Redesigning Forages for Sustainable Dairy Production

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USDA-ARS, Madison, WI
This talk will explore . . .

- Trends in corn silage & alfalfa production and use
- Barriers to increasing alfalfa in dairy diets
- Redesigning alfalfa for dairy cows
- Resigning grasses for dairy cows
Trends . . .

Leading Corn Silage States, 2006

Top 10 States
- 65 % of U. S.
- 66 % of Acres
- 6 states NC
- 2 states NE
- 2 states West
- 7 Lead Dairy
Corn Silage Production - West

2004-06 average
Trends...

Leading Alfalfa Forage States, 2006

Top 10 States
- 61% of U.S.
- 56% of Acres
- 6 states NC
- 4 states West
- 5 Lead Dairy
Alfalfa Forage Production - West
Trends . . .

Alfalfa Hay Production
Trends . . . Alfalfa Silage Production

% Alfalfa Harvested as Haylage, 2006
Trends . . .

- Hay acreage remains unchanged

- Dairy cattle feeding – declining amounts
For many years the Rule of Thumb for feeding alfalfa to dairy cattle was...
Alfalfa Yield Trends . . .

California: 
\[ y = 0.0467x - 86.223 \]
\[ R^2 = 0.9729 \]

Arizona: 
\[ y = 0.0824x - 156.6 \]
\[ R^2 = 0.8935 \]
CA Hay Production Per Dairy Cow (lbs alfalfa/cow/day)

\[ y = 0.0071x^2 - 1.0507x + 52.834 \]

\[ R^2 = 0.9432 \]

Source: Dan Putnam, 2005 Consortium for Alfalfa Improvement
Why this declining trend?

Competition with corn silage
Forage Production, million ton

Year


Milk, lb/cow

SOURCE: Jim Linn, 2006 NAAIC
Wisconsin

Forage Production, million ton
Corn Silage, million ton
Alfalfa Hay, million ton
Milk, lb/cow

Year

SOURCE: Jim Linn, 2006 NAAIC
Why this declining trend?

**Competition from byproducts**

- Canola Meal
- Soybean Meal
- Cottonseed
- Distillers Grains
- Bakery By-Products
- Almond Hulls
- Citrus Pulp
- Tomato Pumice
Why this declining trend?

Many of these byproducts are high in protein
## Protein Sources

<table>
<thead>
<tr>
<th>Source</th>
<th>CP, %</th>
<th>RDP, % CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alfalfa</td>
<td>20+</td>
<td>70</td>
</tr>
<tr>
<td>Dist grains - ethanol</td>
<td>30</td>
<td>60</td>
</tr>
<tr>
<td>SBM – biodiesel</td>
<td>50</td>
<td>65</td>
</tr>
<tr>
<td>Corn gluten feed</td>
<td>22</td>
<td>70</td>
</tr>
<tr>
<td>Corn gluten meal</td>
<td>67</td>
<td>45</td>
</tr>
<tr>
<td>Wheat midds</td>
<td>19</td>
<td>75</td>
</tr>
<tr>
<td>Blood</td>
<td>87</td>
<td>30</td>
</tr>
<tr>
<td>Corn silage</td>
<td>8</td>
<td>65</td>
</tr>
<tr>
<td>Corn grain</td>
<td>10</td>
<td>50</td>
</tr>
<tr>
<td>Dairy Cow Ration</td>
<td>&lt;17</td>
<td>65</td>
</tr>
</tbody>
</table>

**SOURCE:** Jim Linn, 2006 NAAIC
U.S. Ethanol Biorefinery Locations

Biorefineries in Production (106)

Biorefineries under Construction (48)

Last updated: Oct. 30, 2006

Source: Renewable Fuels Association
Forage Fiber Sources – Dairy Rations

Straw – Use is increasing

- Low nutrient value
- Effective fiber

Hay Price, Particle Size and $

- **Ground hay**
  - Quality (125 – 175 RFV) may not have extra value

- **Long hay - Unchopped**
  - Quality has value ($)

**SOURCE:** Jim Linn, 2006 NAAIC
Key Issues with alfalfa quality/value

- It must be measured
- Breaking the yield/quality tradeoff
- Problems with rapid lignification of alfalfa stems under hot conditions
- Enhancing/complementing other feeds
- Solving Waste Problems

SOURCE: Putnam, Dan. 2005
Less alfalfa being fed in dairy rations

- Lower yield of alfalfa than other crops
- Increased use of corn silage
- Minimized forage in ration
  - Cheap grain
  - Greater quality consistency of grain
  - Inability to accurately estimate energy of forage
Dairy Nutritionist Survey

MAJOR CHALLENGES
1. Forage quality - consistency
2. N and P excretion
3. Transition cows
4. Ethanol – starch and Distillers Grains
5. Ration formulation – modeling
6. Fiber digestion
7. Milk price and feed cost

WATER AVAILABILITY

Source: Hutjens – 2006 ADSA meeting
Dairy Ration Overview

% OF DM

40

FORAGES

40

FIBER
Physical & Chemical
Protein, minerals, CHO

20

FORAGE, GRAIN OR BYPRODUCTS

Nutrient needs and $

40

CONCENTRATES
• CORN
• PROTEIN
• MINERALS/ADDITIVES

Non-Fiber CHO
Starch
Protein
RDP & RUP
Minerals

40

Physical & Chemical
Protein, minerals, CHO
We don’t want to see reduced perennial forage crops in rotation because . . .

