965, 1980) because of unrealistic results for poor-quality pastures. For *Bos indicus*, further discounts EUP by 20%. Dermal loss is the same as ARC (1980)

$$EUP = 16.1 \times ln\,(BW) - 42.2.$$

$$EFP = 15.2 \times DMI.$$

$$Dermal\ loss = 0.11 \times BW^{0.75}.$$

- Pregnancy: Same as ARC (1980)
- Lactation: Same as ARC (1980)
- Growth:
  - Based on breed, degree of maturity, and level of nutrition, or using BCS

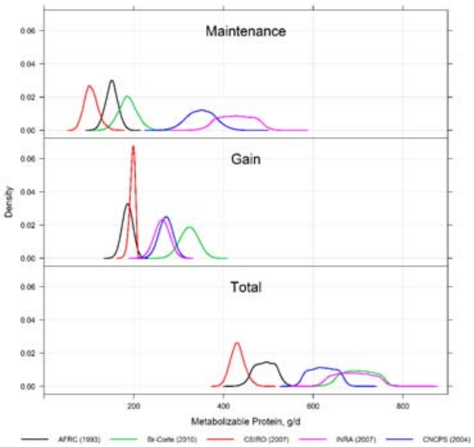
$$CPg = EWG \times \left[(212 - 4 \times R) - \frac{b - 4 \times R}{1 + e^{(-6 \times (Z - 0.4))}}\right],$$

$$CPg = EWG \times (d - f \times BCS),$$

Sensitivity Analysis for Metabolizable Protein Requirement

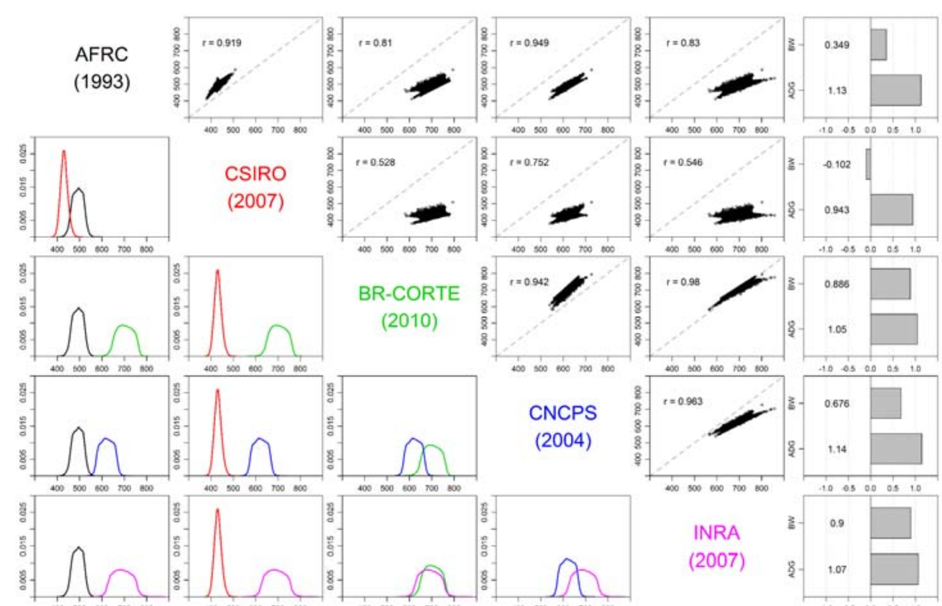
Monte Carlo Simulations - Growth

- Sensitivity analysis using Monte Carlo simulations
- 5,000 iterations using Latin Hypercube sampling method
- Normal distribution for input variables
  - BW of 350 ± 30 kg
  - ADG of 1.2 ± 0.12 kg/d
  - Correlation between BW and ADG using a Gompertz nonlinear function: -0.5142



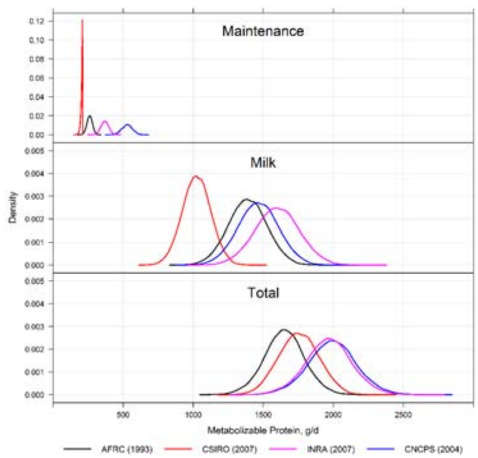
Tedeschi et al. (2013)

