Feed efficiency in ruminants: feed digestion, methanogenesis and energy utilisation

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Conversion of feed into animal product

- Feed conversion efficiency (FCE) of ruminants
  - important because feeding is a high cost
  - roughage essential in most dairy farming systems
  - concentrates to achieve higher energy intake

- Efficiency gain with intensive management, but large environmental impacts & trade-offs

- Generally, there is interest and value to improve FCE by
  - feed intake / productivity
  - feed digestion
Improving FCE, pre- vs. post-absorptive

- Feeding management: **nutritional & digestive factors**
  - rumen fermentation & loss of methane energy
  - site of digestion
  - feed digestibility

- On-going efforts by **genetics & technology**
  - selection for genetic potential
  - improved management: feed production, feeding, housing, animal care

Diagram showing flow from pre-absorptive to post-absorptive nutrients absorbed, nutrient metabolism, nutrient utilisation.
Definition cow FCE: ‘milk from feed’

\[ \text{FCE} = \frac{\text{milk}}{\text{feed intake}} \]
FCE of a lactating cow

FCE = milk : feed intake

Digestible energy (DE)
Metabolizable energy (ME)
Net energy (NE)

Rumen
Small intestine
Large intestine

Faeces
methane
urine

Heat loss

Feed
Pre- & post-absorptive factors affecting FCE

feed intake → fermentation factors → site of digestion → feed digestibility

feed → rumen → small intestine → large intestine → faeces

digestible energy (DE) → metabolizable energy (ME) → net energy (NE) → milk

metabolism → productivity

methane
This presentation

1. feed intake/ feed digestion

2. energy loss with methane

3. metabolism / productivity
1. Feed digestion & FCE

- Rumen main contributor to ME / NE
  - volatile fatty acids & microbiota
- Starch, protein, fat digestion in small intestine
- Fermentation of undigested feed in large intestine

- Variation in feed digestibility: main role rumen
  - passage rate/retention time
  - feed degradability
  - rumen conditions (pH, [ammonia], structural mat)

- Results on dietary protein content – feed digestibility
I. Feed digestion, effect CP \(^{(Spek \ et \ al., \ 2013)}\)

Generally not <14% CP in DM, lower CP would affect digestion

Tested **restricted** feeding, to prevent confounding by DMI

<table>
<thead>
<tr>
<th></th>
<th>CP (% DM)</th>
<th>Salt</th>
<th>Maize silage (% DM)</th>
<th>Soybean hulls</th>
<th>SBM protected</th>
<th>SBM</th>
<th>NE(_L) (MJ/kg DM)</th>
<th>DPV (g/kg DM) ¹</th>
<th>RDP balance (g/kg DM) ²</th>
<th>RDP(g/kg DM) ³</th>
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<tbody>
<tr>
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<td>11.9</td>
<td>0.5</td>
<td>66</td>
<td>21</td>
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<td>5</td>
<td>6.61</td>
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<td>15.6</td>
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<td>80</td>
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<td></td>
<td>15.1</td>
<td>3.0</td>
<td>64</td>
<td>10</td>
<td>13</td>
<td>3</td>
<td>6.47</td>
<td>102</td>
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Dietary protein and salt affect the concentration of milk urea nitrogen (MUN or NE\(_L\)) and the relationship between MUN and excretion of urea nitrogen in milk (MUN\(_E\)) of dairy cattle. The aim of the present study was to examine the effects of dietary content: \(\text{UUN} = -17.7 \pm 7.24 + 10.09 \times \text{MUN} + 2.26 \pm 0.729 \times \text{MUN}\) (for high NaCl); \(R^2 = 0.85\). Removal of the MUN \times \text{NaCl} interaction term lowered the coefficient of determination from 0.85 to 0.77. In conclusion, dietary protein content is positively related

At start 34.0 kg milk/d; 146 DIM; BW 645 kg

¹ Intestinal digestible protein
² Rumen degraded protein balance
³ Rumen degraded protein
Feed digestion, effect CP (Spek et al., 2013)

Higher CP
+3% DMI
+6% ATTD
+9% FPCM

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- Higher CP
  - +3% DMI
  - +6% ATTD
  - +9% FPCM
  - +6% FCE
Feed digestion & FCE

- Low feed digestion ~ low FCE
  - CP limiting at very low levels
  - CP stimulatory for milk (protein) yield & feed intake

- To increase FCE, attention for improved feed intake & feed digestibility

- Large individual variation in feed digestion and FCE
  - in size comparable to treatment effect (feeding strategy)
  - individual differences in anatomy, physiology & behaviour
  - despite its high importance, digestive aspects do not become apparent from observed FCE = \( f^{on} \) (feed intake; milk)
2. Energy metabolism & FCE

- Post-absorptive utilisation nutrients

- Energy utilisation
  - compared to variation in GE to DE, less variation in conversion of DE to ME, or ME to NE, within specific productive state

