Important feeding value parameters in animal nutrition

J. DE BOEVER

Feeding value debate
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Introduction

Grasses and leguminosae

• **Interesting crops for ruminant nutrition:**
  - home grown crops ⇒ cheap feeds
  - when grazed, positive for the health and well-being of the animal
  - allow to recycle animal manure

• **Negative points:**
  - variable nutritive value when grazing
  - low efficiency of protein utilization
  - relative high emission of methane

• **Ration formulation:**
  energy, protein, voluntary intake, physical structure, WSC, fat, minerals, vitamins, ANF’s
  ⇒ data based on own experiments with fresh grass but mainly with silage and literature
Energy value: concept

**GROSS ENERGY (GE)**
- fecal loss: 10-60%
- urinary loss: 3-5%
- gas loss ($CO_2, CH_4$): 5-12%

**METABOLIZABLE ENERGY (ME)**
- heat loss: 35-45%

**NET ENERGY (NE)**
15-45% of GE

\[ NEI = (46.32 + 0.24 \, q) \times ME \times 0.01 \]  
(Van Es, 1978)

with \( q = ME/GE \times 100 \)

GE: bomb calorimeter

\[ ME = 3.8 \, DCP + 9.0 \, DC_{fat} + 3.3 \, DC_{fibre} + 3.5 \, DOC - 0.15 \, sugars \]  
(if sugars >80g/kg DM)

(digestion coefficients determined in trials with sheep and total collection of feces)
Dataset in vivo digestion trials

<table>
<thead>
<tr>
<th></th>
<th>Fresh grass n=6</th>
<th>Grass silage n=66</th>
<th>Grass clover silage* n=17</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDF (total cell walls)</td>
<td>565 ± 27</td>
<td>509 ± 62</td>
<td>449 ± 75</td>
</tr>
<tr>
<td>- Hemicellulose (NDF-ADF)</td>
<td>309 ± 20 (55%)</td>
<td>213 ± 35 (42%)</td>
<td>151 ± 46 (34%)</td>
</tr>
<tr>
<td>- Cellulose (ADF-ADL)</td>
<td>220 ± 29 (39%)</td>
<td>268 ± 32 (53%)</td>
<td>256 ± 40 (57%)</td>
</tr>
<tr>
<td>- ADLignin</td>
<td>37 ± 15 (6%)</td>
<td>28 ± 10 (6%)</td>
<td>42 ± 19 (9%)</td>
</tr>
<tr>
<td>Crude protein</td>
<td>209 ± 60</td>
<td>144 ± 32</td>
<td>163 ± 30</td>
</tr>
<tr>
<td>Water Soluble Carb.</td>
<td>89 ± 35</td>
<td>22 ± 34</td>
<td>39 ± 24</td>
</tr>
<tr>
<td>Lactic ac. + VFA + Alc.</td>
<td>-</td>
<td>97 ± 47</td>
<td>65 ± 23</td>
</tr>
<tr>
<td>Crude fat</td>
<td>41 ± 10</td>
<td>42 ± 9</td>
<td>29 ± 8</td>
</tr>
<tr>
<td>Crude ash</td>
<td>108 ± 12</td>
<td>162 ± 72</td>
<td>131 ± 32</td>
</tr>
<tr>
<td>In vivo DC&lt;sub&gt;OM&lt;/sub&gt; (%)</td>
<td>80.4 ± 6.1</td>
<td>74.2 ± 5.8</td>
<td>70.5 ± 5.4</td>
</tr>
<tr>
<td>NEL&lt;sub&gt;OM&lt;/sub&gt; (MJ/kg DM)</td>
<td>6.73 ± 0.44</td>
<td>6.83 ± 0.71</td>
<td>6.19 ± 0.67</td>
</tr>
</tbody>
</table>

* 10 white clover (20-60%) and 8 red clover (30-90%)
## Energy value (NEL\textsubscript{OM}): factors of influence

