Herbage nutritive value in less-favoured areas of cool regions

Gilles Bélanger, Agriculture and Agri-Food Canada

Perttu Virkajärvi, MTT, Finland
Michel Duru, INRA, France
Gaëtan Tremblay, Agriculture and Agri-Food Canada
Kirsi Saarijärvi, MTT, Finland
Less-favoured areas, it’s personal !!!

- Grew up in area with shallow and stony soils, and short growing season
  - Timothy, red clover, and oats

- Started my career on shallow soils and poorly drained soils
  - Sod-seeding of legumes
  - Subsoil disturbance

- Recent project on production biomass on marginal lands (2008-2012)
Less-favoured areas « favour » herbage nutritive value?

- Less-favoured areas mostly limited by temperature
  - Latitude – Canada and Nordic countries
    - Sown swards
  - Altitude – Mountainous regions of Europe
    - Species-rich permanent pastures
Outline

• Nutritive value attributes
• Challenges and opportunities
• Climate change
• Perspectives
Nutritive value attributes

- Digestibility and fibre
- Nonstructural carbohydrates
- Proteins
- Others:
  - Dietary cation-anion difference (DCAD)
  - Fatty acids
Digestibility
Most important attribute of nutritive value

- Conceptual model (Duru, 2008)
- Two components

Herbage digestibility depends on:

- Digestibility of structural component in herbage mass ($D_s$)
- Ratio of metabolic component in herbage mass ($M/W$)
- Metabolic component with digestibility ($D_m$) of 100%

\[
D_w = [D_s \times (1 - M/W)] + [M/W]
\]

where $M/W$ = Ratio of metabolic component in herbage mass
Digestibility
Conceptual model (Duru 2008)

\[ D_w = [D_S \times (1 - M/W)] + [M/W] \]

- Metabolic component (M) decreases with increasing standing biomass (W)
  \[ M = \alpha W^\beta \]
  \[ M/W = \alpha W^{\beta - 1} \] (Lemaire et al. 1989)

Herbage digestibility changes depend on:
- Plant growth and decrease in the metabolic component
- Differentiation of structural tissue and their digestibility

\[ D_w = D_S + [(1 - D_S) \alpha W^{\beta - 1}] \]
Digestibility decreases with increasing DM yield during growth cycle

Sown swards
Digestibility decreases with increasing DM yield during growth cycle

**Sown swards**

**Species-rich pastures**

![Graph showing the relationship between standing herbage mass and plant digestibility for different days of the growth cycle for Sown swards and Species-rich pastures.](image)
Digestibility decreases with increasing DM yield at contrasted sites

First cut of the first year after establishment

<table>
<thead>
<tr>
<th>Location</th>
<th>IVTD (g kg(^{-1}) DM)</th>
<th>Yield (t DM ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern Canada</td>
<td>810</td>
<td>5.37</td>
</tr>
<tr>
<td>Norway (Tromso)</td>
<td>798</td>
<td>6.71</td>
</tr>
<tr>
<td>Iceland (Reykjavik)</td>
<td>963</td>
<td>2.58</td>
</tr>
</tbody>
</table>

Average of a 11 mixtures and four monocultures (timothy, smooth meadow bromegrass, red clover, and white clover).
Unpublished data. Cost 852 project.
Proteins and Nonstructural carbohydrates (NSC)

- **Herbage proteins**
  - Poorly used by ruminants
  - Substantial N losses to the environment

- **NSC** are a readily fermentable source of energy
  - Increased NSC concentration improves N use efficiency of dairy cows (Moorby et al. 2006; Brito et al. 2009)
  - Better balance between N and energy
Challenges and opportunities

• Sown swards of cool regions
  – Limited choice of species
  – Low temperatures and long days
  – Autumn harvest and grazing

• Species-rich permanent pastures
Sown swards - Limited choice of species

• Timothy: main grass species in eastern Canada and Nordic countries
  • Timothy – the saviour of Icelandic agriculture? (Helgadóttir and Sveinsson, 2008)

Bertrand, A.

