Future of Forage Crops: Alfalfa and Corn Silage

World Ag Expo
February 10, 2005, Tulare, CA

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Future of Forage Crops: Alfalfa and Corn Silage

- Alfalfa and Corn Silage production and acreage
- Advantages of alfalfa for dairy operations
  - Forage needed in diets – cow health & production
  - Crop rotations
  - Environmental
  - The perfect alfalfa plant on dairy farms
- Biotechnology in alfalfa and corn silage
- Future innovations needed to maintain or expand alfalfa acreage
2004 U S Alfalfa Production

- **Hay**
  - 75.4 million tons
  - 21.7 million acre
  - $ 7.0 billion
  - 3rd following corn and soybeans

- **Forage**
  - 83.9 million tons
  - 24.7 million acres
  - ~$8.2 billion
  - 3rd following corn and soybeans
U. S. Alfalfa Hay in 1,000 tons
Leading Alfalfa Hay States, 1,000 acres, 2004

- Top 10 States
  - 63 % of U. S.
  - 59 % of Acre
  - 7 states NC
  - 3 states West
  - 4 Lead Dairy
Leading Alfalfa Hay Production States, 1,000 tons, 2004

- 60 % of U. S.
- 61 % of Acre
- 7 states NC
- 3 states West
- 6 Lead Dairy

Acreage – 21.7 mil
Production – 75 mil
Leading Alfalfa Forage Production States, 1,000 tons, 2004

- Top 10 States
  - 61% of U. S.
  - 61% of Acre
  - 7 states NC
  - 1 state NE
  - 3 states West
  - 5 Lead Dairy

Acreage – 23.3 mil
Production – 84 mil
Alfalfa Hay & Silage Production in Leading Dairy States, 1,000 tons

- % of U. S.
  - 17.8 - 1980
  - 17.7 - 1990
  - 19.9 - 2004

- % of 1980
  - 0 – 1980
  - -30 – 1990
  - -81 – 2004
  - -9 – 2004 HS
Western Alfalfa Acres, 02-04, 1,000

31% of U.S.
Western Alfalfa, 02-04, 1,000 tons

36 % of U. S.
Alfalfa Yield Trends

CA-AZ YIELD TRENDS

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

Arizona
\[ y = 0.0824x - 156.6 \]
\[ R^2 = 0.8935 \]
CA-AZ Production Trends

CA-AZ PRODUCTION TRENDS

- Production (tons x 1000)
- California

Graph showing the production trends from 1910 to 2010, with a significant increase in California's production over time.
Leading Corn Silage Production, 2004

- Top 10 States
  - 62 % of U. S.
  - 64 % of Acre
  - 6 states NC
  - 2 states NE
  - 2 states West
  - 7 Lead Dairy

Bar chart showing top 10 states in corn silage production for 2004.
Leading Corn Silage, 1,000 Acres, 2004

Top 10 States
- 60 % of U. S.
- 66 % of Acre
- 7 states NC
- 2 states NE
- 1 states West
- 6 Lead Dairy
Corn Silage Acreage & Production

![Graph showing corn silage acreage and production from 1973 to 2004. The graph indicates a general increase in production over the years, with some fluctuations. The acreage line shows a relatively flat trend.]
Corn Silage Production in Leading Dairy States, 1,000 tons

6 States
- % of U. S.
  • 26 - 1980
  • 16 - 1990
  • 13 - 2004
- % of 1980
  • 0 – 1980
  • -36 – 1990
  • 85 – 2004
Western Corn Silage, 02-04, 1000 tons

22% of U.S.
Western Corn Silage Acres, 02-04, 1000

14.5% of U.S.
California Dairy Nutritionists
Value Alfalfa Hay

- High energy value
- Its rapid ruminally digested structural fiber which stimulates intake
- Coarse structural fiber that stimulates chewing and salivation which results in rumen buffering and buffering capacity
- High protein
- Relatively high proportion of protein that escapes rumen undegraded

Peter Robinson, University of Davis - CA
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

![Milk Production and Concentrates Fed](chart.png)

