AN OVERVIEW OF THE RUMINANT NUTRITION SYSTEM

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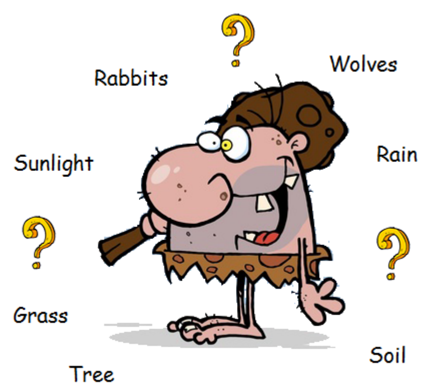
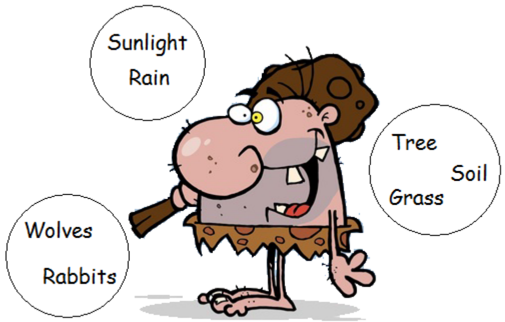


DATA

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.

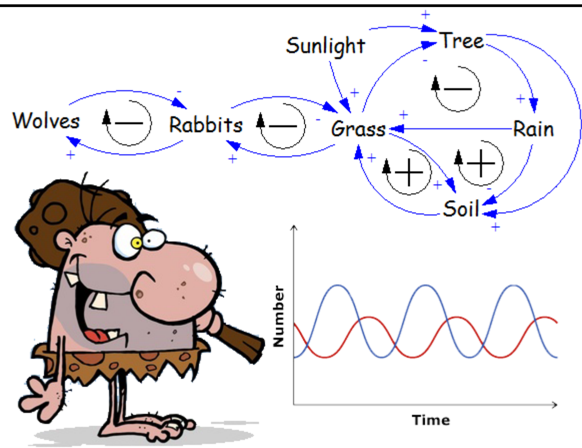


INFORMATION

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

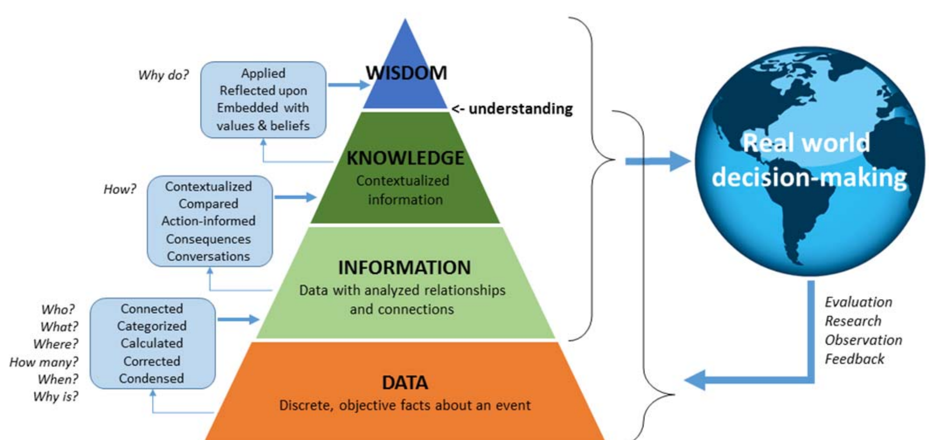
Knowledge is the **information** that has been internalized by the person such that they might put it to use. An important feature of knowledge is that, whereas information and data may reside in texts, objects, and events, knowledge acquisition, ownership, and transfer can only be effected by human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

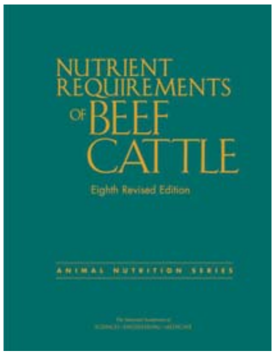
DIKW X REAL WORLD PROBLEMS



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

WHERE TO GET MORE INFORMATION…

BCNRM by NASEM (2016)



The National Academies of
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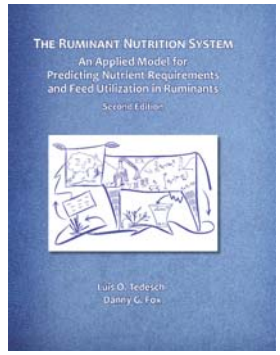
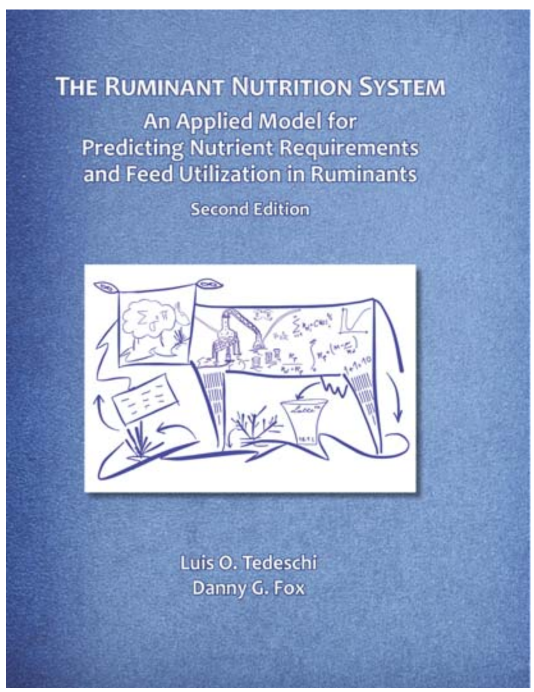
Ruminant Nutrition System by Tedeschi and Fox (2018)