MP Required for Growth



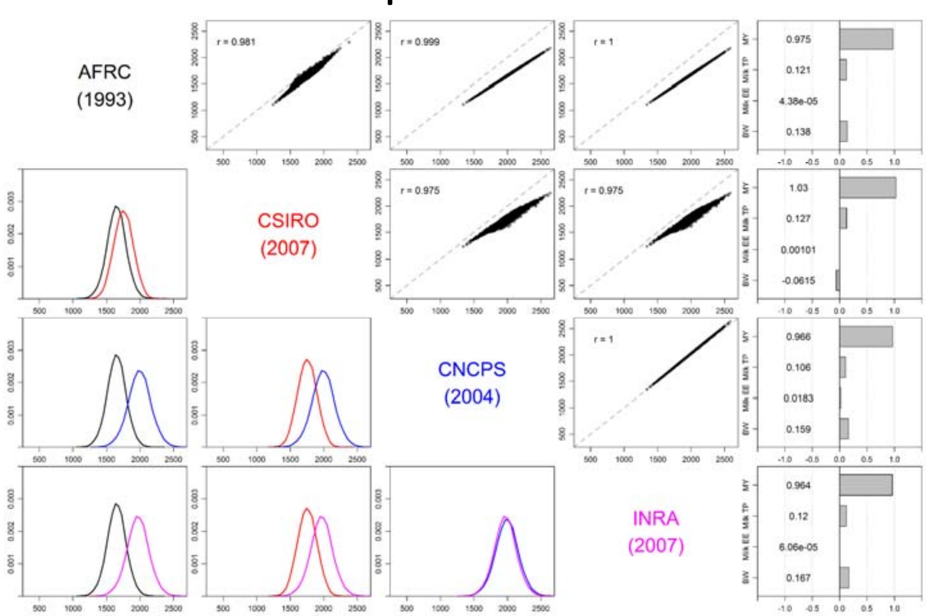
Monte Carlo Simulations - Milk

- Sensitivity analysis using Monte Carlo simulations
- 5,000 iterations using Latin Hypercube sampling method
- Normal distribution for input variables
  - BW of 550 ± 55
  - MY of 32 ± 3.2
  - Milk fat 3.7 ± 0.1%
  - Milk protein 3.2 ± 0.04%
  - Correlation among inputs based on Sieber et al. (1988)



Tedeschi et al. (2013)

MP Required for Milk



Model Inter-Comparison for Milk Prediction

Databases

- Milk production
  - 37 published studies
  - Six regions: Africa, Asia, Europe, Latin America, North America, and Oceania
  - 173 data points
- Nutrition models
  - Planned to compare up to 10 empirical and mechanistic/dynamic models
  - Molly, Dairy NRC (2001), LRNS L1 and L2

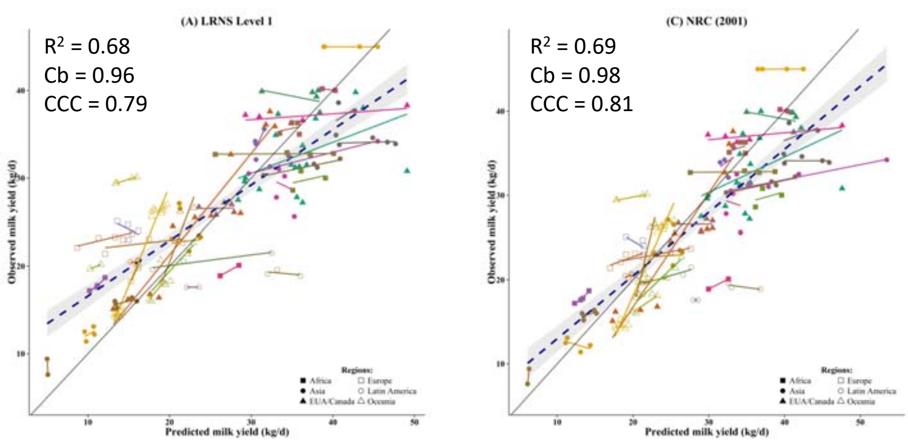
Tedeschi et al. (2014)