Source: ERS-USDA
## Impact of Harvest Management on 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>
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<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>
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<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>
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<tr>
<td>Very 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>
# Alfalfa: Corn Silage

50% forage: 50% concentrate

<table>
<thead>
<tr>
<th>Item</th>
<th>AS¹</th>
<th>2/3 AS</th>
<th>1/3 AS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Milk production</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mature cows, lb/hd/305</td>
<td>21,148</td>
<td>22,422</td>
<td>22,100</td>
</tr>
<tr>
<td>1st calf cows, lb/hd/305</td>
<td>17,911</td>
<td>18,546</td>
<td>18,008</td>
</tr>
<tr>
<td>3.5 % FCM, lb/d</td>
<td>68.2</td>
<td>72.4</td>
<td>70.0</td>
</tr>
<tr>
<td>Milk protein, lb/d</td>
<td>2.09</td>
<td>2.22</td>
<td>2.18</td>
</tr>
</tbody>
</table>

¹ (AS) Alfalfa silage: % DM, 40.2; CP, 19.5; ADF, 33.9; and NDF, 40.1. (CS) corn silage: % DM, 35.5; CP, 7.8; ADF, 25.3; and NDF, 45.3

## High Alfalfa Haylage Diet

<table>
<thead>
<tr>
<th>Item</th>
<th>Control</th>
<th>Protein</th>
<th>Fat</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM intake, lb</td>
<td>48.4(^b)</td>
<td>55.9(^a)</td>
<td>49.5(^b)</td>
</tr>
<tr>
<td>BW gain, lb</td>
<td>50.6</td>
<td>48.4</td>
<td>33.0</td>
</tr>
<tr>
<td>3.5 % FCM, lb</td>
<td>63.4(^c)</td>
<td>75.0(^a)</td>
<td>67.5(^{bc})</td>
</tr>
<tr>
<td>Milk protein, lb</td>
<td>1.89(^b)</td>
<td>2.29(^a)</td>
<td>1.94(^b)</td>
</tr>
</tbody>
</table>

\(^{abc}\) Means in same row with different superscripts differ (p<0.01)

**SOURCE:** Dhiman and Satter, 1993.
Protein Use of Alfalfa

<table>
<thead>
<tr>
<th>Item</th>
<th>silage</th>
<th>hay</th>
<th>silage +FM&lt;sup&gt;1&lt;/sup&gt;</th>
<th>hay+FM&lt;sup&gt;1&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP, % of DM</td>
<td>17.1</td>
<td>15.4</td>
<td>18.6</td>
<td>17.0</td>
</tr>
<tr>
<td>pounds DM per day per cow</td>
<td>49.2&lt;sup&gt;c&lt;/sup&gt;</td>
<td>52.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>51.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>53.4&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>BW change</td>
<td>-0.86&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.99&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.18&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.08&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Milk</td>
<td>77.8&lt;sup&gt;c&lt;/sup&gt;</td>
<td>79.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>82.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>81.4&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Fat</td>
<td>2.65&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.60&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.82&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.69&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Protein</td>
<td>2.29&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2.43&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.51&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.49&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>SNF</td>
<td>6.64&lt;sup&gt;c&lt;/sup&gt;</td>
<td>6.81&lt;sup&gt;b&lt;/sup&gt;</td>
<td>7.05&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.01&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>abc</sup> Means in same row with different superscripts differ (p<0.05)

<sup>1</sup> Diets supplemented with 3 % (DM basis) low-soluble fish meal.

Alfalfa protein is wasted 20+% protein in the field 5% protein exits the rumen
Feed Storage Problems

• However in alfalfa, our primary forage:
Expression of red clover PPO1 in transgenic alfalfa

In alfalfa, browning is dependent on:

- A PPO transgene
- Exogenous o-diphenol, e.g. caffeic acid

Alfalfa can be used as a model to study the inhibition of protein breakdown in silages. 
PPO = Polyphenol Oxidase gene from red clover
Tannins improve protein utilization

