Quantifying rumen function

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Rumen pH

- **Range**
  - 5 (highly fermentable diet / well processed diet)
  - to 8 (low quality forage)

- **< 6 = Chronic acidosis**
  - Reduced intake and performance, foot problems

- **< 5.5 = Acute acidosis**
  - Rumen stasis, water from blood floods rumen to counter high lactate, kidney / nerve damage, death due to excess lactate in blood
Approx. rumen characteristics

- **Size**
  - 100 l in cattle; 8 l in sheep

- **Anaerobic; low redox potential (-0.35)**
  - due to bi-carbonate buffers

- **Temperature 38-41° C**

- **Saliva flow into rumen; (provides buffering)**
  - Cows 98 – 190 l/d; Sheep 10 – 15 l/d

- **Fermentation products**
  - VFAs, CO$_2$, CH$_4$, NH$_3$
Rumen microbes

♦ **Bacteria**
  - \(10^9 - 10^{10}\) viable cells/ml; 200 spp. identified
  - 1-2 microns in diameter (except larger ovals 3-6 microns)

♦ **Protozoa (larger)**
  - \(10^4-10^6/ml\); mostly ciliate, some flagellates
  - 20 spp known; 20-60 microns
  - Phagocytize bacteria

♦ **Fungi**
  - \(< 10^3\); Discovered in ‘75 by Orpin; <20 spp known; Important fiber digesters
Microbial growth determinants

♦ Supply of requirements for microbial
  – Maintenance
  – Growth

♦ Nutrients required
  1. CHO’s – Energy (ATP)
  2. N source
  3. Vitamins
  4. Minerals
Energy sources for MP synthesis

- **Types**
  1. Storage & soluble CHO – rapidly released
     - e.g. ..................................................
  2. Structural CHO – slowly released
     e.g. ..................................................

- **Microbes only use fermentable energy (FME)**
  - Can’t use energy associated with
    - Fats or Pre-fermented compounds
      e.g. ..................................................

Ruminal carbohydrate catabolism

Cellulose
Starch
Soluble sugars

Pectin
Hemicellulose

Pentoses

Pentose cycle

Glycolysis

Pyruvate

Hexoses

Acetyl CoA

Formate

CO₂ + H₂

Methane

Acetate

Butyrate

Propionate

Acrylate pathway
Typical rumen VFA proportions

- Total VFA 70-150 mmol/l
- 60% acetate (66 mM)
- 20% propionate (23 mM)
- 15% butyrate (10 mM)
- 5% others – Isoacids from AA deamination
  - 2 methyl butyric – from isoleucine
  - Isovalerate / 3 methyl butyrate – from leucine
  - Isobutyrate – from valine
Factors influencing VFA proportion

- Type of dietary carbohydrate
- Diet forage: concentrate ratio
- Physical form of the diet
  - Grinding, pelleting, ↓ forage : conc ratio, ↑ Pr.
- Level & frequency of feeding
- Use of chemical additives or ionophores
Effect of diet on VFA proportion

High roughage
- High acetate levels
- High rumen pH (6.1-6.3)
- High methane output
- High milk fat

High conc.
- High propionate levels
- Low rumen pH (5.5-5.8)
- Higher glucose levels
- High body fat
VFA Production vs. Absorption

- Exist in rumen as anionic form (CH$_3$COO$^-$).
- Absorbed in **undissociated** form (CH$_3$COOH).
- Low pH $\uparrow$ undissociated form = $\uparrow$ absorption.
- 80-90% ruminally absorbed; 10-20% in omasum & abomasum.
- Diffusion of undissociated acid is concentration dependent.
VFA Absorption

- All VFAs readily absorbed through rumen wall
- Drained into liver through portal vein
- Energy from VFA represents 75% of DE rqmt
- Next 3 slides detail absorption of individual VFAs
Acetate (increased by fibrous diets)

- $\text{CH}_3\text{COCOOH} + \text{H}_2\text{O} \rightarrow \text{CH}_3\text{COOH} + \text{CO}_2 + 2\text{H}$
  - Pyruvate
  - Acetate

- Absorbed across rumen wall intact & converted to acetyl CoA in liver and enters the TCA.

- Lipogenic (Milk fat precursor)
Propionate (increased by starchy diets)

- \( \text{CH}_3\text{COCOOH} + \text{H}_2 \rightarrow \text{CH}_3\text{CH}_2\text{COOH} + \text{CO}_2 \)
  - Pyruvate
  - Propionate

- 20% is converted to lactate during absorption, enters gluconeogenic pathway in liver via PEP

- 80% absorbed intact, passes into liver & converted via oxaloacetate to PEP

- PEP converted to glucose in the liver by gluconeogenesis

- Glucogenic (glucose precursor supplies 50% of rqmts)
Butyrate (increased by fibrous diets)

- 2 CH$_3$COOH $\rightarrow$ CH$_3$COCH$_2$COOH + H$_2$O
  - Pyruvate \hspace{5mm} Acetoacetate

- CH$_3$COCH$_2$COOH + 4 H $\rightarrow$ CH$_3$\((CH_2)_2\)COOH
  - Acetoacetate \hspace{5mm} Butyrate