Animal Information

Items	Median	Mean	SD	Range		Quartiles	
				Min	Max	25%	75%
Animals							
SBW, kg	567	555	66.4	345	660	522	598
DMI, kg/d	19.1	19.1	3.5	9.1	27.5	17.3	22.1
DIM, days	100	114	64.7	30	265	60	150
MY, kg/d	26.3	26.4	8.3	7.6	45	19.7	32.7
Milk fat, %	3.7	3.7	0.5	2.3	5.0	3.4	4.1
Milk protein, %	3.0	3.1	0.3	2.4	3.9	2.9	3.3

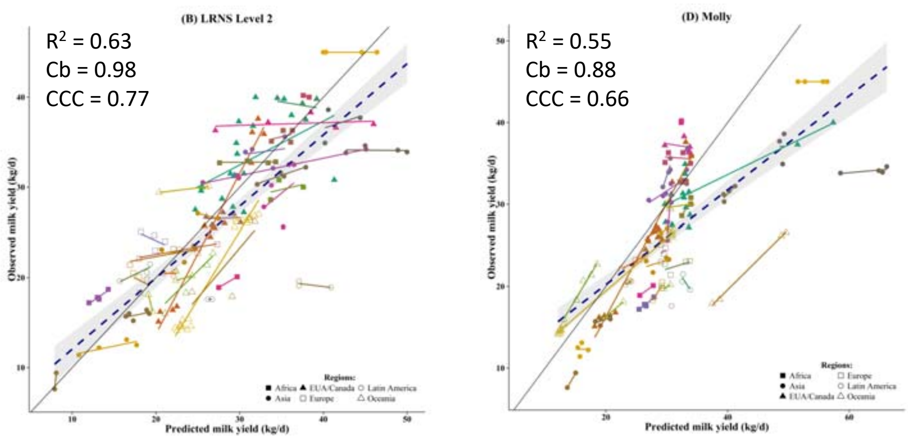
Tedeschi et al. (2014)

Observed X Predicted: Empirical



Tedeschi et al. (2014)

Observed X Predicted: Mechanistic



Tedeschi et al. (2014)

Problems with Model Inter-Comparisons

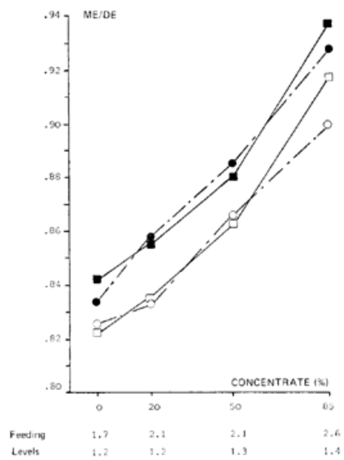
Areas that Need Research

Lessons Learned from NASEM (2016) and RNS (2018)

- Supply of Energy and Protein
  - Efficiency of conversion of DE to ME
  - Microbial crude protein (MCP)
  - Ruminal recycled nitrogen
- Requirements for energy and Protein
  - Energy requirement for grazing animals
  - Energy required for cold or heat stress
  - Metabolizable protein required for maintenance
  - Retained protein
  - Efficiency of conversion of metabolizable protein and amino acids

Tedeschi et al. (2017)

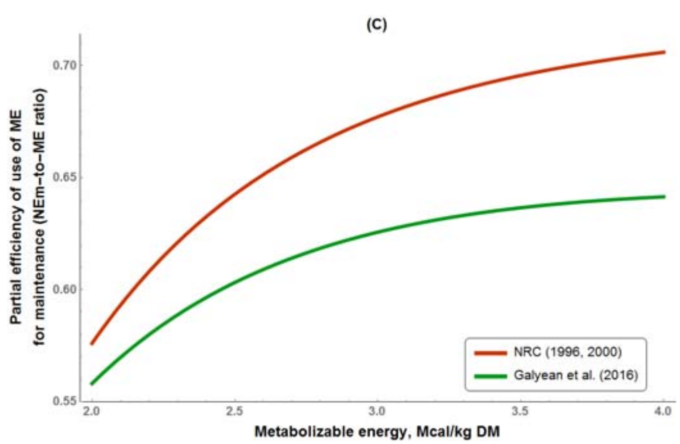
Efficiency of DE → ME?