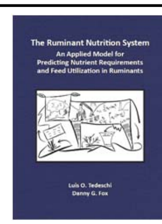


Nutrition modeling is the natural way to use the accumulated scientific knowledge and to apply the Data-Information-Knowledge-Wisdom concept



APPLICATIONS

APPLICATIONS OF THE RNS



- improving the understanding of undergraduate and graduate students and nutrition advisors about ruminant nutrition by evaluating the interactions of feed composition, feeding management, and animal requirements in varying farm conditions
- designing experiments and interpreting and comparing model-predicted requirements, feed utilization, and performance with experimental data
- applying experimental results under different animal, feed, and environmental conditions to improve animal productivity and profitability while reducing nutrient excretion (per unit of meat or milk production) into the environment
- developing recommendations and guidelines for nutritive value of feedstuffs and creating adjustment factors

APPLICATIONS OF THE RNS

- extending and refining the use of conventional diet formulation programs
- estimating biological values for feeds for which no nutritive values have been determined
- predicting requirements and balances for nutrients that need more detailed accounting systems
- pragmatically extrapolating research results to varying farm production conditions
- evaluating and diagnosing feeding programs to account for more of the variation in performance under specific production settings
- delivering information that can be used to improve whole-farm nutrient management planning
- providing feedback on the usability and adequacy of the use of applied models (e.g., RNS) so they can be enhanced and reengineered to fit new production situations
- serving as a meta-modeling tool to generate data to be used in other modeling applications

THE FOUNDATION OF DIETARY SUPPLY

USEFUL ENERGY AND PROTEIN IN FEEDS

- Henneberg and Stohmann developed the proximate analysis system in the 1860s ➔ The "Weende System"
  - Dry matter, ether extract, crude protein, crude fiber, ash
  - Nitrogen-free extract computed by difference
  - Used to characterize feeds and to determine their nutritional value

$$dCP = (0.01 \times CPD) \times CP \quad [5.1]$$

$$dEE = (0.01 \times EED) \times EE \quad [5.2]$$

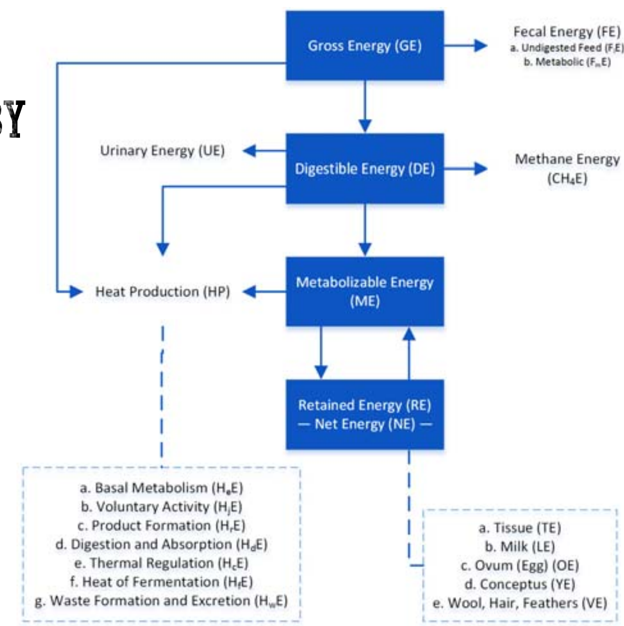
$$dCF = (0.01 \times CFD) \times CF \quad [5.3]$$

$$dNFE = (0.01 \times NFED) \times NFE \quad [5.4]$$

$$TDN = dCP + 2.25 \times dEE + dCF + dNFE \quad [5.5]$$

where *CF* is crude fiber, % DM; *CFD* is CF digestibility, %; *CP* is crude protein determined as total N×6.25, % DM; *CPD* is CP digestibility, %; *dCF* is digestible CF, % DM; *dCP* is digestible CP, % DM; *dEE* is digestible EE, % DM; *dNFE* is digestible NFE, % DM; *EE* is ether extract, % DM; *EED* is EE digestibility, %; *NFE* is nitrogen-free extract, % DM; *NFED* is NFE digestibility, %; and *TDN* is total digestible nutrients, % DM.

ENERGY PARTITION BY RUMINANTS



PREDICTING TOTAL DIGESTIBLE NUTRIENTS

- Digestibility trials using the digestible EE, CP, CF, and NFE
- Empirical equations
- Theoretical equations
- Mechanistic modeling

$$dCP = (0.01 \times CPD) \times CP \quad [5.1]$$
$$dEE = (0.01 \times EED) \times EE \quad [5.2]$$
$$dCF = (0.01 \times CFD) \times CF \quad [5.3]$$
$$dNFE = (0.01 \times NFED) \times NFE \quad [5.4]$$
$$TDN = dCP + 2.25 \times dEE + dCF + dNFE \quad [5.5]$$

where *CF* is crude fiber, % DM; *CFD* is CF digestibility, %; *CP* is crude protein determined as total N×6.25, % DM; *CPD* is CP digestibility, %; *dCF* is digestible CF, % DM; *dCP* is digestible CP, % DM; *dEE* is digestible EE, % DM; *dNFE* is digestible NFE, % DM; *EE* is ether extract, % DM; *EED* is EE digestibility, %; *NFE* is nitrogen-free extract, % DM; *NFED* is NFE digestibility, %; and *TDN* is total digestible nutrients, % DM.

