Challenges of utilization of High Protein Forages by Lactating Dairy Cows

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Introduction

- Forages are essential for cow health
- High quality forages often have high concentrations of CP
- Forage (silage) N is rapidly and extensively degraded in the rumen → High rumen ammonia concentrations and rumen N losses
- N utilization can be low (20-25%) in cows fed high quality forages (silages)
- Increased risk of
  - Ammonia volatilization
  - Nitrate losses
Rumen ammonia concentration in cows fed diets based on grass silage (Kim et al., 1999)

- CP content 196 g/kg DM
- In cows fed grass or legume silages rumen postprandial rumen ammonia N is very high
- High peak values
Effects of dietary CP and rumen ammonia on rumen N losses in cows fed grass silage based diets (MTT data)

- Rumen N losses increase with increasing Dietary CP content (70% of increased CP lost from the rumen)
- Rumen N losses increase with rumen ammonia concentration
Effects of protein supplementation of grass silage based diets

- Substantial production responses are obtained to supplementary protein, but:
  - Marginal responses have been relatively low (Fish meal 0.15, Rapeseed (Canola) 0.15, Soybean 0.12)
  - N efficiency (Milk N / N intake) always decreases
  - Nearly all incremental manure N excreted as urinary N
- Production economy and environment in conflict
Effects of increasing dietary CP concentration of grass silage based diets on protein yield and N efficiency

\[ y = -0.0206x^2 + 9.02x - 14 \]
\[ R^2 = 0.892 \]

Protein Yield (g/d)

\[ y = -0.0014x + 0.504 \]
\[ R^2 = 0.958 \]

N efficiency

\[ y = -0.0012x + 0.479 \]
\[ R^2 = 0.604 \]
Effects of increased CP intake from earlier harvest to protein yield and N efficiency

- Protein yield responses to earlier harvest of grass silage as good as with the best protein supplements
- Increased ME supply
  - Intake
  - Digestibility
- Provided grass not harvested too early

Data from Rinne et al. 1999; Kuoppala et al. 2005
Effect of protein supplementation on protein yield & N utilization

Shingfield et al. (2001)
Strategies to improve efficiency of N utilization

- Improve efficiency of microbial N synthesis
  - Ratio between RDN and fermentable energy
  - Synchronization of the rates of N and energy release
- Reduce extent of proteolysis in the silo and/or in the rumen
- Optimize energy and protein supplementation
Synchronization of energy and N release in the rumen

- Asynchronous release of energy and N from silage has been suggested as one reason for low efficiency of MPS.
- The studies testing this hypothesis have often been confounded by dietary ingredients (nutrient supply).
**Effect of synchronization of energy and N release on microbial synthesis in sheep (Henning et al. 1993)**

<table>
<thead>
<tr>
<th></th>
<th>Exp1</th>
<th>Exp2</th>
</tr>
</thead>
<tbody>
<tr>
<td>N intake (g/d)</td>
<td>14.2</td>
<td>13.9</td>
</tr>
<tr>
<td>NAN flow (g/d)</td>
<td>13.8</td>
<td>14.6</td>
</tr>
<tr>
<td>Microbial N (g/kg OMADR)</td>
<td>15.0</td>
<td>17.3</td>
</tr>
</tbody>
</table>

E = Energy, N = Nitrogen, P = Pulse dose 2 x day, G = Continuous infusion
Effects of degree of synchrony of energy and N release on N metabolism (Kim et al., 1999)

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia N (mg /L)</td>
<td>211</td>
<td>136</td>
<td>162</td>
<td>172</td>
</tr>
<tr>
<td>Urine N (g/d)</td>
<td>189</td>
<td>129</td>
<td>133</td>
<td>136</td>
</tr>
<tr>
<td>PD (mmol/d)</td>
<td>245</td>
<td>281</td>
<td>273</td>
<td>241</td>
</tr>
<tr>
<td>Microbial N (g/d)</td>
<td>173</td>
<td>204</td>
<td>197</td>
<td>169</td>
</tr>
<tr>
<td>Plasma urea N (mg/L)</td>
<td>211</td>
<td>164</td>
<td>174</td>
<td>163</td>
</tr>
</tbody>
</table>