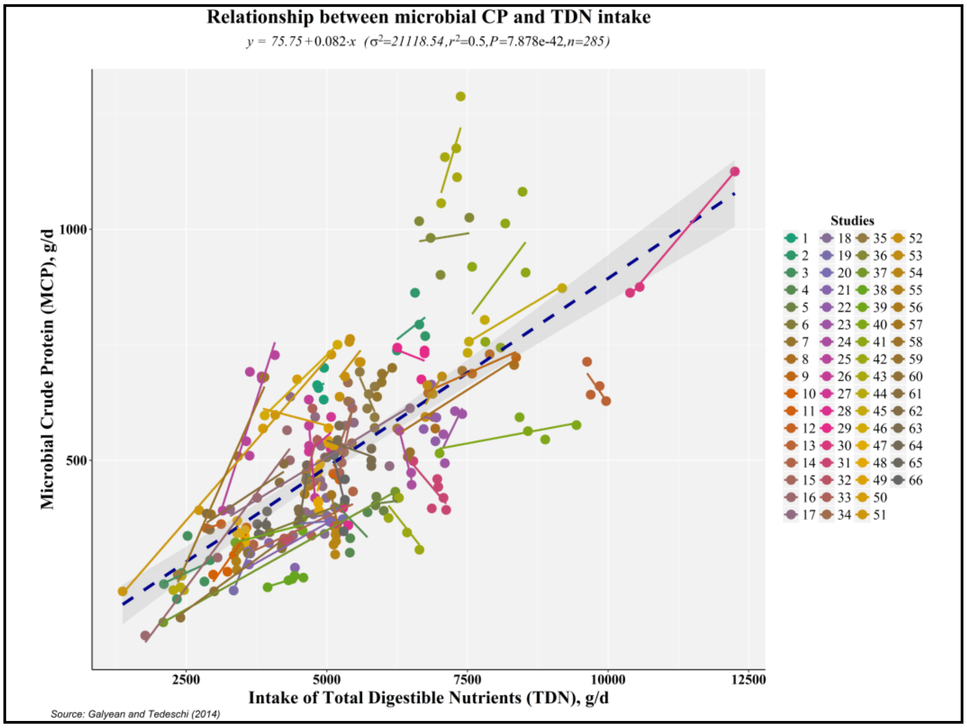
- NRC (1984, 1996, 2000)
  - Fixed at 82%
- NRC (2001)
  - ME = 1.01×DE – 0.45
- Hales et al. (2012, 2013)
  - Jersey steers, high-concentrate diets → 95%
- Galyean et al. (2016)
  - 23 respiration calorimetry studies
  - ME = 0.9611×DE – 0.299
- Consistency and dependency
  - DE → ME → NE
  - Methane feedback?

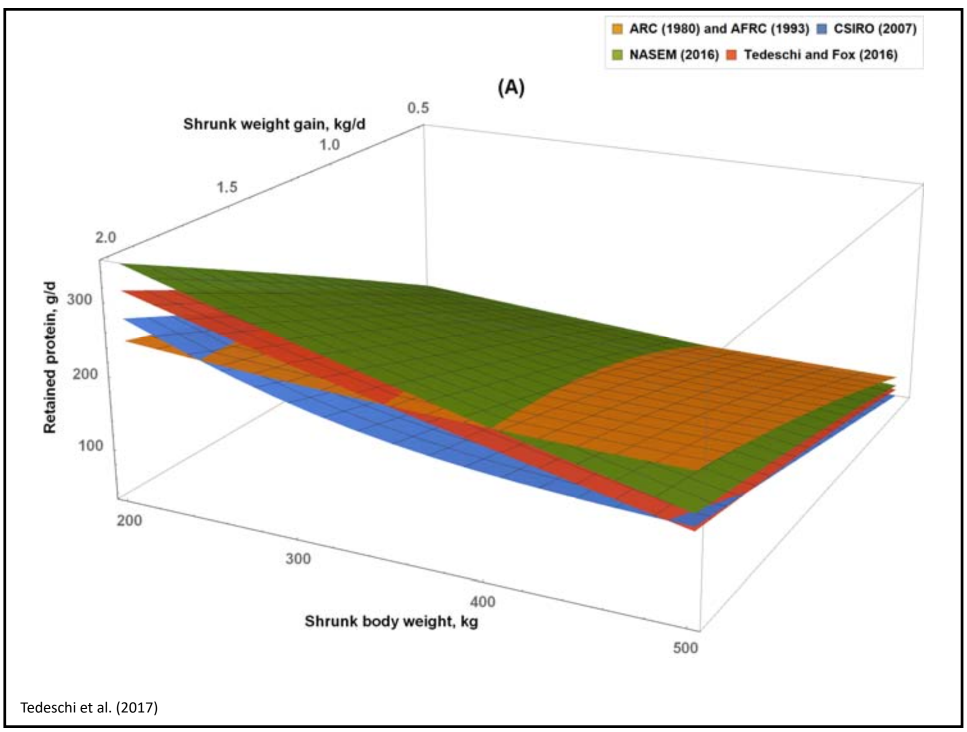
Vermorel and Bickel (1980)

