U S DAIRY FORAGE RESEARCH CENTER PROGRAMS – THEIR IMPORTANCE TO CALIFORNIA

Neal P. Martin

ABSTRACT

The U S Dairy Forage Research Center (USDFRC), USDA-ARS, is a federally funded facility engaged in forage research related to the US dairy industry; an industry generating annually $21 billion in milk sales. The Center has a laboratory-greenhouse complex located on the University of Wisconsin – Madison campus and a 1700-acre farm housing 320 milking cows located at Prairie du Sac, WI. The mission of the USDFRC is to develop knowledge needed to enhance sustainable, competitive dairy forage systems that are in harmony with the environment, promote animal health, and ensure a safe, economical, healthy food supply for US citizens. Multi-disciplinary research is conducted by 12 scientists at the Madison facility and three scientists located in affiliated cluster sites (two in St Paul, MN and one in Ithaca, NY) (1 soil scientist, 3 plant scientists, 2 agricultural engineers, 2 plant chemists/biochemists, 2 rumen microbiologists, and 4 dairy scientists). Current research thrusts are: 1) integration of cropping systems and nutrient management on dairy farms; 2) identification of factors that affect the indigestibility and digestion kinetics of cell walls and limit forage utilization; 3) utilization of site-specific estimates of nutritive value feeds to improve the sustainability of dairy farms; 4) improving efficiency of nitrogen utilization in dairy products; and 5) evaluation of value-added products from perennial legumes and manure.

Key Words: alfalfa, maceration, digestibility, neutral detergent fiber, and dairy cows

INTRODUCTION

The U. S. Dairy Forage Research Center (USDFRC), USDA-ARS, is a federal facility engaged in forage research related to the U. S. dairy industry; an industry generating annually $21 billion in milk sales. Most, but not all, of the research deals with harvested forage crops used as the primary ingredient in diets of dairy cows; annually estimated to be 100 million tons valued at $8 billion.

The mission of the USDFRC is to develop and disseminate knowledge and tools needed to enhance sustainable and competitive dairy forage systems that are in harmony with the environment, promote animal health, and ensure a safe and healthy food supply for US citizens.

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The USDFRC consists of: 1) a laboratory-greenhouse complex on the University of Wisconsin campus in Madison, WI, and 2) a 1700-acre farm located at Prairie du Sac, WI. The farm has 320 milking cows and a like number of dry cows and replacement animals. Multi-disciplinary research is conducted by 12 scientists at the Madison facility and three scientists located in affiliated cluster sites (two in St Paul, MN and one in Ithaca, NY) (1 soil scientist, 3 plant scientists, 2 agricultural engineers, 2 plant chemists/biochemists, 2 rumen microbiologists, and 4 dairy scientists).

RESEARCH APPLICATIONS – CALIFORNIA

Research efforts at the USDFRC have general application to most of the US dairy industry. Dairy production is growing rapidly in western US, lead by California producers. Western dairies rely heavily on purchased forage crops, especially alfalfa hay, and grains. I will focus on the Center’s effort to improve utilization of alfalfa via maceration, a research covering the 20-year history of the Center effort for 15 years to illustrate our interdisciplinary research approach.

Valued-added Processing Research in Alfalfa

Extensive research on the wet fractionation of alfalfa was carried out at the University of Wisconsin in the 1970’s, Koegel et al., 1992. The USDFRC has continued to investigate ways of improving processing of wet alfalfa in stationary processing facilities as well as limited field processing. Wet fractionation consists of expressing juice from freshly cut forage, which has been severely broken or macerated. A protein concentrate is usually made from the juice by heating it to 80 C and straining the coagulated protein from the remaining liquid. The pressed fibrous part of the forage is fed to ruminants usually after ensiling or dehydrating or could be used to generate high value products from fermentation.

The wet-fractionation process has two advantages for agriculture: (1) forage crops can be harvested almost independent of weather, since moisture is removed by mechanical expression rather than by field drying, and (2) a versatile protein concentrate is obtained which can be fed to non-ruminants, including humans, as well as being used to supplement rations of ruminants such as high producing dairy cows.