LEVEL OF SOLUTION 0

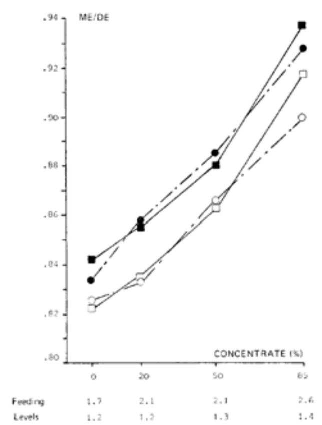
Empirical Model

Table 5.2. Empirical regression equations to estimate total digestible nutrients

Feed class [1]	Total digestible nutrients, %
Dry forages	
(H)	92.464 – 3.338×CF – 6.945×EE – 0.762×NFE + 1.115×CP + 0.031×CF² – 0.133×EE² + 0.036×CF×NFE + 0.027×EE×NFE + 0.100×EE×CP – 0.022×EE2×CP
(K)	-17.2649 + 1.2120×CP + 0.8352×NFE + 2.4637×EE + 0.4475×CF
Pasture	
(H)	–54.572 + 6.769×CF – 51.083×EE + 1.851×NFE – 0.334×CP – 0.049×CF² + 3.384×EE² – 0.086×CF×NFE + 0.687×EE×NFE + 0.942×EE×CP – 0.112×EE²×CP
(K)	-21.7656 + 1.4284×CP + 1.0277×NFE + 1.2321×EE + 0.4867×CF
Silages	
(H)	–72.943 + 4.675×CF – 1.280×EE + 1.611×NFE + 0.497×CP – 0.044×CF² – 0.760×EE2 – 0.039×CF×NFE + 0.087×EE×NFE – 0.152×EE×CP + 0.074×EE²×CP
(K)	-21.9391 + 1.0538×CP + 0.9736×NFE + 3.0016×EE + 0.4590×CF
Energy feeds	
(H)	–202.686 – 1.357×CF + 2.638×EE + 3.003×NFE + 2.347×CP + 0.046×CF² + 0.647×EE² + 0.041×CF×NFE – 0.081×EE×NFE + 0.553×EE×CP – 0.046×EE²×CP
(K)	40.2625 + 0.1969×CP + 0.4228×NFE + 1.1903×EE - 0.1379×CF
Protein feeds	
(H)	–133.726 – 0.254×CF + 19.593×EE + 2.784×NFE + 2.315×CP + 0.028×CF² – 0.341×EE² – 0.008×CF×NFE – 0.215×EE×NFE - 0.193×EE×CP + 0.004×EE±×CP
(K)	40.3227 + 0.5398×CP + 0.4448×NFE + 1.4218×EE - 0.7007×CF

[1] References (H) = Harris et al. (1972) and (K) = Kearl (1982).

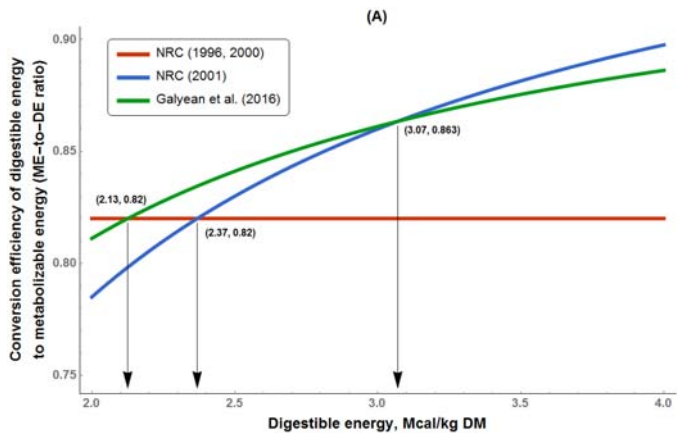
EFFICIENCY OF DE → ME?



- 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?

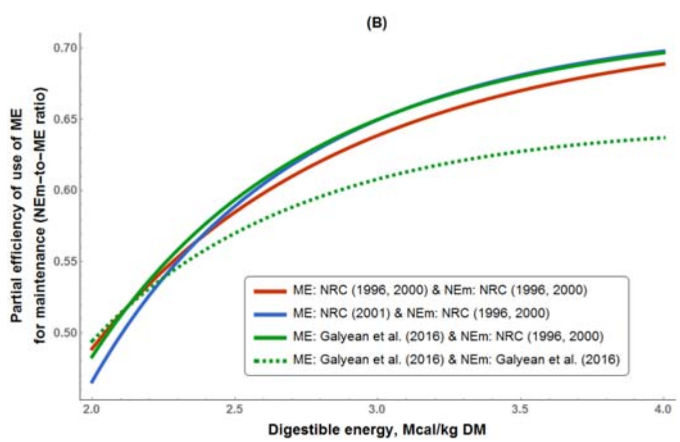
Vermorel and Bickel (1980)

CONSISTENCY AND DEPENDENCY (1/3)



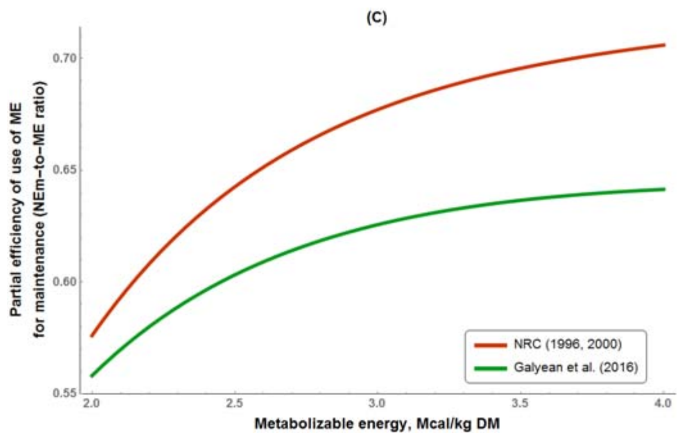
Tedeschi and Fox (2018)

CONSISTENCY AND DEPENDENCY (2/3)



Tedeschi and Fox (2018)

CONSISTENCY AND DEPENDENCY (3/3)



Tedeschi and Fox (2018)

LEVEL OF SOLUTION 1

Theoretical Model

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

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

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

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

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

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

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

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

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.

