An overview of silage research in Finland: from ensiling innovation to advances in dairy cow feeding

Pekka Huhtanen¹, Seija Jaakkola² and Juha Nousiainen³

¹Department of Agricultural Research for Northern Sweden, Swedish University of Agricultural Sciences, S-901 83 Umeå, Sweden,
²Department of Agricultural Sciences, PO Box 28, FI-00014 University of Helsinki, Finland,
³Valio Ltd., Farm Services, PO Box 10, FI-00039 Valio, Finland,
Outline

- Introduction
- Ensiling
- Feed Evaluation / Nutrient Supply
  - Energy
  - Protein
- Feed Intake
- Silage quality and milk production
- Protein / amino acid supplementation
- Implications
Introduction

- Short grazing period (100 - 120 days)
- Grassland relatively production more competitive
- DM yields of grass about 2-fold compared to cereal grains both in field trials and practise
  - DM yield can increase >200 kg/d in early summer
- High OM digestibility even at high NDF due to relatively low temperatures and day length
- Traditions in silage making
  - Virtanen got a Nobel prize 1945 of silage inventions
- Feeding systems based on grass silage likely the most efficient and sustainable alternative for utilisation of resources for human food production
Theoretical basis of A.I.V. - method (Virtanen 1933)

- Rapid achievement of pH 4 in silage
  - the activity of proteolytic enzymes of plant-cells and anaerobic micro-organisms decreases
  - the respiration of plant-cells is suppressed
  - butyric fermentation is suppressed
### Developments in silage making in Finland

<table>
<thead>
<tr>
<th>Initial decade</th>
<th>Additives / Harvesting technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>1920</td>
<td>Hydrochloric acid, sulphuric acid</td>
</tr>
<tr>
<td>1950</td>
<td>Sodiumnitrite, caliumformiate,</td>
</tr>
<tr>
<td></td>
<td>ammoniumbisulfate</td>
</tr>
<tr>
<td></td>
<td>Forage harvesters (chopping)</td>
</tr>
<tr>
<td>1960</td>
<td>Formic acid</td>
</tr>
<tr>
<td></td>
<td>Combinations of inorganic acids</td>
</tr>
<tr>
<td></td>
<td>and organic acids</td>
</tr>
<tr>
<td></td>
<td>Formaldehyde</td>
</tr>
<tr>
<td></td>
<td>Additive applicators at harvesters</td>
</tr>
<tr>
<td>1970</td>
<td>Lactic acid bacteria, enzymes</td>
</tr>
<tr>
<td></td>
<td>Wilting and techniques related to it</td>
</tr>
<tr>
<td>1980</td>
<td>Ammoniumtetraformiate</td>
</tr>
<tr>
<td></td>
<td>Large round bales</td>
</tr>
<tr>
<td>1990/2000</td>
<td>Additives to improve aerobic</td>
</tr>
<tr>
<td></td>
<td>stability</td>
</tr>
<tr>
<td></td>
<td>More efficient harvesting systems</td>
</tr>
</tbody>
</table>
Ensiling of cereals in Finland

- **Small grain cereals (whole crop silage)**
  - Harvested at the dough stage, ensiling based on low pH generated by fermentation and/or acid based additives
  - Better results than with alkaline preservation - low dry matter content even at a late maturity
  - Improves the fermentation quality of legumenous silage when ensiled as a mixture

- **High moisture grain /grimped grain**
  - Efficient and economical storage method as an alternative to grain drying
  - Diminishes the challenges of short growing season, increases grain yield, reduces the use of fossil fuels
  - Same animal performance with ensiled and dry barley in growing cattle and dairy cows
The application rate of formic acid (FA) affect protein degradation and the concentration of fermentation acids and water soluble carbohydrates (WSC) in the silage (Jaakkola et al. 2006, Exp 1 and Exp 2).
Evaluation of forage feeding value

- The aim was to development a robust and low cost method to predict energy concentration of farm silage samples accurately
- NIRS the most feasible option
- In vivo calibration ideal, but expensive and impractical
- It was decided to calibrate a laboratory method predicting OMD (D-value) and use that for NIRS calibration
- Pepsin-cellulase solubility of OM (OMS) was selected as reference method, because it does not need rumen fluid and is less variable in activity than rumen fluid
- Digestibility trials to determine digestibility at M were conducted to collect a dataset for calibration of OMS
Relationships between pepsin-cellulase solubility and in vivo OMD

\[ y = 0.0009x + 0.0493 \]

\[ R^2 = 0.8211 \]
**iNDF vs. OMD**

- It was found that iNDF was closely related to OMD in the first digestibility trials in mid 90’s.
- Determined by 12 d *in situ* incubation with 6 / 17 µm nylon bags.
- More uniform relationship between iNDF and OMD vs. OMS and OMD.
- Can be used in empirical regression models and summative models, and is required in mechanistic models (iNDF is the most important feed parameter in Nordic Dairy Cow Model Karoline).
- Can be calibrated for NIRS (CV error 10.0 g/kg DM; Nousiainen et al., 2004).
The relationship between iNDF and \textit{in vivo} OMD