Part of the research carried out at the University of Wisconsin involved the evaluation of the pressed fibrous fraction of alfalfa as ruminant feed. Scientists learned that when some of the protein and the soluble carbohydrates had been removed in the juice the remaining fibrous cell wall constituents fed as silage or hay resulted in milk production equal to unprocessed alfalfa. Maceration of fiber increased the digestibility of the fiber and it was determined that when the macerated, pressed fiber was spread in the sun to dry for hay, the drying rate increased significantly relative to conventionally conditioned alfalfa. Thus, USDFRC scientists and University of Wisconsin faculty and graduate students initiated research to develop a field maceration concept and machinery to increase drying rates and digestibility of alfalfa.
Field Maceration of Alfalfa

Maceration is an intensive forage-conditioning process that can increase field-drying rates by as much as 300%, Hintz et al. 1999, Figure 1. Because the degree of conditioning associated with maceration results in the formation of many small fragments that can fall out of the windrow, macerated forage is pressed into a continuous cohesive strip called a *mat*. For this reason, macerated forage is sometimes referred to as *mat-processed* forage. By equalizing the drying rates of leaves and stems and pressing them together into a mat, the loss of leaves due to overdrying and shattering is virtually eliminated, thus reducing losses of quality and dry matter (DM) during harvest, Koegel et al. 1992.

![Figure 1. Drying rates for alfalfa swaths with and without maceration (from Shinnors et al., 1987).](image)

In addition to hastening drying rates, the radical change in forage physical structure has shown promise for improving other aspects of forage harvesting, storage, and utilization. Maceration shreds the forage and reduces its rigidity, improving bulk density, silage compaction, and ensiling characteristics. During ensiling it was shown that macerated silage could be packed to a greater density than unmacerated silage: enough to increase bunker silo capacity by 20%. Another evaluation with alfalfa hay showed densities of macerated hay bales increased from 20 to 50%. These gains will reduce shipping costs as well as increasing load capacities. Macerated silage reached final densities faster than control silage, and this may improve silage quality by providing faster oxygen exclusion and allowing anaerobic fermentation to begin sooner.
In two studies, Muck (Hintz et al., 1999) observed significant improvements in silage quality as a result of maceration, Table 1. In both trials, macerated alfalfa had higher lactic acid bacteria (LAB) populations than the control, and reached final pH in half the time of unmacerated alfalfa. Faster fermentation and higher concentrations of the end products indicated that the macerated silage would be more stable and less prone to spoilage than the conventionally harvested alfalfa. However, because addition of LAB inoculants did not improve macerated silage, which had higher numbers of bacteria present, the authors suggest higher inoculum numbers may be needed to dominate the microbial population.

Table 1. Ensiling characteristics of control and mat-processed macerated alfalfa

<table>
<thead>
<tr>
<th>Item</th>
<th>Experiment 1</th>
<th>Experiment 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inoculated</td>
<td>Control</td>
</tr>
<tr>
<td>Dry Matter, %</td>
<td>56.2</td>
<td>58.1</td>
</tr>
<tr>
<td>LAB, log(cfu/g)</td>
<td>4.82</td>
<td>2.38</td>
</tr>
<tr>
<td>pH</td>
<td>4.68</td>
<td>5.66</td>
</tr>
<tr>
<td>TKN, % DM</td>
<td>2.82</td>
<td>2.81</td>
</tr>
<tr>
<td>NPN, % TKN</td>
<td>40.5</td>
<td>50.83</td>
</tr>
<tr>
<td>Lactic Acid, % DM</td>
<td>6.71</td>
<td>1.13</td>
</tr>
</tbody>
</table>

aData of Muck et al. (1989).
bLAB = lactic acid bacteria counts before ensiling.
cTKN = total Kjeldahl nitrogen after ensiling.
dNPN = nonprotein nitrogen after ensiling.
e,f Within a row and experiment, means lacking a common superscript letter differ (P < .05).

Macerating forage also increases the surface area available for microbial attachment in the rumen, thereby increasing forage digestibility and animal performance. Feeding trials with sheep have shown increases in dry matter intake of 5 to 31% and increases in DM digestibility of from 14 to 16 percentages units, Hintz et al., 1999. In addition, lactation studies have demonstrated increase in milk production and body weight gain for lactating Holstein cows, Table 2; however, there is a consistent decrease in milk fat percentage when dairy cattle are fed macerated forage. In situ studies have shown that maceration decreases lag time associated with neutral detergent fiber (NDF) digestion, Hintz et al., 1999. In situ digestibility studies have shown that maceration increases the size of the instantly soluble DM pool and decreases lag time associated with NDF digestion, but it does not alter the rate or extent of DM and NDF digestion.