- Condensed tannins are polyphenolic compounds that bind to protein in the pH range 3.5 to 7, potentially protecting protein in the silo, rumen, & soil.
- Protein-tannin complexes dissociate at pH <3.5 and >8.5, permitting digestion in the gastrointestinal tract of cattle.
- Livestock given tannin-containing feeds need less protein supplementation and excrete less urea.
- Tannins slow nitrogen release from crop residues and manure.
- Major U.S. feedstuffs, including alfalfa, have inadequate tannin levels to protect protein (< 0.2% DM). Probably about 2% tannin is needed.
Added value of forage with tannin (per ton dry matter)

**Alfalfa silage**  $23

**Alfalfa hay**  $11
Uptake and loss of manure and forage residue N by subsequent annual crops
Strategies for decreasing 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)
NDF Digestibility of Forages

Legume silage/hay

Grass silage/hay

Corn silage

NDF digestibility, % of NDF

Poorest  Fair  Average  Good  Excellent
20  25  30  35  40  45  50  55  60  65  70  75
Engineering the lignin biosynthetic pathway in alfalfa
Genetic engineering for improved forage quality in alfalfa

- **Altered lignin content/composition in alfalfa**
  
  - Low lignin transgenic alfalfa produced based on “knockouts” of enzymes involved in lignin biosynthesis.

<table>
<thead>
<tr>
<th></th>
<th>COMT pkat/mg</th>
<th>CCOMT pkat/mg</th>
<th>Klason Lignin %</th>
<th>S/G ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>6.55</td>
<td>23.77</td>
<td>17.91</td>
<td>.47</td>
</tr>
<tr>
<td>COMT-</td>
<td>1.24</td>
<td>22.26</td>
<td>12.46</td>
<td>.04</td>
</tr>
<tr>
<td>CCOMT-</td>
<td>14.39</td>
<td>0.78</td>
<td>14.58</td>
<td>1.05</td>
</tr>
<tr>
<td>Dual-</td>
<td>0.78</td>
<td>5.59</td>
<td>14.72</td>
<td>.23</td>
</tr>
</tbody>
</table>

*Dixon et. al., 2000*
Lower Stem IVD – 2001 summary

LSD .05 = 1.14

Attributes of Idea Alfalfa Plant

- Better balance of protein and rapidly fermentable carbohydrate
- At optimum aNDF of 40 %
  - 18 % crude protein
  - Less ash
  - 30 % nonfiber carbohydrate (NFC)
- Improve current balance of amino acids with slower rate of degradation in ensiling
- Increase fat to 4 %
- Improve the extent of digestion of fiber
- Removal or suppression of bloat causing properties
The Perfect Alfalfa Plant

- Yield of individual cuttings high enough to reduce number of cuts per year (2 or 3)
- Maturation that is not strongly tied to quality
- Minimal leaf loss during growth and harvest
- Total protein available to the animal, 16-18 %, of that 30-35 % ruminal undegradable
- Cell wall digestibility ~ 80 % (20-30 % rapidly fermented pectin)
- Protein loss during ensiling no greater than 10-15 %
Alfalfa Biotechnology Research

- Over-expression of salt tolerance
- Commercialization of Roundup Ready gene and down regulation of lignin genes to increase digestibility
- Identifying alfalfa genes controlling yield and winter-hardiness
- Identifying genes controlling salt and drought tolerance
- Cloning genes for vegetative storage proteins

SOURCE: Brummer et al., 2004
Alfalfa Biotechnology Research

- Developing molecular markers, studying down regulation of lignin genes, insertion of genes for condensed tannins, identifying and introgression of drought and aluminum tolerance genes
- Developing molecular markers and using markers for identifying genes for yield and winter survival
- Characterize genes controlling post-harvest proteolysis
- Insertion of genes to allow remediation of atrazine and genes to control pectin in cell walls

SOURCE: Brummer et al., 2004
Corn Silage Hybrid Development

- Waxy
- Brown Midrib
- Multi-leaf (Leafy)
- High oil
- Opaque 2 (high lysine)

SOURCE: Hartnell et al., 2005
Corn Silage Hybrid Development

Biotech – Input traits

- Insect protection against European corn borer, corn rootworm and others
- Herbicide-tolerant