- Control diet grass silage + barley + groundnut meal (196 g CP/kg DM)
- Two kg of maltodextrin infused continuously (Cont.), 0-6 h (Synchr.) or 6-12 h after feeding (Asynchr.)
Effect of degree of synchrony of energy and N release on rumen pH and ammonia N (Kim et al., 1999)
Response to high moisture ear corn (HMEC) in cows fed alfalfa hay (AH) or silage (AS) (Vagnoni & Broderick, 1997)

<table>
<thead>
<tr>
<th>HMEC, %</th>
<th>24</th>
<th>40</th>
<th></th>
<th></th>
<th></th>
<th>Interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forage</td>
<td>AH</td>
<td>AS</td>
<td>AH</td>
<td>AS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CP (g/kg DM)</td>
<td>170</td>
<td>173</td>
<td>162</td>
<td>164</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TDMI (kg/d)</td>
<td>22.8</td>
<td>21.9</td>
<td>24.2</td>
<td>23.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protein (g/d)</td>
<td>960</td>
<td>900</td>
<td>1060</td>
<td>1070</td>
<td>0.09</td>
<td></td>
</tr>
<tr>
<td>N Efficiency</td>
<td>0.248</td>
<td>0.238</td>
<td>0.270</td>
<td>0.278</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Microbial CP (g/d)</td>
<td>1981</td>
<td>1925</td>
<td>2081</td>
<td>2262</td>
<td>0.02</td>
<td></td>
</tr>
</tbody>
</table>

- Increased HMEC increased protein yield (170 vs. 100) and microbial CP (337 vs. 100) on AS versus AH
- AS was more limited in AA supply
- Increased CHO markedly improved N efficiency
Response to fishmeal (FM) in cows fed alfalfa hay (AH) or silage (AS)  
(Broderick, 1995; Vagnoni & Broderick, 1997)

<table>
<thead>
<tr>
<th>Variable</th>
<th>AS</th>
<th>AH</th>
<th>AS+FM</th>
<th>AH+FM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diet CP (g/kg DM)</td>
<td>168.5</td>
<td>153.8</td>
<td>185.5</td>
<td>170.8</td>
</tr>
<tr>
<td>DMI (kg/d)</td>
<td>23.0</td>
<td>24.7</td>
<td>23.8</td>
<td>24.7</td>
</tr>
<tr>
<td>Protein (g/d)</td>
<td>1093</td>
<td>1153</td>
<td>1193</td>
<td>1177</td>
</tr>
<tr>
<td>N efficiency</td>
<td>0.281</td>
<td>0.304</td>
<td>0.270</td>
<td>0.278</td>
</tr>
</tbody>
</table>

Without FM, AH increased milk protein 70g/d
Response to FM higher with AS than AH (100 vs. 24)
High marginal response to supplementary protein with AS (0.185) suggests the diet was limited by AA supply
Effects of forage conservation method and proportion concentrate on rumen N metabolism in growing cattle

<table>
<thead>
<tr>
<th></th>
<th>Silage</th>
<th>Hay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentrate (g/kg DM)</td>
<td>250</td>
<td>500</td>
</tr>
<tr>
<td>CP (g/kg DM)</td>
<td>168</td>
<td>165</td>
</tr>
<tr>
<td>Rumen ammonia N (mmol/l)</td>
<td>13.9</td>
<td>12.8</td>
</tr>
<tr>
<td>N intake (g/d)</td>
<td>178</td>
<td>181</td>
</tr>
<tr>
<td>Duodenal flow (g/d)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-ammonia N</td>
<td>142</td>
<td>152</td>
</tr>
<tr>
<td>Microbial N</td>
<td>77</td>
<td>89</td>
</tr>
<tr>
<td>Feed N</td>
<td>53</td>
<td>52</td>
</tr>
<tr>
<td>N degradability</td>
<td>0.71</td>
<td>0.72</td>
</tr>
</tbody>
</table>