Consistency and Dependency



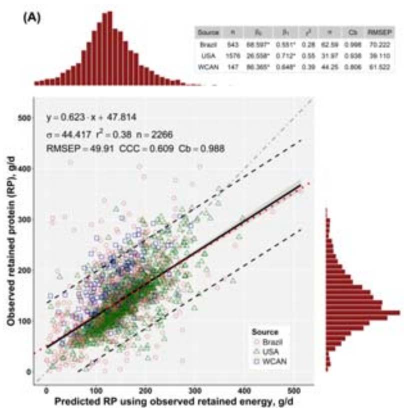
Tedeschi and Fox (2018)


Relationship between microbial CP and TDN intake
y = 75.75 + 0.082·x (σ²=21118.54, r²=0.5, P=7.878e-42, n=285)
Microbial Crude Protein (MCP), g/d
Intake of Total Digestible Nutrients (TDN), g/d
Studies
Source: Galyean and Tedeschi (2014)

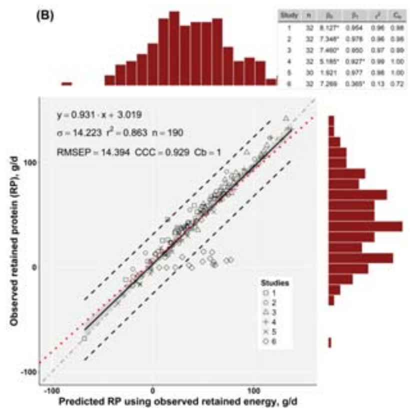

ARC (1980) and AFRC (1993)
CSIRO (2007)
NASEM (2016)
Tedeschi and Fox (2016)
(A)
Shrunk weight gain, kg/d
Retained protein, g/d
Shrunk body weight, kg
Tedeschi et al. (2017)

Evaluation of Predicted RP

Comparative Slaughter



Respiration Calorimetry



A = Tedeschi and Fox (2016, 2018), B = Tedeschi et al. (2017)

Theoretical Retained Protein

```
Eq1 = RE == 5.686 RP + 9.367 RF;
Eq2 = EBF == EBW - EBP/EBPFFM /. EBPFFM -> 0.2201;
Eq3 = fEBF - iEBF == (fEBW - fEBP/EBPFFM) - (iEBW - iEBP/EBPFFM);
Eq4 = RF == fEBF - iEBF;
Eq5 = RP == fEBP - iEBP;
Eq6 = EWG == fEBW - iEBW;
(*Eq6=SWG==0.8656(fEBW-iEBW);*)
Sol1 = Solve[{Eq3 /. EBPFFM → 0.2201, Eq4, Eq5, Eq6},
    RF, {fEBF, iEBF, fEBW, iEBW, fEBP, iEBP}][[1]];
Eq7 = RF == Sol1[[1]][[2]];
Sol2 = Solve[{Eq1, Eq7}, RP, {RF}][[1]]
Eq8 = RP == Sol2[[1]][[2]] /. EWG → 0.956 SWG
{RP → 0. + 0.254042 EWG - 0.0271209 RE}

RP == 0. - 0.0271209 RE + 0.242864 SWG
```