Traits under development

- Drought tolerance, cold tolerance
- Insect-stalk snap resistance
- Increased grain to stover ratio
- Slower dry down rate
- Mycotoxin resistance (primarily aflatoxin)

SOURCE: Hartnell et al., 2005
Corn Silage Hybrid Development

- **Biotech – Forage enhanced traits**
  - Reduced or altered lignin to enhance stover
  - Altered carbohydrate – improved microbial efficiency & reduced impact on fiber digestion & rumen pH
  - Increased protein quality & amino acid balance
  - Enhance digestible biomass
  - Plant production of enzymes – digestibility
  - Production of fermentation adjuvants in plant that aid in fermentation in the silo & rumen

*SOURCE: Hartnell et al., 2005*
Alfalfa in Crop Rotations:

- Adds nitrogen via biological fixation
- Improves water infiltration and soil quality
- Reduces soil erosion from wind and water
- Improves yield of subsequent crop
- Reduces N fertilizer demands of subsequent crops
Alfalfa in Crop Rotations:

- Helps protect surface and ground water
- Acts as waste-water recycler
Legumes serve as N buffers

- **Legume**
  - Low N
  - High N

- **Grass**

Graph showing the relationship between N derived from soil and manure (kg N/ha) and fNdfa with three harvests indicated.

Russelle et al., 2002
Alfalfa and grass CRP effectively filter tile drain water.

>40 million acres are tile drained in the Upper Midwest

Randall, Huggins, Russelle et al., 1997
Risk of groundwater nitrate contamination

Alfalfa is well adapted to grow in these areas
Consortium for Alfalfa Improvement

- Share expertise of Noble Foundation, Forage Genetics, Plant Science Unit and USDFRC to redesign alfalfa for dairy cattle
  - November 2000 at Noble Foundation
  - September 2002 at Forage Genetics
  - February 2003 at Noble Foundation
  - January 2004 at Noble Foundation
  - August 2004 at USDFRC
New Alfalfa Products of high value are needed to expand acreage...

- Research efforts underway to:
  - Develop alfalfa with value-added traits
  - Develop new processing technologies
Development of Green Genes

- Fractionation of alfalfa
  - dry - electricity
  - wet - phytase
    - cellulase
    - biopluping
    - biobleaching
    - bioremediation
Biomass Conversion to Ethanol

- Grind
- Pretreatment to Remove Inhibitors
- Enzymatic Breakdown of Polysaccharides
- Sugars
- Electricity & Processing Heat
- Residual Solids
- Fermentation
- Sugars
- Ethanol Recovery
Fiber Board and Filter Mats from Manure
Using Biotech To Keep Alfalfa and Corn Silage Competitive

Solutions to major challenges in agriculture

Manure Management for Water Quality
Costs to Animal Feeding Operations of Applying Manure Nutrients to Land

Nutrient necessities

By Kim Bower-Spence

E xceeding a dairy from 200 to 2,000 cows is a lot easier said than done, stated Phil Kulp, Kulp Family Dairy LLC, in rural South Dakota. The 440-cow dairy has grown from 70 to more than 400 milking cows in the past 10 years. The family’s milk production has risen from 4,000 to 10,000 milk cows. The family is added another herd of 420 cows in 2007. Their dairy management plan includes an emphasis on water quality and sustainability. The Kulp family owns a Water Quality Management Plan (WQMP) in place to conserve nutrient inputs.

The Kulp family includes Phil and his wife, Becky; his brother, Rob Kulp; and about 30 employees.

Phil Kulp, Norby Kulp, and the two sons who work with them have been able to expand their farm operations even further with the help of the WQMP. The plan addresses nutrient management through crop residue, on-farm storage, and nutrient management plans.

The WQMP is designed to help dairies meet the new nutrient management standards set by the states. The plan ensures compliance with state regulations by setting targets for nutrient reductions and monitoring progress.

The plan includes a nutrient management plan (NMP) that details how nutrients will be managed on the farm. The NMP includes information on the types and amounts of nutrients applied, the methods of application, and the expected outcomes.

The WQMP also includes a nutrient database that tracks the amount of nutrients applied and removed from the farm. This information helps to ensure compliance with state regulations and provides a record of nutrient management practices.

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