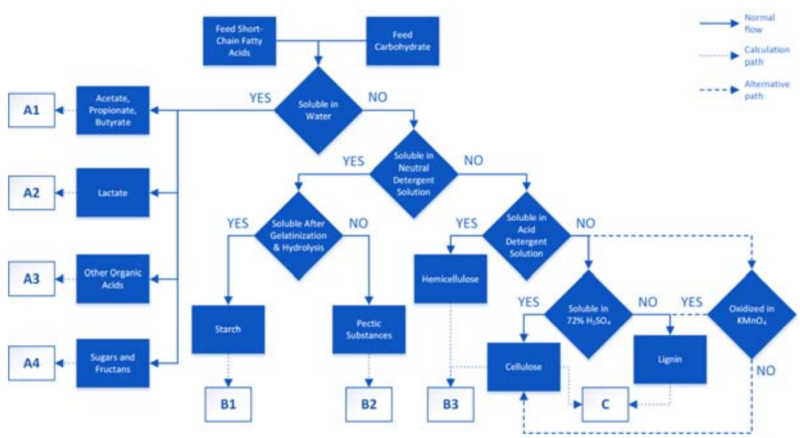
LEVEL OF SOLUTION 2

Mechanistic Model

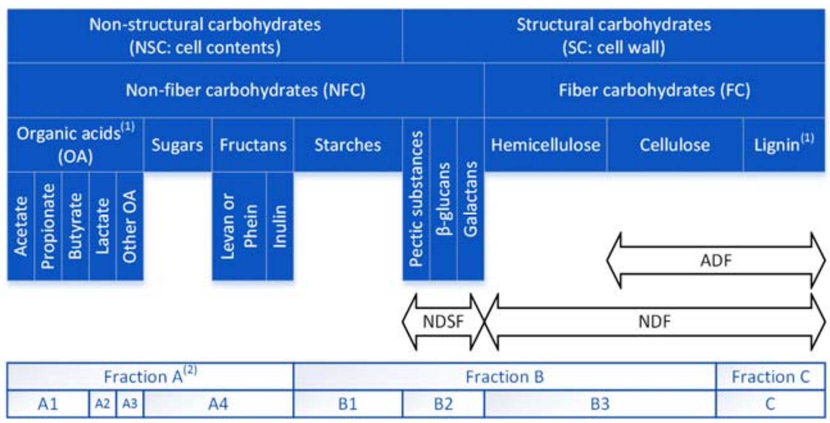
MECHANISTIC MODELING

- 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

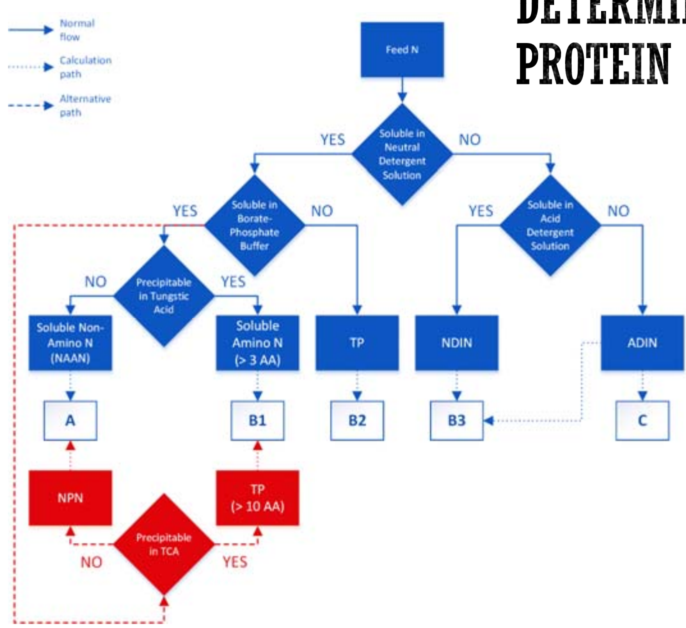
DETERMINING FEED CARBOHYDRATE



CARBOHYDRATE FRACTIONATION



DETERMINING FEED PROTEIN

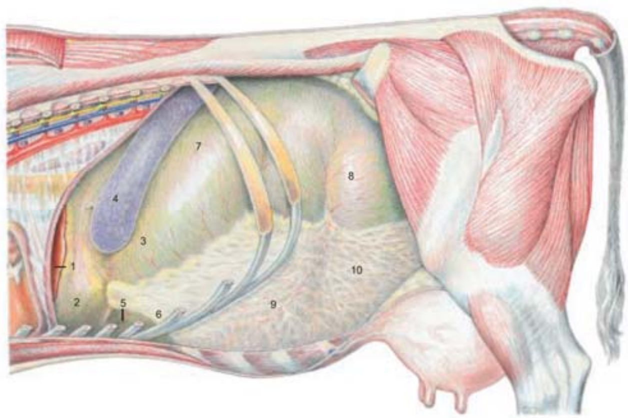


PROTEIN FRACTIONATION

<table>
<tr><th colspan="13">Feed crude protein (CP)</th></tr>
<tr><th colspan="7">Borate-phosphate buffer soluble CP</th><th colspan="6">Borate-phosphate buffer insoluble CP</th></tr>
<tr><th colspan="5">Non-protein N (NPN)</th><th colspan="2">Soluble true protein</th><th colspan="2">Neutral detergent fiber (NDF) soluble N</th><th colspan="4">NDF insoluble N (NDIN)</th></tr>
<tr><td rowspan="2">NH_3 + Amines</td><td rowspan="2">Amides</td><td rowspan="2">Nitrates</td><td rowspan="2">Peptides</td><td rowspan="2">Non-essential AA</td><td rowspan="2">Albumins</td><td rowspan="2">Globulins</td><td rowspan="2">Glutelins</td><td rowspan="2">Prolamines</td><td>NDIN – ADIN</td><td colspan="3">ADF insoluble N (ADIN)</td></tr>
<tr><td>Extensins</td><td>Maillard's</td><td>Lignin N</td><td>Tannin N</td></tr>
<tr><td colspan="5">Fraction A</td><td colspan="5">Fraction B</td><td colspan="3">Fraction C</td></tr>
<tr><td colspan="3">A1</td><td colspan="2">A2</td><td colspan="2">B1</td><td colspan="2">B2</td><td>B3</td><td colspan="3">C</td></tr>
</table>