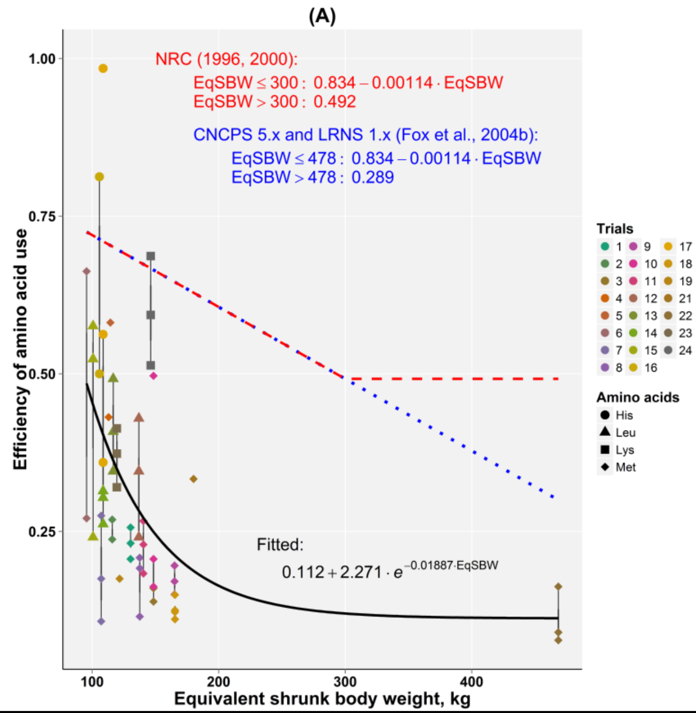
Caloric value:

- Garrett et al. (1959):
  - Protein = 5.686 Mcal/kg
- Blaxter and Rook (1953):
  - Fat = 9.367 Mcal/kg

Fat-free matter (FFM):

- Garrett and Hinman (1969):
  - Water = 73%
  - Protein = 22%
  - Ash = 5%

Tedeschi and Fox (2018)



Tedeschi and Fox (2018)

Looking forward..

- Research still needed
  - There are too many gaps & these are different times
- Scripted programming (e.g., R, python, julia)
  - Easy dissemination (free of charge)
  - High usability and adoptability ("easy" to learn)
  - Integration and modification "on the fly"
- Artificial Intelligence, Machine Learning, Deep "layers" Learning
  - What to do with big data?
  - May or may not help modeling
  - We still need concepts to understand underlying mechanisms

References 1/2

- Baldwin, R. L. 1995. Modeling Ruminant Digestion and Metabolism. Chapman & Hall, New York, NY.
- Cannas, A., L. O. Tedeschi, D. G. Fox, A. N. Pell, and P. J. Van Soest. 2004. A mechanistic model for predicting the nutrient requirements and feed biological values for sheep. J. Anim. Sci. 82 (1):149-169.
- Chalupa, W., and R. C. Boston. 2003. Development of the CNCPS and CPM models: The Sniffen affect. Pages 15-24 in Proceedings of Cornell Nutrition Conference for Feed Manufacturers. Syracuse, NY. New York State College of Agriculture & Life Sciences, Cornell University.
- Christensen, F. W. 1932. The protein requirements of beef cattle. J. Anim. Sci. 1932 (1):26-33.
- Eisemann, J. H., and L. O. Tedeschi. 2016. Predicting the amount of urea nitrogen recycled and used for anabolism in growing cattle. J. Agric. Sci. 154:1118-1129.
- Forbes, E. B. 1924. Cooperative Experiments upon the Protein Requirements for the Growth of Cattle - II. No. 42. Bulletin of the National Research Council. National Academy Press, Washington, DC. 49p.
- Fox, D. G., C. J. Sniffen, and P. J. Van Soest. 1981. A net protein system for cattle: Meeting protein requirements of cattle. Pages 280-295 in Proceedings of an International Symposium on Protein Requirements for Cattle (MP109-P). F. N. Owens, ed. Stillwater, OH. Oklahoma State University.
- Fox, D. G., and J. R. Black. 1984. A system for predicting body composition and performance of growing cattle. J. Anim. Sci. 58 (3):725-739.
- Fox, D. G., C. J. Sniffen, and J. D. O'Connor. 1988. Adjusting nutrient requirements of beef cattle for animal and environmental variations. J. Anim. Sci. 66 (6):1475-1495.
- Fox, D. G., C. J. Sniffen, J. D. O'Connor, J. B. Russell, and P. J. Van Soest. 1990. The Cornell Net Carbohydrate and Protein System for evaluating cattle diets. Search:Agriculture. No. 34. Cornell University Agricultural Experiment Station, Ithaca, NY. 128p.
- Fox, D. G., L. O. Tedeschi, T. P. Tylutki, J. B. Russell, M. E. Van Amburgh, L. E. Chase, A. N. Pell, and T. R. Overton. 2004. The Cornell Net Carbohydrate and Protein System model for evaluating herd nutrition and nutrient excretion. Anim. Feed Sci. Technol. 112 (1):29-78.
- Mazanov, A., and J. V. Nolan. 1976. Simulation of the dynamics of nitrogen metabolism in sheep. Br. J. Nutr. 35 (1):149-174.
- Mitchell, H. H. 1929. The Minimum Protein Requirements of Cattle. No. 67. Bulletin of the National Research Council. National Academy Press, Washington, DC. 84p.