(Jaakkola & Huhtanen, 1993)
Reducing proteolysis

- NPN in red clover is markedly lower compared with grass or alfalfa silages
- Reduced proteolysis is associated with polyphenol oxidase (PPO) activity in red clover
- Comparisons of red clover vs. alfalfa and red clover vs. grass silages can be used as a model to describe potential benefits of reducing proteolysis
Efficiency of N utilization of red clover (RC) and grass silages in the rumen (Data from MTT omasal sampling studies)

- N utilization in the rumen much better with RC than with grass silages (zero N balance at 136 vs. 168 g CP/kg DM)
- Lower rumen ammonia at same CP concentration
  - Reduced protein degradation
  - Improved microbial synthesis
Effect of replacing grass silage with red clover silage on NAN flow and protein yield

- Increased N intake from gradual or total replacement of grass with RC increased NAN Flow
- BUT increased protein flow did not increase milk protein yield
- WHY?

\[
y = 0.635x + 147 \\
R^2 = 0.895
\]

\[
y = 0.062x + 810.4 \\
R^2 = 0.0187
\]
Effect of red clover versus alfalfa silages on rumen N efficiency and milk protein yield
(data from Brito et al. 2006; Dewhurst et al., 2003)

![Graph showing rumen N efficiency and milk protein yield for different treatments.](image-url)
Fecal CP higher for red clover (RC) (data from MTT)

- Negative intercept in Lucas test higher for RC vs. primary growth grass
- Fecal CP per kg DMI 16 g higher for RC
- Apparent CP digestibility lower for RC
- Does PPO inhibit protein digestion in the small intestine???
AA composition of forage RUP

- Forage protein is especially low in Met and His
  Compared to milk protein
- Met (+Lys) likely to be the first limiting AA
  on typical US dairy cow diets
- His is likely to be the first limiting AA on
  grass silage based diets
- Due to non-ideal AA composition of forage
  RUP, its utilization is likely to be lower than
  that protein supplements
Monitoring N efficiency on the farm

- Milk and plasma urea are closely correlated
- Milk urea concentration is closely associated with RDP excess and ammonia absorption from the rumen
- Tissue AA catabolism is another source of plasma and milk urea
- High milk urea concentrations are associated with excesses of RDP and MP
Prediction of urine N (Feed N - Fecal N - Milk N) from dietary CP concentration and milk urea output.

\[
\text{Urine N} = -188 + 9.7 \text{ Milk Urea (g/d)} + 2.27 \text{ CP (g/kg DM)} \\
\text{se. est} = 21.3
\]

\[ R^2 = 0.8724 \]

P. Huhtanen 2003
Modification of forage plants to improve N efficiency

- Increase microbial protein synthesis
  - Increase rate of dNDF digestion
  - Decrease concentration of iNDF

- Decrease RDP excess
  - Decrease CP concentration
  - Reduce NPN fraction (proteolysis)
  - Decrease rate of insoluble N degradation

- Decrease the rate of deamination of AA
  - Suppression of AA catabolizing microbes
Model simulations

- Nordic Dairy Cow Model (Karoline)
- Dynamic mechanistic model (Danfær et al. 2006)
- Only one parameter changed; others constant
- Forage: Concentrate 55:45
- Concentrate CP 180 g/kg DM

![Graphs showing predicted versus observed CP flow and ECM yield]
Simulated responses in N utilization to changes in rate of digestion of grass pdNDF (fixed intake)

Forage pdNDF kd (1/h)

N (g/d)

0.04 0.05 0.06 0.07 0.08 0.09

N intake
Duodenal N Flow

Forage pdNDF kd (1/h)

N Flow (g/d)

0.04 0.05 0.06 0.07 0.08 0.09

Microbial N
Feed N

Forage pdNDF kd (1/h)

Nitrogen (g/d)

0.04 0.05 0.06 0.07 0.08 0.09

Milk N
Fecal N
Urine N

Forage pdNDF (kg/kg DM)