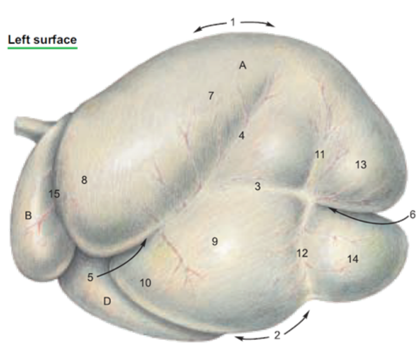
DYNAMICS IN THE RUMEN

ABDOMINAL CAVITY – LEFT SIDE



Budras et al. (2003)

THE RUMEN – LEFT SIDE

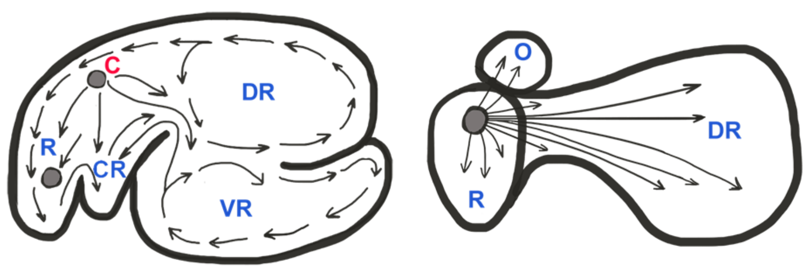


Legend:

A Rumen
1 Dorsal curvature
2 Ventral curvature
3 Left longitudinal groove
4 Left accessory groove
5 Cranial groove
6 Caudal groove
7 Dorsal sac
8 Atrium
9 Ventral sac
10 Recess of ventr. sac of rumen
11 Dorsal coronary groove
12 Ventral coronary groove
13 Caudodorsal blind sac
14 Caudoventral blind sac
15 Ruminoreticular groove
16 Right longitudinal groove
17 Right accessory groove
18 Insula
19 Intraruminal orifice
20 Pillars
21 Papillae

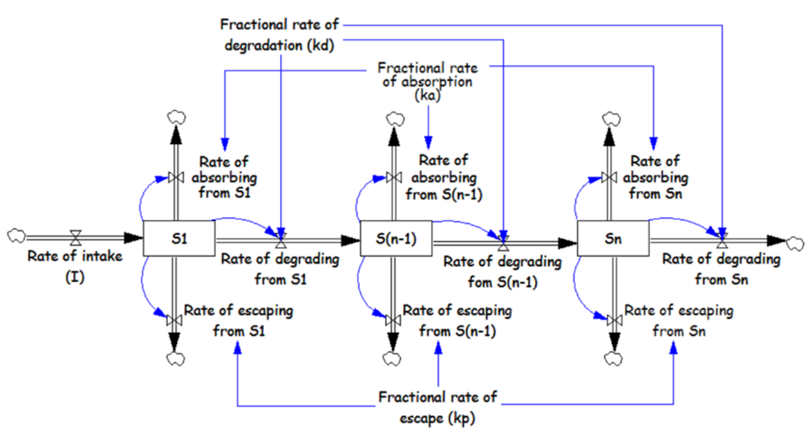
Budras et al. (2003)

THE RUMEN MOVEMENTS

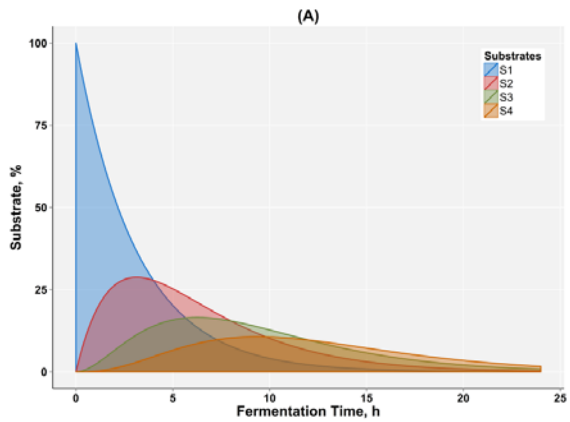


Tedeschi and Fox (2018)

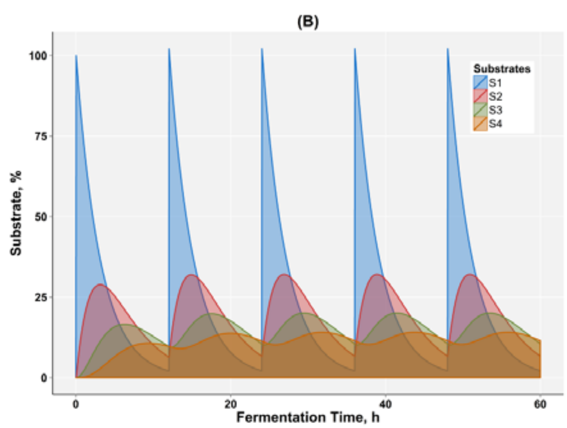
FUNDAMENTAL RUMINAL DYNAMICS



RUMINAL DEGRADATION RATE (SINGLE FEEDING EVENT)



RUMINAL DEGRADATION RATE (MULTIPLE FEEDING EVENTS)