References 2/2

- Baldwin, R. L. 1995. Modeling Ruminant Digestion and Metabolism. Chapman & Hall, New York, NY.
- National Research Council. 1996. Nutrient Requirements of Beef Cattle. (7th ed.). Nutrient requirements of domestic animals. National Academy Press, Washington, DC.
- National Research Council. 2000. Nutrient Requirements of Beef Cattle. (updated 7th ed.). Nutrient requirements of domestic animals. National Academy Press, Washington, DC.
- National Research Council. 2001. Nutrient Requirements of Dairy Cattle. (7th ed.). Nutrient requirements of domestic animals. National Academy Press, Washington, DC.
- Nolan, J. V., and R. A. Leng. 1972. Dynamic aspects of ammonia and urea metabolism in sheep. Br. J. Nutr. 27 (1):177-194.
- Russell, J. B., J. D. O'Connor, D. G. Fox, P. J. Van Soest, and C. J. Sniffen. 1992. A net carbohydrate and protein system for evaluating cattle diets: I. Ruminal fermentation. J. Anim. Sci. 70 (11):3551-3561.
- Sniffen, C. J., J. D. O'Connor, P. J. Van Soest, D. G. Fox, and J. B. Russell. 1992. A net carbohydrate and protein system for evaluating cattle diets: II. Carbohydrate and protein availability. J. Anim. Sci. 70 (11):3562-3577.
- Tedeschi, L. O., D. G. Fox, and J. B. Russell. 2000. Accounting for ruminal deficiencies of nitrogen and branched-chain amino acids in the structure of the Cornell net carbohydrate and protein system. Pages 224-238 in Proceedings of Cornell Nutrition Conference for Feed Manufacturers. Rochester, NY. New York State College of Agriculture & Life Sciences, Cornell University.
- Tedeschi, L. O., D. G. Fox, and J. B. Russell. 2000. Accounting for the effects of a ruminal nitrogen deficiency within the structure of the Cornell net carbohydrate and protein system. J. Anim. Sci. 78 (6):1648-1658.
- Tedeschi, L. O., D. G. Fox, M. A. Fonseca, and L. F. L. Cavalcanti. 2013. Models of protein and amino acid requirements for cattle. Pages 1-45 (CD format) in Proceedings of the 50th Annual Meeting of the Brazilian Society of Animal Science. L. G. Nussio, ed. Campinas, São Paulo, Brazil. Sociedade Brasileira de Zootecnia (SBZ). Available at: http://www.sbz.org.br/reuniao2013/?lang=en. Accessed on: October 4, 2017.
- Tedeschi, L. O., and D. G. Fox. 2018. The Ruminant Nutrition System: An Applied Model for Predicting Nutrient Requirements and Feed Utilization in Ruminants. (2nd ed.). XanEdu, Acton, MA.
- Van Soest, P. J., C. J. Sniffen, D. R. Mertens, D. G. Fox, P. H. Robinson, and U. C. Krishnamoorthy. 1981. A net protein system for cattle: The rumen submodel for nitrogen. Pages 265-279 in Proceedings of an International Symposium on Protein Requirements for Cattle (MP109-P). F. N. Owens, ed. Stillwater, OH. Oklahoma State University.