<table>
<thead>
<tr>
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<th>Fresh grass n=6</th>
<th>Grass silage n=66</th>
<th>Grass clover silage n=17</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDF</td>
<td>-0.83</td>
<td>-0.44</td>
<td>-0.65</td>
</tr>
<tr>
<td>ADF</td>
<td>-0.89</td>
<td>-0.27</td>
<td>-0.87</td>
</tr>
<tr>
<td>ADLignin</td>
<td>-0.88</td>
<td>-0.71</td>
<td>-0.83</td>
</tr>
<tr>
<td>Hemicellulose</td>
<td>(0.59)ns</td>
<td>-0.49</td>
<td>ns</td>
</tr>
<tr>
<td>Cellulose</td>
<td>(-0.74)ns</td>
<td>ns</td>
<td>-0.71</td>
</tr>
<tr>
<td>WSC</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Crude protein</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Crude fat</td>
<td>(0.66)ns</td>
<td>0.67</td>
<td>0.93</td>
</tr>
<tr>
<td>In vivo DC\textsubscript{OM}</td>
<td>0.94</td>
<td>0.98</td>
<td>0.99</td>
</tr>
<tr>
<td>In vivo DC\textsubscript{CF}</td>
<td>0.93</td>
<td>0.90</td>
<td>0.75</td>
</tr>
</tbody>
</table>
Protein value: concept

• **PROTEIN DIGESTIBLE in the INTESTINES: PDI**
  \[
  PDI = DRBP + DMP - EPL
  \]

  **Digestible rumen bypass protein:**
  \[
  DRBP = CP \times \%RBP \times \%dRBP
  \]
  \%RBP: feed protein bypassing the rumen
  \%dRBP: intestinal digestibility of bypass protein

  **Digestible microbial protein:**
  \[
  DMP = MPE \times 0.75 \times 0.85
  \]
  microbial growth efficiency: 174 g MP per kg sugars, 138 for NDF, 99 for CP

  **minus endogenous losses:**
  \[
  EPL = 75 \text{ g per kg undigestible DM}
  \]

• **DEGRADABLE PROTEIN BALANCE: DPB**
  \[
  DPB = MPN - MPE
  \]
  in theory 0, but in practice: + 150-200 g per day

  \%RBP and \%dRBP are determined with nylon bag technique using fistulated cows
## Protein value: dataset in vivo trials

<table>
<thead>
<tr>
<th></th>
<th>Fresh grass n=10</th>
<th>Grass silage n=25</th>
<th>Grass clover silage n=17</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude protein (g/kg DM)</td>
<td>170 ± 33</td>
<td>156 ± 31</td>
<td>174 ± 33</td>
</tr>
<tr>
<td>PDI (g/kg DM)</td>
<td>75 ± 6</td>
<td>56 ± 9</td>
<td>60 ± 9</td>
</tr>
<tr>
<td>- DRBP (g/kg DM)</td>
<td>43 ± 9</td>
<td>31 ± 6</td>
<td>42 ± 7</td>
</tr>
<tr>
<td>- DMP (g/kg DM)</td>
<td>50 ± 9</td>
<td>44 ± 5</td>
<td>43 ± 5</td>
</tr>
<tr>
<td>- EPL (g/kg DM)</td>
<td>18 ± 9</td>
<td>20 ± 3</td>
<td>25 ± 4</td>
</tr>
<tr>
<td>%RBP</td>
<td>30.6 ± 3.5</td>
<td>25.9 ± 4.2</td>
<td>34.1 ± 5.4</td>
</tr>
<tr>
<td>%dRBP</td>
<td>84.9 ± 2.5</td>
<td>79.0 ± 5.0</td>
<td>72.1 ± 3.8</td>
</tr>
</tbody>
</table>
Imbalance MPN vs. MPE

**MPN (g/kg DM)**

- Grass
- Grass silage
- Grass clover silage
- Grass hay
- Maize silage

**MPE (g/kg DM)**

- Grass
- Grass silage
- Grass clover silage
- Grass hay
- Maize silage

**MPN2h (g/kg DM)**

- Grass
- Grass silage
- Grass clover silage
- Grass hay
- Maize silage

**MPE2h (g/kg DM)**

- Grass
- Grass silage
- Grass clover silage
- Grass hay
- Maize silage
## Protein value: factors of influence