• Comparison with species from warmer areas?
IVTD (g kg\(^{-1}\) DM)

DM yield (T ha\(^{-1}\))

Average over 2 years

Relationship yield - nutritive value

Timothy vs. Tall fescue

6 June

12 June

20 June

27 June

Tall fescue

Timothy
Timothy vs. Tall fescue

Relationship yield - nutritive value

NDF (g kg\(^{-1}\) DM)

DM yield (T ha\(^{-1}\))

Average over 2 years
Timothy vs. Tall fescue

Relationship yield - nutritive value

N concentration (g kg\(^{-1}\) DM)

DM yield (T ha\(^{-1}\))

Average over 2 years
### Timothy vs. Tall fescue

<table>
<thead>
<tr>
<th></th>
<th>Timothy</th>
<th>Tall fescue</th>
</tr>
</thead>
<tbody>
<tr>
<td>IVOMD (g kg⁻¹ DM)</td>
<td>692</td>
<td>727</td>
</tr>
<tr>
<td>NDF (g kg⁻¹ DM)</td>
<td>635</td>
<td>570</td>
</tr>
<tr>
<td>N (g kg⁻¹ DM)</td>
<td>16.2</td>
<td>17.4</td>
</tr>
</tbody>
</table>

**IVOMD**: *in vitro* organic matter digestibility;

**NDF**: neutral detergent fiber.

Timothy vs. Perennial ryegrass

In vitro true digestibility (g kg\(^{-1}\) DM)

<table>
<thead>
<tr>
<th>Date</th>
<th>Timothy</th>
<th>Perennial ryegrass</th>
</tr>
</thead>
<tbody>
<tr>
<td>23 June</td>
<td>923</td>
<td>950</td>
</tr>
<tr>
<td>3 July</td>
<td>938</td>
<td>942</td>
</tr>
<tr>
<td>10 July</td>
<td>877</td>
<td>941</td>
</tr>
</tbody>
</table>

*Timothy has a lower nutritive value than perennial ryegrass*

Red clover vs. lucerne

<table>
<thead>
<tr>
<th></th>
<th>Lucerne</th>
<th>Red clover</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM yield (t ha(^{-1}))</td>
<td>3.6</td>
<td>3.5</td>
</tr>
<tr>
<td>N (g kg(^{-1}) DM)</td>
<td>31.0</td>
<td>32.1</td>
</tr>
<tr>
<td>NSC (g kg(^{-1}) DM)</td>
<td>70.5</td>
<td>94.3</td>
</tr>
<tr>
<td>NDF (g kg(^{-1}) DM)</td>
<td>390</td>
<td>330</td>
</tr>
<tr>
<td>IVTD (g kg(^{-1}) DM)</td>
<td>795</td>
<td>858</td>
</tr>
<tr>
<td>dNDF (g kg(^{-1}) NDF)</td>
<td>485</td>
<td>568</td>
</tr>
</tbody>
</table>

Red clover:
- Widely used in Nordic countries
- More digestible than lucerne
(Broderick et al. 2000)

Better balance between energy and protein

NDF: Neutral detergent fiber;
NSC: Nonstructural carbohydrates;
IVTD: *in vitro* true digestibility of DM;
dNDF: *in vitro* digestibility of the NDF.

Averages of 2 production years with 2 growth cycles/year.
Low temperatures

• Low temperatures improve digestibility
  – Sown swards (Thorvaldsson et al. 2007; Bertrand et al. 2008)
  – Permanent pastures (Duru et al. 2008)

• Low temperatures reduce the rate of decline in digestibility
  (Thorvaldsson 1992; Thorvaldsson et al. 2007)

<table>
<thead>
<tr>
<th>Growth temperature (°C)</th>
<th>Decline in IVTD with time (g kg⁻¹ °C – d⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 – 13</td>
<td>0.18</td>
</tr>
<tr>
<td>13 – 17</td>
<td>0.37</td>
</tr>
<tr>
<td>17 – 21</td>
<td>0.43</td>
</tr>
</tbody>
</table>

IVTD: *in vitro* true digestibility of DM.  
Long days

• Rapid development of grasses
  - Variation in heading dates for timothy
    • 2 weeks in Canada (Bélanger and Richards 1995)
    • 3 days in Finland (Kangas et al. 2010)
  - 4 – 6 weeks for perennial ryegrass in the UK (Sheldrick 2000).

• Narrow window of opportunity for harvesting or grazing at optimal stage of development
Autumn harvest or grazing management

- Autumn grazing or harvests can reduce persistence and spring growth potential of desired species

<table>
<thead>
<tr>
<th>Autumn harvest of lucerne in eastern Canada</th>
</tr>
</thead>
<tbody>
<tr>
<td>3rd harvest</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>2 harvests</td>
</tr>
<tr>
<td>No</td>
</tr>
<tr>
<td>3 harvests</td>
</tr>
<tr>
<td>400 GDD</td>
</tr>
<tr>
<td>500 GDD</td>
</tr>
<tr>
<td>600 GDD</td>
</tr>
</tbody>
</table>

Autumn harvest or grazing management

Carbohydrate reserves (g plant$^{-1}$)

- 2nd harvest 7 Aug.
- 3rd harvest 400 GDD 8 Sept.
- 3rd harvest 500 GDD 17 Sept.