More uniform between forage types than the relationship between
iNDF determination by NIRS

\[ y = 1.05x - 1.52 \]
\[ R^2 = 0.929 \]
\[ \text{RMSPE} = 11.5 \]

\[ y = -1.26x + 833 \]
\[ R^2 = 0.88 \]
\[ \text{RMSE} = 19.0 \]

\[ y = -1.34x + 837 \]
\[ R^2 = 0.85 \]
\[ \text{RMSE} = 21.6 \]

\[ y = 0.68x + 0.3 \]
\[ R^2 = 0.80 \]
Rumen fermentation

- With diets based on grass silage and barley/oats concentrates:
  1. Effects of starch on propionate small (quadratic)
  2. Starch increase butyrate (protozoa)
  3. Propionate increase with dietary concentration of lactic acid
  4. Lactic acid decrease (in most cases) and sometimes butyrate

- Rumen fermentation pattern rather resistant to the changes in the proportion of concentrate or to fat supplementation
Effects of starch and lactic acid on rumen fermentation in cattle fed grass silage-based diets

Data from studies conducted at University of Helsinki and MTT (n = 106 diets)
Protein value of silage

- Efficiency of microbial protein synthesis in animals fed grass silage-base diets
  1. Asynchronous supply of energy and N from silage
  2. Lower supply of energy (ATP) from silage fermentation products than from water soluble CHO for rumen microbes
  3. The nature of N present in the silage [NPN (ammonia, amines, free AA, peptides) vs. true protein]
The effects of formic acid treated silage (S) and hay (H) from the same sward fed with 3 levels of concentrate (25, 50 and 75% of DM) on rumen N metabolism

Jaakkola & Huhtanen 1993
The effects of application rate of formic acid (L/tn) on silage fermentation (g/kg DM or N) and ruminal N metabolism (g N/d)

Jaakkola et al. 2006
The best-fit mixed model regression equation of milk protein yield responses to forage variables (meta-analysis of 547 diets; Adj. RMSE = 16.0)

<table>
<thead>
<tr>
<th>Effect</th>
<th>Unit</th>
<th>Estimate</th>
<th>Error</th>
<th>P-Value</th>
<th>Response per SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td></td>
<td>-310</td>
<td>46.8</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>CMP$^2$</td>
<td>kg/d</td>
<td>790</td>
<td>66.7</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>CMP × CMP</td>
<td>kd/d</td>
<td>-192</td>
<td>38.7</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>Forage DMI$^3$</td>
<td>kg/d</td>
<td>27.7</td>
<td>1.42</td>
<td>&lt;0.001</td>
<td>1.53</td>
</tr>
<tr>
<td>D-Value$^4$</td>
<td>g/kg DM</td>
<td>0.49</td>
<td>0.069</td>
<td>&lt;0.001</td>
<td>40.9</td>
</tr>
<tr>
<td>Forage CP</td>
<td>g/kg DM</td>
<td>0.417</td>
<td>0.114</td>
<td>&lt;0.001</td>
<td>22.4</td>
</tr>
<tr>
<td>Ammonia N</td>
<td>g/kg N</td>
<td>-0.217</td>
<td>0.067</td>
<td>0.001</td>
<td>21.5</td>
</tr>
</tbody>
</table>

$^1$SD = standard deviation
$^2$CMP = Concentrate metabolisable protein
$^3$DMI = dry matter intake
$^4$D-value = Digestible organic matter in dry matter

Huhtanen et al. 2010
Conclusions about silage protein value (1)

1. Extent of fermentation rather than fermentation per se affect microbial protein synthesis

2. Despite increased MPS with restricted fermentation, milk protein yield responses have not been greater than predicted from increased DMI

3. Meta-analysis of data from studies in which soluble N determined indicate that only ammonia N but not soluble NAN has a negative influence on milk protein yield

4. A study with $^{15}$N-labelled silage SNAN indicated that approximately 15% of this fraction escape ruminal degradation (Ahvenjärvi et al. 2007)
Conclusions about silage protein value (2)

5. Digestibility and intake potential are the main determinants of the supply of metabolizable protein (MP) from silage.

6. The value of determination ruminal degradability of forage CP can be questioned:
   - The methods are inaccurate - differences overestimated?
   - The value of undegraded forage protein is rather low (digestibility, AA composition)
   - Energy supply is the main determinant of milk protein production
   - TDN predicted milk protein yield better than MP (NRC, 2001)
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
- Increased faecal N with red clover
Development of intake prediction model

- Feed intake is regulated by many feed and animal factors plus their interactions
- Variation in animal’s intake potential and concentrate feeding can mask the effects forage factors on intake
- Mixed model regression analysis with random study effect allows to estimate the effects of different dietary factors on intake when the other factors are constant; e.g. studies comparing the effects of maturity, fermentation quality, DM, NDF etc.
- Quantitative responses to different factors can be predicted by this method
- The effects of different factors were combined into relative silage DMI-index
Silage DMI-index (1)