- Perennial forage crops are good for environment
- Good for cow health
Challenges . . . of the dairy forage industry
Research strategies and opportunities . . . of the U.S. Dairy Forage Research Center
Barriers to increasing alfalfa in dairy diets

Redesigning alfalfa for dairy cows

- Improve protein utilization
- Increase fiber digestion
- Increase yield
# Forage Quality

<table>
<thead>
<tr>
<th>Description</th>
<th>CP</th>
<th>EE</th>
<th>Ash</th>
<th>Starch</th>
<th>Pectin</th>
<th>aNDF</th>
<th>ADF</th>
<th>ADL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ALFALFA HAY</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exceptional</td>
<td>25.4</td>
<td>2.7</td>
<td>10.4</td>
<td>3.1</td>
<td>14.2</td>
<td>30.0</td>
<td>24.0</td>
<td>4.53</td>
</tr>
<tr>
<td>Very high</td>
<td>24.0</td>
<td>2.6</td>
<td>9.9</td>
<td>2.9</td>
<td>13.2</td>
<td>34.1</td>
<td>27.0</td>
<td>5.38</td>
</tr>
<tr>
<td>High quality</td>
<td>22.5</td>
<td>2.5</td>
<td>9.5</td>
<td>2.7</td>
<td>12.3</td>
<td>38.2</td>
<td>30.0</td>
<td>6.23</td>
</tr>
<tr>
<td>Good quality</td>
<td>21.0</td>
<td>2.4</td>
<td>9.1</td>
<td>2.5</td>
<td>11.4</td>
<td>42.2</td>
<td>33.0</td>
<td>7.08</td>
</tr>
<tr>
<td>Fair quality</td>
<td>19.5</td>
<td>2.2</td>
<td>8.7</td>
<td>2.3</td>
<td>10.5</td>
<td>46.3</td>
<td>36.0</td>
<td>7.93</td>
</tr>
<tr>
<td><strong>CORN SILAGE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V. high grain</td>
<td>8.3</td>
<td>3.2</td>
<td>4.1</td>
<td>31.1</td>
<td>1.7</td>
<td>36.0</td>
<td>21.0</td>
<td>1.57</td>
</tr>
<tr>
<td>High grain</td>
<td>8.6</td>
<td>3.1</td>
<td>4.6</td>
<td>27.2</td>
<td>1.6</td>
<td>40.5</td>
<td>24.0</td>
<td>1.91</td>
</tr>
<tr>
<td>Normal</td>
<td>8.8</td>
<td>3.0</td>
<td>5.1</td>
<td>23.2</td>
<td>1.5</td>
<td>45.0</td>
<td>27.0</td>
<td>2.25</td>
</tr>
<tr>
<td>Low grain</td>
<td>9.0</td>
<td>2.8</td>
<td>5.7</td>
<td>19.2</td>
<td>1.4</td>
<td>49.5</td>
<td>30.0</td>
<td>2.59</td>
</tr>
<tr>
<td>V. low grain</td>
<td>9.3</td>
<td>2.7</td>
<td>6.2</td>
<td>15.3</td>
<td>1.3</td>
<td>54.0</td>
<td>33.0</td>
<td>2.93</td>
</tr>
</tbody>
</table>

## Apparent Dry Matter Digestibility of AH and CS

<table>
<thead>
<tr>
<th>Item</th>
<th>AH 24%ADF</th>
<th>AH 27%ADF</th>
<th>CS proc 24%ADF</th>
<th>CS proc 27%ADF</th>
</tr>
</thead>
<tbody>
<tr>
<td>% aNDF</td>
<td>30.0</td>
<td>34.1</td>
<td>40.5</td>
<td>45.0</td>
</tr>
<tr>
<td>% dNDF</td>
<td>15.6</td>
<td>16.0</td>
<td>24.9</td>
<td>27.3</td>
</tr>
<tr>
<td>% NDS</td>
<td>70.0</td>
<td>65.9</td>
<td>59.5</td>
<td>55.0</td>
</tr>
<tr>
<td>% dNDS</td>
<td>68.6</td>
<td>64.6</td>
<td>58.3</td>
<td>53.9</td>
</tr>
<tr>
<td>% True DMD</td>
<td>84.2</td>
<td>80.6</td>
<td>83.2</td>
<td>81.2</td>
</tr>
</tbody>
</table>

*Source: Adapted from Mertens, 2003.*
Alfalfa for Dairy Rations

• Currently using harvesting management to improve alfalfa quality
  – Immature alfalfa has many appealing nutritional properties
    • Low in fiber
      – High digestibility
      – High intake potential
    • Rapid rate of digestion
    • High in crude protein

Source: Adapted from Mertens, 2003.
Milk Yield from Alfalfa Silage and Hay Diets

- Fish meal is beneficial in alfalfa silage diets, but not alfalfa hay diets.
- Bottom line: alfalfa silage nitrogen is not efficiently used by the cow.