- 3rd harvest 600 GDD 7 Oct.

- 2 harvests
- 3 harvests 400 GDD
- 3 harvests 500 GDD
- 3 harvests 600 GDD

Autumn harvest or grazing management

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbohydrate reserves (g plant⁻¹)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrogen reserves (g plant⁻¹)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Carbohydrate reserves (g plant⁻¹):**
  - 3rd harvest 600 GDD 7 Oct.
  - 3rd harvest 500 GDD 17 Sept.
  - 3rd harvest 400 GDD 8 Sept.

- **Nitrogen reserves (g plant⁻¹):**
  - 3rd harvest 600 GDD 7 Oct.
  - 3rd harvest 500 GDD 17 Sept.
  - 3rd harvest 400 GDD 8 Sept.
Autumn harvest or grazing management

- Minimize risks of winter damage to swards
- Low temperatures are favourable to the production of energy-rich forages

## Autumn harvest of tall fescue in eastern Canada

<table>
<thead>
<tr>
<th>Date</th>
<th>Water soluble carbohydrates (g kg(^{-1}) DM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sept. 1</td>
<td>69</td>
</tr>
<tr>
<td>Sept. 15</td>
<td>89</td>
</tr>
<tr>
<td>Oct. 1</td>
<td>113</td>
</tr>
<tr>
<td>Oct. 15</td>
<td>129</td>
</tr>
<tr>
<td>Oct. 30</td>
<td>142</td>
</tr>
</tbody>
</table>

Species-rich permanent pastures

- Nutritive value is partly function of species present
  - Managing what you have; no reseeding
- Difficulty to analyze, understand, and manage nutritive value
- Use of plant functional types to embrace large species diversity (Duru et al. 2008)
  - Acquisitive growth strategy (resource capture)
  - Conservative growth strategy (resource conservation)
## Species-rich permanent pastures

### Features of two sites and four grasslands of the French Pyrenees

<table>
<thead>
<tr>
<th>Feature</th>
<th>Ercé</th>
<th>Portet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude (m)</td>
<td>650</td>
<td>1250</td>
</tr>
<tr>
<td>Average daily temperature (Feb.-June)</td>
<td>10.6 °C</td>
<td>7.9 °C</td>
</tr>
<tr>
<td>Main grass species</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acquisitive growth strategy</td>
<td>Lolium perenne</td>
<td>Dactylis glomerata</td>
</tr>
<tr>
<td></td>
<td>Holcus lanatus</td>
<td>Arrhenatherum elatius</td>
</tr>
<tr>
<td>Conservative growth strategy</td>
<td>Festuca rubra</td>
<td>Festuca rubra</td>
</tr>
<tr>
<td></td>
<td>Agrostis capillaris</td>
<td>Agrostis capillaris</td>
</tr>
</tbody>
</table>
### Species-rich permanent pastures

#### Features of two sites and four grasslands of the French Pyrenees

<table>
<thead>
<tr>
<th></th>
<th>Ercé</th>
<th>Portet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude (m)</td>
<td>650</td>
<td>1250</td>
</tr>
<tr>
<td>Average daily temperature (Feb.-June)</td>
<td>10.6 °C</td>
<td>7.9 °C</td>
</tr>
<tr>
<td><strong>Main grass species</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acquisitive growth strategy</td>
<td><em>Lolium perenne</em></td>
<td><em>Dactylis glomerata</em></td>
</tr>
<tr>
<td></td>
<td><em>Holcus lanatus</em></td>
<td><em>Arrhenatherum elatius</em></td>
</tr>
<tr>
<td>Conservative growth strategy</td>
<td><em>Festuca rubra</em></td>
<td><em>Festuca rubra</em></td>
</tr>
<tr>
<td></td>
<td><em>Agrostis capillaris</em></td>
<td><em>Agrostis capillaris</em></td>
</tr>
<tr>
<td><strong>Percentage of plant with acquisitive growth strategy</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Communities dominated by plant with acquisitive growth strategy</td>
<td>92 - 96</td>
<td>68 - 72</td>
</tr>
<tr>
<td>Communities dominated by plant with conservative growth strategy</td>
<td>4 - 8</td>
<td>32 - 38</td>
</tr>
</tbody>
</table>
Species-rich permanent pastures

Acquisitive strategy: greater digestibility at early stage but greater decline with time.
Species-rich permanent pastures

Greater digestibility of communities with acquisitive growth strategy for all standing biomass.
Species-rich permanent pastures

Ercé (650 m)

Portet (1250 m)
Species-rich permanent pastures

• Improved digestibility/yield relationships with communities having mostly species with acquisitive growth strategy
  – Fertilisation and cutting management

• Herbage digestibility was greater for the site at a higher altitude for a same grassland type and herbage biomass.