FRACTIONAL PASSAGE RATES

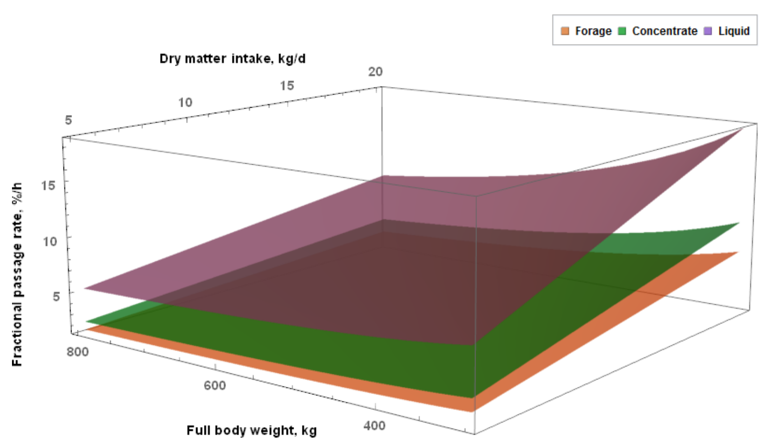
$$kp_{Forage} = 2.365 + 21.4 \times Ff \times DMI/FBW + 73.4 \times (1 - Ff) \times DMI/FBW + 0.069 \times Ff \times DMI \quad [8.140]$$

$$kp_{Liq} = 1.169 + 137.5 \times Ff \times DMI/FBW + 172.1 \times (1 - Ff) \times DMI/FBW \quad [8.141]$$

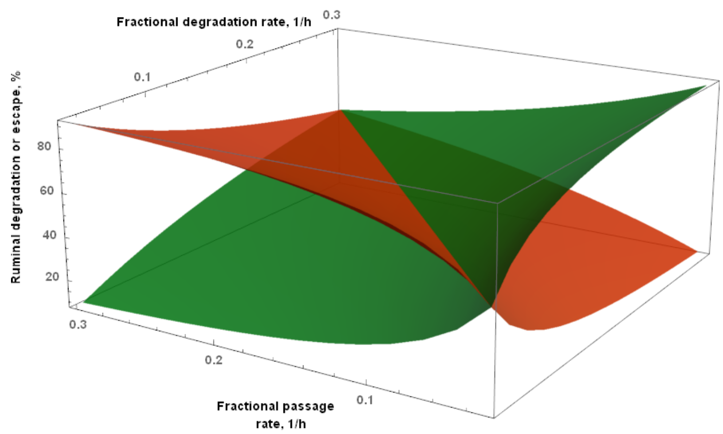
$$kp_{Liq} = 4.524 + 22.3 \times Ff \times DMI/FBW + 204.6 \times (1 - Ff) \times DMI/FBW + 0.344 \times Ff \times DMI \quad [8.142]$$

Where *DMI* is dry matter intake, kg/d; *FBW* is full body weight, kg; *Ff* is the fraction of diet forage, dimensionless; and kp_{Forage}, kp_{Conc}, and kp_{Liq} are fractional passage rates, %/h.

FRACTIONAL PASSAGE RATES

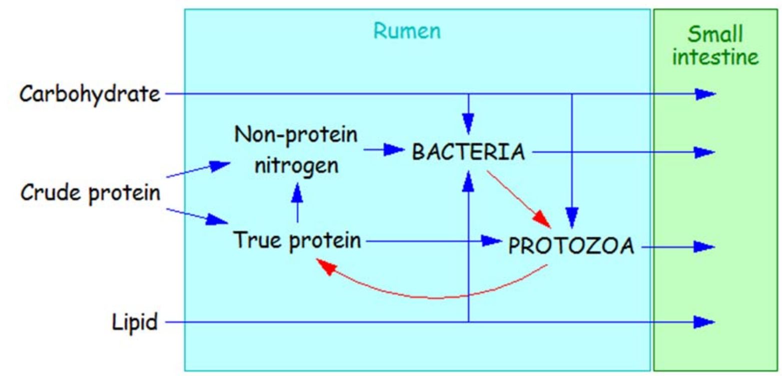


RELATIONSHIP BETWEEN KD AND KP ON RUMINAL FERMENTATION

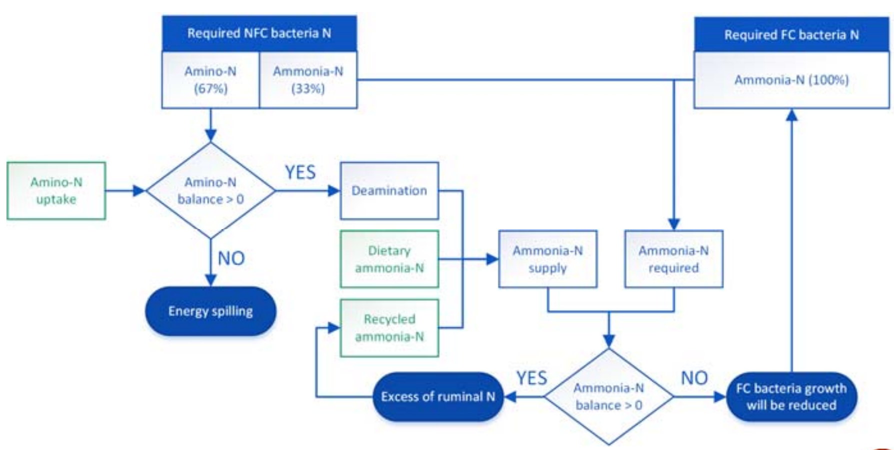


RUMINAL MICROBES

FEED TRANSFORMATIONS IN THE GIT



BACTERIA SUBMODEL



DETERMINING BACTERIA GROWTH

$$\frac{dS}{dt} = \frac{-u \times x}{Y} \quad [8.35]$$

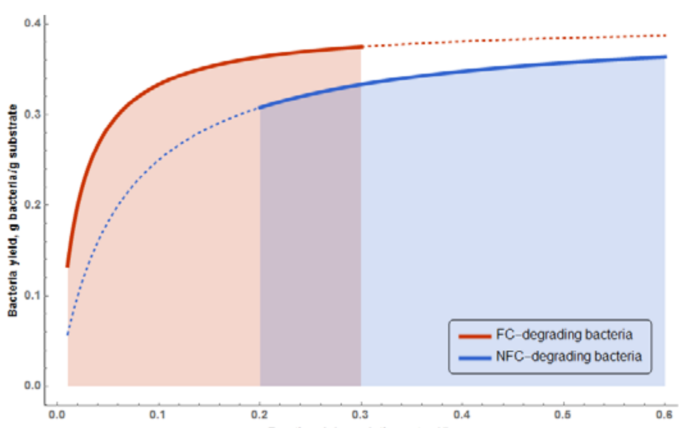
$$\left(\frac{dS}{dt}\right)_M = -m \times x \quad [8.36]$$