<table>
<thead>
<tr>
<th>Grass (n=10)</th>
<th>Rumen bypass protein</th>
<th>Microbial protein</th>
<th>Endogenous losses</th>
<th>Protein balance</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP</td>
<td>0.81</td>
<td>ns</td>
<td>ns</td>
<td>0.98</td>
</tr>
<tr>
<td>WSC</td>
<td>ns</td>
<td>0.96</td>
<td>ns</td>
<td>-0.77</td>
</tr>
<tr>
<td>DC_{OM}</td>
<td>0.62</td>
<td>ns</td>
<td>-0.81</td>
<td>ns</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Grass silage (n=25)</th>
<th>Rumen bypass protein</th>
<th>Microbial protein</th>
<th>Endogenous losses</th>
<th>Protein balance</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP</td>
<td>0.63</td>
<td>ns</td>
<td>ns</td>
<td>0.95</td>
</tr>
<tr>
<td>WSC</td>
<td>-0.52</td>
<td>0.78</td>
<td>-0.52</td>
<td>-0.53</td>
</tr>
<tr>
<td>DC_{OM}</td>
<td>ns</td>
<td>ns</td>
<td>-0.66</td>
<td>ns</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Grass clover (n=17)</th>
<th>Rumen bypass protein</th>
<th>Microbial protein</th>
<th>Endogenous losses</th>
<th>Protein balance</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP</td>
<td>0.66</td>
<td>ns</td>
<td>ns</td>
<td>0.98</td>
</tr>
<tr>
<td>WSC</td>
<td>-0.67</td>
<td>0.86</td>
<td>-0.66</td>
<td>ns</td>
</tr>
<tr>
<td>DC_{OM}</td>
<td>ns</td>
<td>0.66</td>
<td>-0.92</td>
<td>ns</td>
</tr>
</tbody>
</table>
Voluntary intake

- Determined by the rate of disappearance from the rumen, in its turn a function of the degradation rate by combined action of microbial fermentation and mechanical breakdown through eating, ruminating and rumen contractions (Balch and Campling, 1969)

- De Brabander (30 years ago): intake trials with Holstein and white red dairy cows:
  - wilted grass silage (n=23): 12.2 (9.8 – 14.2) kg DM per day
  - $DC_{OM} + 1\%-\text{unit} \rightarrow \text{DM-intake: + 0.17 kg}$

- Thomas (1980) review of dairy cow experiments with well-preserved grass silages:
  - $\text{DOMD} + 1\%-\text{unit} \rightarrow \text{DM-intake + 0.15 kg}$

- Oba and Allen (1999): 13 forage comparisons with dairy cows
  - $DC_{NDF} + 1\%-\text{unit} \rightarrow \text{DM-intake: + 0.17 kg}$
Production performances

Multiplicative effect of better digestibility:
more energy, somewhat more protein, higher intake

• Thomas (1980) review of dairy cow experiments with well-preserved grass silages:
  - DOMD + 1%-unit $\rightarrow$ Milk prod.: + 0.29 kg/d

• Oba and Allen (1999):
  - $D_{NDF}$ + 1%-unit $\rightarrow$ FCMilk: + 0.25 kg/d

• Keady et al. (2012)
  - DMD + 1%-unit $\rightarrow$ + 0.33 kg milk
    $\rightarrow$ + 24 g daily carcass gain of beef cattle
    $\rightarrow$ + 9.3 g daily carcass gain of finishing lambs

• Bannink et al. (2010): forage of better quality $\rightarrow$ lower CH$_4$ emission per kg milk
Roughage value: concept

• RV depends on:
  - physical structure: plant particles stimulate rumination and saliva secretion (≥1 cm)
  - acidotic effect ~ content and degradation rate of NS carbohydrates \(\Rightarrow\) sugars

• Roughage evaluation system (De Brabander and De Boever)
  Standard cow requires RV in the ration ≥ 1 per kg DM
  Fresh grass: 200 g Cfibre/kg DM → RV = 1.6
  Grass silage: 250 g Cfibre/kg DM → RV = 2.9

**No problems with lack of physical structure!**
Water soluble carbohydrates (WSC)

- WSC: sucrose and fructosans

- PhD Taweel (2004): cows fed/grazing perennial ryegrass cv’s differing in WSC
  - no effect on rumen pH, nor on rate of fibre degradation or clearance
  ⇒ due to relative slow rate of intake (~ salivation) of sugar release from plant cells
  - but lower ammonia conc. in the rumen as well as lower urea content in the milk
  - no effect on DMI, milk production nor milk composition

- Ellis et al. (2011 & 2012): dynamic model study
  - increase of WSC at the expense of CP: N-effic. ↑↑, milk prod. ↓, g CH₄/kg milk ↑
  - increase of WSC at the expense of NDF: N-effic. ↑, milk prod. ↑↑, g CH₄/kg milk ↓
  - greater effects at low N-fertilization or low amount of concentrates