• Milk with greater omega-3 fatty acids in mountainous areas
  – Botanically-diverse vegetation?
Will climate change improve herbage nutritive value in less-favoured areas?

- **Direct effect of increased temperature**
  - Decreased digestibility of timothy (Bertrand et al. 2008)

- **Indirect effect through:**
  - Changes in species
    - Perennial ryegrass in Nordic countries (Thorsen and Höglind 2010)
    - More favorable for species with acquisitive growth strategy in permanent pastures (Duru et al., 2013)
  - Increased DM yield
    - Negative relationship between DM yield and nutritive value

- **Extension of the growing season**
  - One additional harvest (Thorsen and Höglind 2010)
## Impact of climate change on timothy yield and nutritive value

<table>
<thead>
<tr>
<th></th>
<th>Baseline 2 harvests</th>
<th>2040 – 2069 3 harvests</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Normandin</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yield (t DM ha(^{-1}))</td>
<td>7.6</td>
<td>10.2</td>
</tr>
<tr>
<td>NDF (g kg(^{-1}) DM)</td>
<td>512</td>
<td>506</td>
</tr>
<tr>
<td>dNDF (g kg(^{-1}) NDF)</td>
<td>710</td>
<td>694</td>
</tr>
<tr>
<td><strong>St. John’s</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yield (t DM ha(^{-1}))</td>
<td>7.7</td>
<td>9.9</td>
</tr>
<tr>
<td>NDF (g kg(^{-1}) DM)</td>
<td>498</td>
<td>502</td>
</tr>
<tr>
<td>dNDF (g kg(^{-1}) NDF)</td>
<td>718</td>
<td>710</td>
</tr>
</tbody>
</table>

Simulations with CATIMO model.
Jing et al. Agriculture and Agri-Food Canada. Unpublished data.
Less-favoured areas are back...

- Increasing productivity, important until the 80’s
  - Emphasis on inputs
  - Improvement of marginal lands (drainage, liming, breeding)

- Environmental protection and product quality (90’s)
  - To produce more with less, produce more efficiently

- Ecological intensification (2000’s)
  - Feeding and driving the world !!!
  - Need to produce more
Improving nutritive value of current species

• Managing the negative relationship between herbage digestibility and yield
  – Harvest management (intervals)
    • To optimize yield and nutritive value
    • Empirical and process-based models (CATIMO, STICS)
  – Mixtures
    • Increased yield with no change in digestibility (Sturludóttir et al. 2013)
  – Persistence
    • Always a consideration in cool regions with harsh winters
    • Intervals between harvests
    • Autumn management
    • C and N reserves
Improving nutritive value of current species

• Sown swards
  – Breeding for improved nutritive value
    • Requires genotypes with weaker negative relationship between yield and nutritive value
    • Emphasis of digestibility of structural component (NDF, stems)
    • Genetic variability exists in timothy but no cultivars yet
    • Other attributes (NSC)

• Multi-species swards
  – Fertilisation and harvest (grazing) management
  – Long-term approach favoring species with acquisitive growth strategy
Improving adaptation of species with better nutritive value

- Tall fescue, perennial ryegrass, lucerne
- Tolerance to abiotic stresses
  - Winter
  - Soil acidity and poor drainage
- Improved soil characteristics
Climate change and nutritive value

• The « tool box » will improve with new species for sown swards
  – Perennial ryegrass, tall fescue, lucerne, corn
  – Increased risks of winter damage
    • Lucerne (Bélanger et al. 2002)
    • Perennial ryegrass (Höglind et al. 2012)
  – Increased pest pressure and demand on land.

• Climate change will favour species with an acquisitive growth strategy in species-rich pastures
  – Biodiversity?
    • Likely to decrease if herbage production increases
Summary

• Challenges and opportunities for herbage nutritive value in less-favoured areas of cool regions

• Make good use of the existing “tool box”
  – Management and breeding

• Expand the “tool box”
  – Adaptation and climate change
Gilles.Belanger@agr.gc.ca

Questions, comments ?