N efficiency / FN / (FN + UN)

0.04 0.05 0.06 0.07 0.08 0.09

Protein yield (g/d)

0.25 0.30 0.35 0.40 0.45

Protein Yield

0.1000 0.1025 0.1050 0.1075 0.1100 0.1125 0.1150
Simulated responses in N utilization to changes in CP concentration in grass

Forage CP (g/kg DM)

N intake
Duodenal N Flow
N Flow (g/d)
Microbial N
Feed N
Milk N
Fecal N
Urine N
N efficiency
FN / (FN + UN)
Protein Yield
Protein yield (g/d)
Simulated responses in N utilization to changes in pdNDF (fixed intake)

- N intake
- Duodenal N Flow
- N Flow (g/d)
- Microbial N
- Feed N
- Milk N
- Fecal N
- Urine N
- Protein Yield
- N efficiency / FN / (FN + UN)
Simulated responses in N utilization to changes in soluble N in grass

- N intake
- Duodenal N Flow

- N Flow (g/d)

- Microbial N
- Feed N

- Forage Soluble N (g/kg N)

- Nitrogen (g/d)

- Protein yield (g/d)

- N efficiency / FN / (FN + UN)

- N efficiency
- FN / (FN + UN)
- Protein Yield

- Forage Soluble N (g/kg N)
Simulated responses in N utilization to changes in rate of degradation of insoluble N
Simulated responses in N utilization to changes in rate of AA deamination

- N intake
- Duodenal N Flow

- Forage Insoluble N kd (1/h)
- Milk N
- Fecal N
- Urine N

- Nitrogen (g/d)
- Rate of AA deamination (1/h)

- Microbial N
- Feed N

- N efficiency / FN / (FN + UN)
- Protein yield (g/d)

- Protein Yield
- Nitrogen (g/d)
- Feed N
- Fecal N
- Urine N

- Rate of AA deamination (1/h)
- Forage Insoluble N kd (1/d)

- N efficiency
- FN / (FN + UN)
- Protein Yield

- N Intake
- Duodenal N Flow

- Nitrogen (g/d)
- Rate of AA deamination (1/h)
Responses to increased MP partly related to increased ME supply

<table>
<thead>
<tr>
<th>N</th>
<th>Intercept</th>
<th>ME (MJ/d)</th>
<th>MP (g/d)</th>
<th>RMSE</th>
<th>Adj R2</th>
</tr>
</thead>
<tbody>
<tr>
<td>364</td>
<td>199</td>
<td>0.378</td>
<td>25.1</td>
<td>0.939</td>
<td></td>
</tr>
<tr>
<td>364</td>
<td>94</td>
<td>1.29</td>
<td>0.287</td>
<td>24.3</td>
<td>0.947</td>
</tr>
<tr>
<td>37</td>
<td>228</td>
<td>0.349</td>
<td>30.6</td>
<td>0.944</td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>53</td>
<td>2.09</td>
<td>0.216</td>
<td>26.1</td>
<td>0.957</td>
</tr>
</tbody>
</table>

When ME intake was in the model, marginal response to ME decreased both in data from production trials (n=364) and omasal flow studies (n=37)

MP (g) = NAN * 0.80 * 0.85; ME = 16 * DOM (kg)
Conclusions (1)

- Meeting ME requirements of high producing dairy cows without overfeeding RDP is a challenge
- N fertilization of grass should be optimized on the basis of plant requirements
- Good ensiling management required to avoid unnecessary proteolysis and losses of WSC
Conclusions (2)

- Red clover improves N utilization in the rumen compared to both grass and alfalfa but overall protein utilization has been poor
- Modifying forages for improved N utilization:
  - Improve digestibility (less iNDF, faster kd for dNDF)
  - Reduce CP concentration
  - Reduce proteolysis in the silo (less NPN) and rate of degradation of insoluble protein
Simulated responses in N utilization to changes in rate of digestion of grass pdNDF (ad libitum intake)
Simulated responses in N utilization to changes in \( \text{pdNDF} \) (ad libitum intake)