- Silage quality
  - lower pH and ammonia-fraction in silage (Downing and Gamroth, 2007)
  - higher risk for heating and mould at desiling
Fats

• Lipid content in herbs and grasses varies from 30 to 100 g/kg DM (Bauchart et al., 1984): grass species, breed, growth stage (leaf/stem ratio), season and light intensity

• Fats in herbage: triglycerides, phospholipids (membranes), wax, cutine, suberine, steroids

• Triglycerides in perennial rye grass (Elgersma et al., 2003):
  - 74% C18:3, 13% C16:0, 10% C18:2, 2% C18:1, 1% C18:0

• Fate of TG:
  - immediately after grazing/cutting: lipolysis by plant lipases
  → lower in clovers than in grasses due to PPO in red clover and saponins in white clover (Van Ranst et al., 2009)
  - oxidative losses during wilting
  - in the rumen: extensive microbial biohydrogenation of C18:2 and C18:3 with intermediates CLA (rumenic acid) and vaccenic acid (anticarcenogenic)

• Herbage is a major source of PUFAs for ruminants desired in milk and meat
• More fat also results in a higher NE-content, but total content in ration should < 7%, particularly with unsaturated fats, because of negative effect on fibre degradation
Minerals and trace elements

<table>
<thead>
<tr>
<th>Minerals</th>
<th>Ca</th>
<th>P</th>
<th>Mg</th>
<th>Na</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Required for milk production (g/kg DM)</td>
<td>3-5</td>
<td>3-3.5</td>
<td>2-2.5</td>
<td>1-1.5</td>
<td>7.5-8.5</td>
</tr>
<tr>
<td>Pasture grass</td>
<td>5.5</td>
<td>4.0</td>
<td>2.3</td>
<td>2.5</td>
<td>35.0</td>
</tr>
<tr>
<td>Red clover</td>
<td>15.0</td>
<td>2.5</td>
<td>3.0</td>
<td>1.5</td>
<td>27.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trace elements</th>
<th>Fe</th>
<th>Mn</th>
<th>Zn</th>
<th>Cu</th>
<th>I</th>
<th>Se</th>
<th>Co</th>
</tr>
</thead>
<tbody>
<tr>
<td>Required for milk production (mg/kg DM)</td>
<td>20-30</td>
<td>20-40</td>
<td>30-40</td>
<td>11-13</td>
<td>0.4-0.6</td>
<td>0.15-0.25</td>
<td>0.10-0.15</td>
</tr>
<tr>
<td>Pasture grass</td>
<td>140</td>
<td>100</td>
<td>40</td>
<td>7.0</td>
<td>0.40</td>
<td>0.07</td>
<td>0.10</td>
</tr>
<tr>
<td>Red clover</td>
<td>127</td>
<td>45</td>
<td>27</td>
<td>8.8</td>
<td>0.47</td>
<td>0.18</td>
<td>0.11</td>
</tr>
</tbody>
</table>

* Source: Product Board Animal Feed, the Netherlands

- Sufficient provision of Ca and P
- There may be a lack of Mg and Na, but this can be corrected by fertilization
- Too much K → weak faeces
- Cu, I, Se and Co may be marginal
Vitamins

• Grass is rich in β-carotene: important for fertility and immunity, as anti-oxidant

• Contains sufficient vit. E: important for immunity and as anti-oxidant (important because of high content of unsaturated fatty acids)
Antinutritional factors

• Tannins:
  - condensed: reduce digestibility, bind with protein, decrease intake
  - harmful when > 4% (Waghorn et al., 1990)

• Saponins in leguminosae: clover, alfalfa → bloat
  - increases with high light intensity and low nitrogen conditions
Conclusions

• Higher energy value: mainly by $\text{DC}_{\text{OM}}$ and to a minor extent by Cfat

• Higher protein value = complex parameter
  - bypass protein weakly related with CP because of negative relation with %RBP
  - microbial protein highly determined by WSC $\rightarrow$ reduces protein-energy imbalance
  - lower endogenous losses with higher $\text{DC}_{\text{OM}}$

• Higher voluntary intake: with higher $\text{DC}_{\text{OM}}$, more particularly $\text{DC}_{\text{NDF}}$

• Higher (milk) production $\rightarrow$ increase in $\text{DC}_{\text{OM}}$
  - mainly by better $\text{D}_{\text{NDF}}$
  - increase of WSC at the expense of NDF

• Added value: PUFA’s