- Butyrate converted to 3 hydroxybutyrate / β-hydroxybutyrate during absorption, then gets to liver

- Butyrate is lipogenic
Methane (favored by high fiber diets)

- Mainly formed from reduction of CO₂
  \[ \text{CO}_2 + 4\text{H}_2 \rightarrow \text{CH}_4 + 2\text{H}_2\text{O} \]
- Or acetate decarboxylation
  \[ \text{CH}_3\text{COOH} \rightarrow \text{CO}_2 + \text{CH}_4 \]
- Energy lost as CH₄ = approx. 8% of GE
  - but CH₄ contains much GE (55 MJ/kg DM)
- Starchy diets, ↑ Pr (H₂ sink) yield which ↓ CH₄ yield
- CH₄ suppressants favor Pr synthesis instead of CH₄
  e.g. Chloroform and Monensin inhibit methanobacteria
N requirements for MP synthesis

♦ Sources
  – Dietary RDP
  – Endogenous N
  – Recycled urea

♦ Types
  – NH$_3$ - used by fibrolytic bacteria
  – Free aas & peptides – used by NSC fermenters
  – Branched chain VFA /isoacids
    – used by fibrolytic bacteria
Effect of increasing diet CP on rumen NH$_3$ & mic. Protein yield

Rumen NH$_3$ < 20 mg/l probably limits mic. prot. synthesis; 50 mg/l recommended to maximize mic. protein yield, (Satter and Slyter, 1974)
> 50% of amino acids absorbed from the gut of ruminants are microbial in origin
Microbial protein synthesis

Ammonia
B C VFA’s
Peptides
Minerals
Vit/mins

Energy (ATP) ➔ Microbial Protein
The concept of $Y_{\text{ATP}}$

- Relates amount of microbial protein produced (i.e., yield) to ATP required for the process.

  - E.g. If microbial yield of 22 g DM requires 2 mols of ATP, then $Y_{\text{ATP}} = 22/2 = 11$ g/mol ATP.

- Previously, $Y_{\text{ATP}}$ was assumed to be constant at 10.5 g DM/mol of ATP (Bauchop & Elden, 1960).

- $Y_{\text{ATP}}$ is now known to vary with bacterial type, substrate, and bacterial energy requirements.
This data shows that $Y_{\text{ATP}}$ varies considerably with bacteria type (Martin, 2003).
Alternative ways of expressing microbial yield

- E.g. amount of microbial mass produced / amount of substrate fermented / digested

- **NRC**
  - Bacterial CP = 130 g/kg TDN intake

- **AFRC (1984)**
  - Microbial N = 32 g /kg OM digested in the rumen
    (range = (12 - 54 g/kg OM digested in the rumen)

- **AFRC (1999)**
  - Microbial CP = 9 to 11g /MJ Fermentable metabolizable energy
Synchrony theory

- Synchronizing the supply of dietary nitrogen and energy to the rumen improves the efficiency of MP synthesis

i.e.

- If dietary CHO & CP have similar fermentation rates, efficiency of MP synthesis will be high

(Davies, 2000)
Asynchronous ruminal energy & protein supply from a straw + urea diet

Deduction: NH₃ is wasted & MP synthesis is reduced if cows are fed asynchronous diets
Asynchronous ruminal energy & protein supply from ground corn and soybean diet

**Diet**
- starch + soy protein

**Deduction:** \( \text{NH}_3 \) is wasted & MP synthesis is reduced if cows are fed asynchronous diets.
Synchronous ruminal energy & protein supply from a grass hay + soybean meal diet

Deduction: NH$_3$ is reduced & MP synthesis is optimized when cows are fed synchronous diets
Effect of infusing $H_2O$ / glucose in cows fed silage on post ruminal microbial N (MN) & Non ammonia N (NAN) synthesis

Rooke et al, 1987

Water

NH$_3$ conc.

1200  2400

Duodenal NAN 89 g/d
Duodenal MN 63 g/d

Glucose (31 g/h)

NH$_3$ conc.

1200  2400

Duodenal NAN 106 g/d
Duodenal MN 81 g/d

Rooke et al, 1987
(Davies, 2000)
Problems with the synchrony theory

1. Bacteria can make & store starch (75% of cell DM).

2. Synchronizing energy & protein does not always improve MP synthesis e.g.

   • Infusing sugars into cows fed:
     i. Grass silage + conc = improved MP synthesis
     ii. Grass silage alone = no effect on MP synthesis
Factors affecting the efficiency of MP synthesis

- Dietary protein & energy forms
- Ruminal energy & protein balance
- Ruminal outflow rate / feeding level
- Feeding frequency / dilution rate
- Rumen pH
- Mineral & vitamin availability
- Recycling of bacterial N due to
  - Bacterial lysis & protozoal predation
Rumen function summary

Protein

Balanced energy: protein

*Particularly from high urea/ammonia diets
References


Van Soest (1994) Nutritional ecology of the ruminant

Introduction to rumen studies (1986) Czerkawski.