$$\left(\frac{dS}{dt}\right)_G = \frac{-u \times x}{Y_G} \quad [8.37]$$

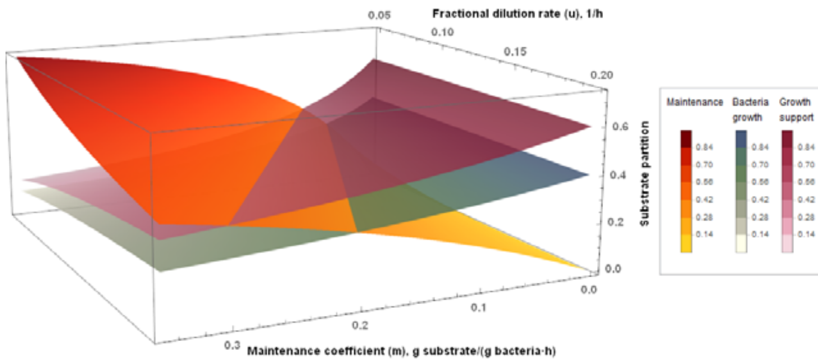
$$\frac{1}{Y} = \frac{m}{u} + \frac{1}{Y_G} \quad [8.38]$$

Where m is the maintenance coefficient (i.e., amount of substrate per amount of bacteria per unit of time), g/(g·h); S is the amount of substrate, g; u is the fractional growth rate, 1/h; x is the amount of bacteria, g; Y is the yield of bacteria (i.e., amount of bacteria per amount of substrate), g/g; and Y_G is the yield of bacteria for growth, g/g.