- Digestibility (D-value) was the best single predictor of SDMI (linear increased with increased D-value)
  - NDF a poor predictor; iNDF + pdNDF much better
- Linear negative effect of total acid concentration
  - VFA (especially propionic acid) has some additional negative effect
- Quadratic effect of DM concentration (max at 350-400 g/kg)
- Intake of regrowth silages less that of primary growth silages (0.4 kg/d) when other factors are constant
- Positive associative effects of mixtures of grass and legumes, and grass and whole-crop silages
Silage DMI-index (2)

- Quantitative effects of different factors are converted to index units: 1 point = 0.1 kg DM
- Points from different factors are added together; SDMI-index = 100 + \( \sum \) (D, acids, DM....)
- The model was evaluated by combining data from all forage studies
- Residual RMSE was 0.36 for diets based on grass silage and < 50% of legume and whole-crop silages of forage DM; The model explained 0.85 of variation in forage DMI within study
- Intake of diets with >50% of legume and whole-crop silages less predictable
Concentrate and total DMI-index

- The effects of concentrate factors on DMI were evaluated from studies in which different concentrate treatments were evaluated (same forage within a study)
- Quadratic effect of the amount of concentrate
- Quadratic effects of concentrate CP
- Positive effect of concentrate NDF
- Negative effect of concentrate fat
- Interaction between concentrate DMI and SDMI-index
  - Increased CDMI decrease more DMI of silages with high intake potential (SDMI-index)
- Total DMI-index = SDMI-index + CDMI-index - 100
- Adjusted RMSE = 0.37 kg/d (n = 943 diets); DMI response of one point was 0.095 kg
Prediction of actual DMI

- TDMI-index model predicts DMI responses to changes in diet composition but not actual intake
- Observed intake is $f$ (cow, diet)
- The cow effects should be “cleaned” of diet effects to predict diet effects without bias
- DMI can be predicted accurately from ECM yield and LW, but the “prediction” can be made only after the diet is fed
- We used standardised ECM (sECM) yield in the model
  - $sECM = f$ (ECM, DIM, TDMI-index, Metabolizable Protein)
  - Actual DMI = $f$ (sECM, LW, DIM, TDMI-index)
  - Adjusted RMSE = 0.36 (treatment mean data) and 0.91 (individual cow data)
Reduced silage digestibility can only partly be compensated by increased concentrate feeding.

- 10 g/kg DM in D-value = 0.45 kg ECM
- 10 g/kg in DM decrease in D-value = 0.82 kg more concentrate DM
- One day delay in harvest of primary growth grass = 0.45 kg more concentrate DM/d
Highlights of protein nutrition studies

- Determination of limiting AA in cows fed grass silage-based diets
  - Post-ruminal infusions of Met and Lys had no influence
  - His increased protein yield, but no further responses with Met, Lys or Met + Lys
  - Studies with BCAA did not reveal 2nd limiting AA
  - Responses only with low CP diets when the contribution of microbial CP to MP supply large
  - Plasma His concentrations are low with low CP diets based on grass silage + barley / oats

- Rapeseed (canola) meal is a better protein supplement for dairy fed grass silage-based diets than soybean meal
- No effects of reduced protein degradability of RSM
Comparison effects of RSM and SBM, and untreated and treated RSM on milk protein yield

- Virtually no SBM is used for dairy cows in Finland nowadays.
Implications of the research

- The research has aimed to develop low cost forage evaluation methods, feed evaluation systems that predict production responses accurately and precisely allowing optimization of the diets for maximum milk income over feed costs – not only for minimum diet costs.

- The requirements for that system are:
  1. Accurate and low cost forage analysis methods
  2. Feed intake models that can separate animal and diet effects and accurately predict intake responses
  3. Feed evaluation systems that predict production responses accurately
  4. Accurate production response models
  5. Possibility to include environmental constraints
Prediction of milk yield from nutrient supply (Adj. RMSE = 0.42)

<table>
<thead>
<tr>
<th>Item</th>
<th>Estimate</th>
<th>SE</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>5.3</td>
<td>1.27</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Production ME(_p) intake (MJ/d)</td>
<td>0.14</td>
<td>0.015</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Production ME(_p) intake (MJ/d)</td>
<td>-0.00018</td>
<td>0.00006</td>
<td>0.001</td>
</tr>
<tr>
<td>Feed MP (g/kg DM)</td>
<td>0.109</td>
<td>0.0097</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>NFC (kg/kg DM)</td>
<td>19.3</td>
<td>4.38</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>NFC(^2) (kg/kg DM)</td>
<td>-32.5</td>
<td>7.01</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>C-Fat (g/kg DM)</td>
<td>0.091</td>
<td>0.0128</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>C-Fat(^2) (g/kg DM)</td>
<td>-0.0011</td>
<td>0.00022</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Days in milk</td>
<td>-0.022</td>
<td>0.0048</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

Implications of the research

- The research has produced a model (Lypsikki) that is the basis of the current ration formulation system in Finland (KarjaKompassi - CowCompass)
- The model is based on
  1. Developed forage analysis systems
  2. Finnish feed energy and protein system (MTT, 2010)
  3. Developed feed intake models
  4. Models predicting production responses from nutrient supply (based on meta-analysis > 1 000 treatment means)
  5. Constraints for N and P surplus per kg milk (also for CH₄)