- Variation due to
  - ‘digestive’ tissues (≈50% total heat produced)
  - physical activity, body composition, nutrient storage, protein turnover, other metabolic processes and maintenance
  - e.g. if protein in excess, than ME/NE reduced (due to protein catabolism)
Meta-analysis: efficiency of feed energy use

Mills et al, 2009; Reynolds et al., 2009

1335 cow observations with respiration calorimetry & digestion trials
Energy metabolism & FCE

- Profound effect of maintenance dilution with increase in milk yield

- Selecting for more milk has
  - low effect on maintenance requirement
  - low effect on efficiency energy / nutrient utilization
    (Strathe et al. (2011) could not establish a relationship with genetic improvement during 2 decades)
  - high effect on feed intake, nutrient partitioning and nutrient storage
    (Bauman et al., 1983; Reynolds et al., 2009)

- Variation between animals in energy metabolism
  - due to type of nutrient type, metabolism of absorbed energy/nutrients, and nutrient partitioning

- Again, not apparent from observed FCE
3. Methane loss & FCE

- Energy loss with methane emission
- Reducing methane should benefit cow

Results on dietary effects on enteric methane

I. same meta-analysis (Mills et al., 2009; Reynolds et al., 2009)
   ● energy metabolism & methane

II. methane mitigation by nitrate in cows for 90 days (Van Zijderveld et al., 2011)
   ● iso-nitrogenous/iso-caloric; urea vs. nitrate
   ● effects on ME, NE, cow performance
I. Meta-analysis: methane & DMI

Methane highly related to DMI

Source:
Mills et al, 2009; Reynolds et al., 2009
Meta-analysis: methane & GE intake

Mills et al, 2009; Reynolds et al., 2009

Increase DMI, less methane from feed
Meta-analysis: methane & milk yield

Mills et al, 2009; Reynolds et al., 2009

Increase in DMI and milk yield
- FCE increases
- methane per unit milk decreases

Less methane with increase FCE mainly due to increased milk yield (genetic improvement in past decades)
II. Reducing methane of benefit to FCE

- Can a significant reduction in methane increase FCE?
  - it probably can with
    - more propionate at expense of acetate
      (ME propionate 1.6 vs. ME acetate 0.9 MJ/mol)
    - more digestible substrates bypassing rumen fermentation
    - due to more energy / nutrients absorbed
  - but, it seems unlikely with
    - nitrate to ammonia
    - other (more) reduced end-products formed that deliver no extra energy / nutrients

- Example: testing 2% (DM basis) nitrate as feed additive
  - methane persistently reduced
  - no significant effects on DM intake
Iso-N exchange urea/nitrate & iso-caloric

Van Zijderveld, et al., 2011

2.1% nitrate in dietary DM
Nitrate-N exch. with urea-N

20 lactating cows
104 days in milk
19.1 kg DM intake/d
33.2 kg milk/d

Despite 16% reduction in methane and clear effect on ME intake (+4%),
FPCM yield same (+1%, but DMI +1%)
Energetic benefit of reducing methane

- Heat production in energy balance trials (Brouwer equation)
  \[
  \text{Heat (kJ/d)} = 16.2 \times O_2 + 5.0 \times CO_2 - 6.0 \times N - 2.2 \times CH_4
  \]
  \(O_2, CO_2, CH_4\) in L/d; \(N\) in g urine N/d

- Effect methane reduction is overestimated if hydrogen used for alternative reduced end-products delivers more heat than hydrogen used for methanogenesis
  \((\Delta G \text{ -125 kJ/mol } H_2 \text{ nitrate to ammonia}; \Delta G \text{ -17 kJ/mol } H_2 \text{ to } CH_4)\)

- Spared methane energy benefits animal and hence FCE less than assumed, depending on the type of reduced end-products formed
  
  (PhD Thesis, Van Zijderveld, Wageningen University, 2011)

- No clear effect on milk was found by Van Zijderveld et al. (2011)
Concluding

- **Feed digestion**: variation profound and likely largest proportion of variation in observed FCE across diets

- **Feed intake**: historic changes in FCE particularly due to genetic improvement for milk yield, diluting maintenance
  - metabolic characteristics (energetic efficiencies, maintenance, absorption) did not change dramatically

- **Metabolism**: large individual differences in feed intake (capacity), feed digestion, type of nutrient absorbed, nutrient metabolism & partitioning
  - note: in practice or when selecting high FCE individuals, no observations available on digestion or metabolism!

  *Bauman et al. (1983)*: ‘improvement in FCE will depend on our ability to understand the control of nutrient metabolism, partitioning and feed intake’

- **Methane**: inhibition not/not fully beneficial to FCE
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for research & experimentation
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for practice (on farm)

for inventories (Tier 3)