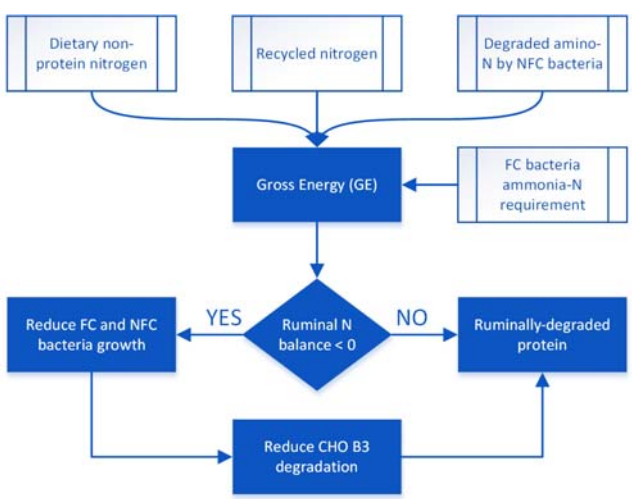
FC X NFC GROWTH DYNAMICS



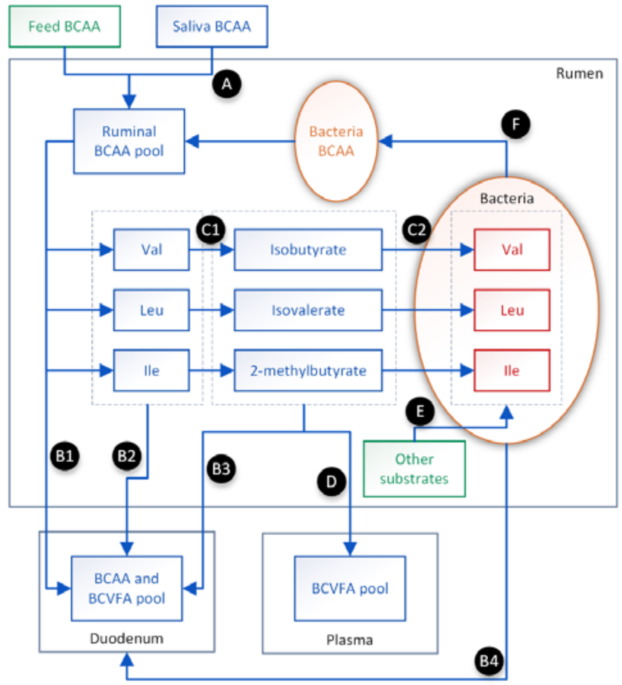
MAINTENANCE X GROWTH YIELD



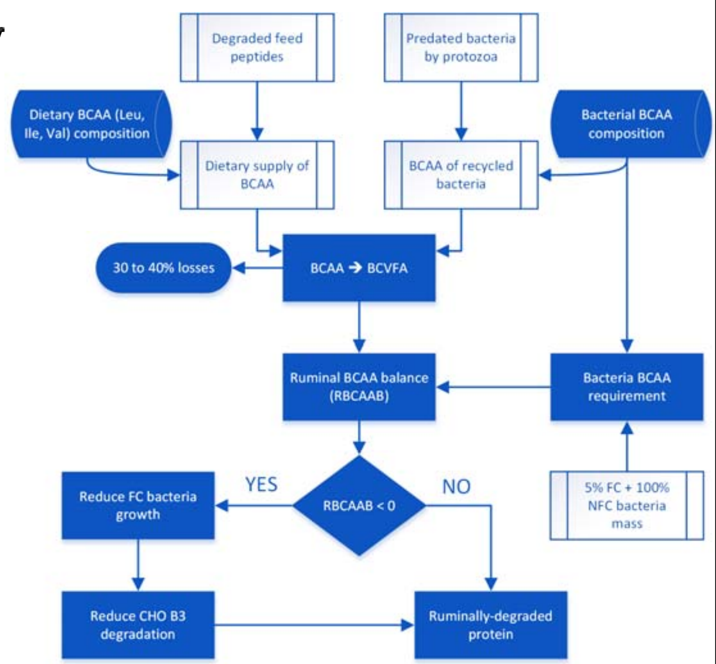
DEFICIENCY OF RUMINAL N



BCAA METABOLISM

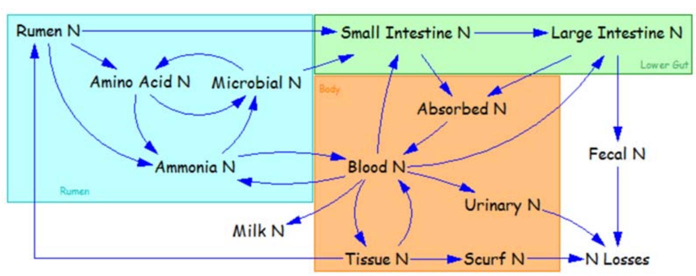


DEFICIENCY OF BCAA



RUMINAL RECYCLED N

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)

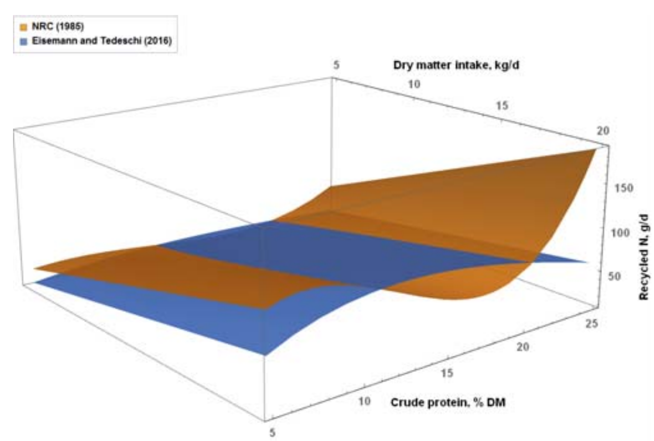
Tedeschi and Fox (2018) based on Nolan and Leng (1972), Mazanov and Nolan (1976)

PREDICTING RECYCLED NITROGEN: THE UREA USED FOR ANABOLISM (UUA)

- UUA is the amount of recycled N that is effectively used by the ruminal microbes, but two sources of N retention (Lobley et al. 2000):
  - synthesis of nitrogenous compounds by the GIT microbes and
  - anabolic reactions of ammonia within the body of the ruminant animal
- The amount of recycled N to the GIT increases as N intake decreases (Eisemann and Tedeschi 2016), and about 54% to 57% of the recycled N is used for the synthesis of microbial protein (Marini and Van Amburgh 2003; Reynolds and Kristensen 2008)

META-REGRESSION TO PREDICT UUA:

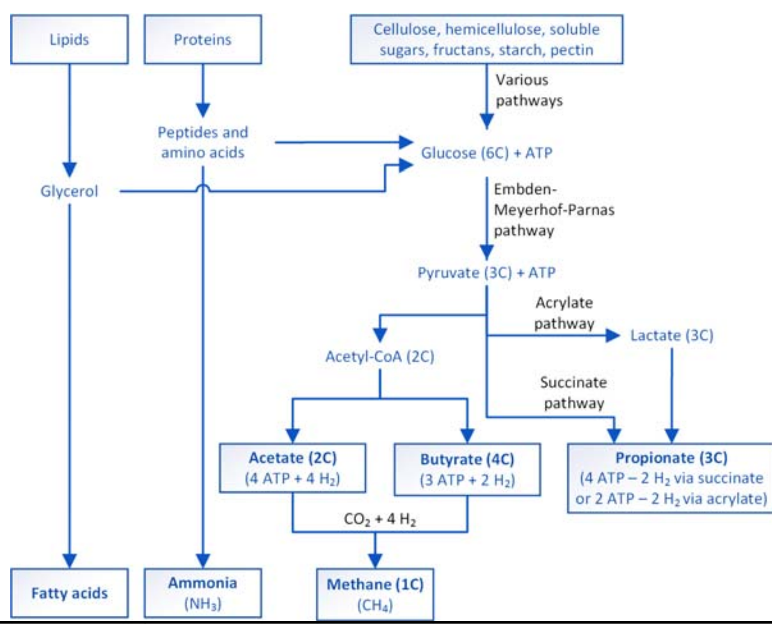
$$(-0.1113+0.966\times EXP(-0.0616\times CP))\times(1.192\times CP\times DMI-11.98)$$



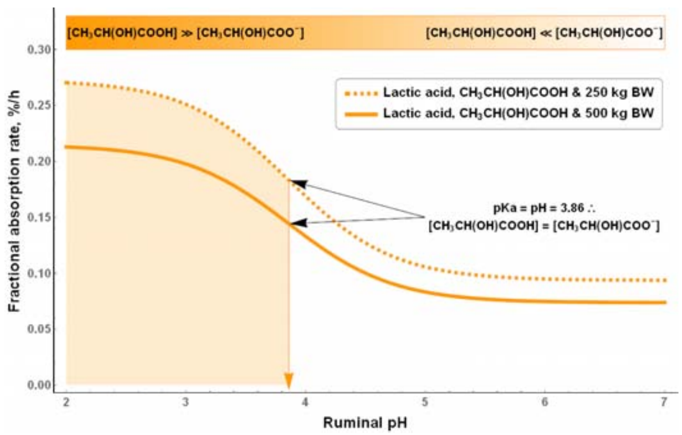
Tedeschi and Fox (2018)

VOLATILE FATTY ACIDS

VOLATILE FATTY ACID SUBMODEL



LACTIC ACID RUMINAL DYNAMICS



VFA RUMINAL DYNAMICS