Source: Vagnoni and Broderick, 1997
Feed Storage Problems

• However in alfalfa, our primary forage:
Research Challenge/Opportunity . . .

- **Protein utilization:**
  - high-quality forage reduces N use efficiency . . .
  - leading to higher manural N loading back to fields . . .
  - creating an increased risk of N leaving farm via runoff, leaching, or ammonia emissions.
Protein utilization: PPO

Polyphenol oxidase (PPO) and o-diphenols
--A process for preserving protein in ensiled forages
Polyphenol oxidase (PPO) and o-diphenols in red clover

- PPO oxidizes o-diphenols to o-quinones
- Responsible for post harvest browning
- PPO and o-diphenols are abundant in red clover
PPO and o-diphenols prevent post-harvest proteolysis

• Evidence for PPO/o-diphenol role
  – Alfalfa lacks PPO/o-diphenols
  – Proteolytic inhibition O$_2$-dependent
    » Inhibition involves a heat labile factor

• Experimental demonstration
  – Loss-of-function in red clover
  – Gain-of-function in alfalfa
Expression of red clover PPO1 in transgenic alfalfa

In alfalfa, browning is dependent on:
- A PPO transgene
- Exogenous o-diphenol, e.g. caffeic acid

Red Clover vs. Alfalfa Silage

Protein breakdown (% of alfalfa)
Protein Utilization: Tannins

- Tannins have been shown to improve protein utilization and animal performance.
Milk Yield (lbs/day) - Alfalfa and Birdsfoot Trefoil Silages

Hymes-Fecht et al., 2005
Added value of forage with tannin (per ton dry matter)

Alfalfa silage $ 23
Alfalfa hay $ 11
Strategies: reducing post-harvest proteolysis in alfalfa silage

- Some compounds bind with alfalfa protein to decrease rate of post-harvest proteolysis. Transgenic alfalfa will be produced that contain these compounds.
  - Tannins – altered expression of genes for alfalfa tannin biosynthesis
  - Polyphenol oxidase (PPO) – gene isolated from red clover (USDA)
Research Challenge/Opportunity . . .

. . . fiber digestion
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Source: Adapted from Mertens, 2003.
NDF Digestibility of Alfalfa Stems

Source: Jung and Lamb, 2002. Unpub USDA-ARS. St. Paul, MN
Engineering the lignin biosynthetic pathway in alfalfa

Figure 2. Biosynthesis of monolignols in alfalfa
Low Lignin Alfalfa...
Higher Fiber Digestibility

Fiber digestibility of alfalfa stems in transgenic lines at Nampa, ID.

Transgenic plants have been generated that show decreased lignin content and increased fiber digestibility.

Source: McCaslin et. al., 2002
Alfalfa Improvement Opportunities

- **Modify fiber composition**
  - Replace with soluble CHO (pectin, etc.)

- **Improve fiber digestibility**
  - Lower lignin
  - Modify lignin
  - Replace lignin with cellulose
  - Reduce physical limitations
  - Increase rate of digestion
Redesign Alfalfa for Dairy Cattle

Consortium for Alfalfa Improvement

• Noble Foundation
• Forage Genetics International
• Plant Science Research Unit, USDA-ARS
• US Dairy Forage Research Center, USDA-ARS
Grasses for Hay, Silage, Pasture
Grasses for Hay or Silage

• Alpha smooth bromegrass - high digestibility and persistence with alfalfa

• Badger smooth bromegrass - high digestibility
Pasture grasses

• **Albert orchardgrass**
  - high forage and seed yield, good quality, excellent disease resistance.

• **Spring Green festulolium**
  - Superior cold tolerance and winter survival.
  - Over 1 million pounds of seed sold.
  - Will be available in 2005 as certified organic seed.
New Pasture Grasses for 2006/07 *(Listed by experimental names)*

- WR00 & WR04
  Reed canarygrass - improved, more rapid, stand establishment.
New Pasture Grasses for 2006/07 *(Listed by experimental names)*

- WMF1 Meadow fescue - superior forage yield, palatability, acceptance, and intake under management-intensive rotational grazing.
- WCO1 Festulolium - improved cold tolerance and winterhardiness, high palatability and acceptance, excellent disease resistance.
Summary

- Corn silage, alfalfa and perennial grasses main forage fed to dairy cows
- Determining attributes of ideal forage for harvest or grazing needs holistic approach
Summary

- **Ideal attributes – plant modification**
  - Those that increase milk potential (per acre or per ton)
  - Enhance digestible NDF
  - Improve protein utilization
  - Increase sugar content
  - Reduce incidence of bloat
  - Improve agronomic traits (insect, weed, virus, drought and cold tolerance)
  - Increase mineral availability
  - Enhance yield

- Progress in attaining these attributes has been slow using traditional plant breeding, but will accelerate with the use of biotechnology

http://ars.usda.gov/mwa/madison/dfrc
Any questions?