Most of the Center lactation studies have been done with macerated haylage. These studies show we do not fully understand how to feed macerated alfalfa silage. The fat depression in cows and body weight gain and a lowering of the acetate-to-propionate ratio during fermentation of macerated vs. conventional material shows high quality macerated haylage behaves more like concentrate than fibrous forage. We expect that macerated alfalfa hay may show larger improvements in milk production when compared to conventionally conditioned alfalfa hay (personal communication with Mertens and Broderick). Mertens has proposed the physical form of the fiber is as important as the
nutritional value of alfalfa hay. In addition, we expect more protein to escape rumen degradation from macerated alfalfa hay than macerated alfalfa haylage.

Table 2. Intake and performance of lactating dairy cattle fed control and mat-processed macerated alfalfa.

<table>
<thead>
<tr>
<th>Item</th>
<th>Experiment 1a</th>
<th></th>
<th>Experiment 2b</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Macerated</td>
<td>Control</td>
<td>Macerated</td>
<td>Control</td>
</tr>
<tr>
<td>Dry matter intake, kg/d</td>
<td>19.6</td>
<td>19.9</td>
<td>23.3</td>
<td>23.4</td>
</tr>
<tr>
<td>Milk, kg/d</td>
<td>24.2</td>
<td>24.5</td>
<td>37.1&lt;sup&gt;c&lt;/sup&gt;</td>
<td>34.5&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>Fat, %</td>
<td>3.53&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.71&lt;sup&gt;d&lt;/sup&gt;</td>
<td>3.37&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.66&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>4%FCM, kg/d</td>
<td>22.4</td>
<td>23.5</td>
<td>33.5</td>
<td>32.6</td>
</tr>
<tr>
<td>Body Weight change, kg/d</td>
<td>.44&lt;sup&gt;c&lt;/sup&gt;</td>
<td>.08&lt;sup&gt;d&lt;/sup&gt;</td>
<td>.09</td>
<td>-.06</td>
</tr>
<tr>
<td>Nel from forage, Mcal/kg</td>
<td>1.22</td>
<td>1.09</td>
<td>NR&lt;sup&gt;f&lt;/sup&gt;</td>
<td>NR</td>
</tr>
</tbody>
</table>

<sup>a</sup>Data of Mertens et al. (1990); diets consisted of 65% alfalfa and 35% concentrate.

<sup>b</sup>Data of Mertens and Koegel (1996); averaged over hay and silage preservation methods; diets balanced to contain 30% NDF and 16% CP.

<sup>c</sup>FCM = fat corrected milk.

<sup>d</sup>Within a row and experiment, means lacking a common superscript letter differ (P < .05).

<sup>e</sup>NR = not reported.

California research, Orloff et al. 1997, has shown under California conditions in the Imperial Valley, that macerated alfalfa can dry to hay fast enough to allow for additional cuttings or an increase in yield under irrigation of 10%.

Because maceration is an energy-intensive operation, equipment manufacturers interested in commercializing the technology may wish to decrease the conditioning intensity as a means of reducing costs. USDRFC scientists developed a conductivity test to measure maceration intensity. Maceration intensity has also been shown to be correlated with DM digestion. Different manufacturers will also likely develop machines, which use different intensities of maceration. Therefore USDFRC scientists are continuing to develop methods to determine maceration intensity and its relationship to improved utilization.

We expect to continue to study lactation performance of macerated alfalfa hay and haylage. In addition, Koegel and Mertens are cooperating with Dan Putnam to determine field drying rate advantages as influenced by maceration degree in two locations of California. We especially expect to show maceration can increase the digestibility of 3rd cutting alfalfa, which often has excessive fiber to reach dairy-grade hay.

USDFRC scientists have developed the maceration process, proto-type maceration equipment, while investigating changes in forage quality in storage, in the cow, and dairy cow performance. In addition, scientists are investigating methods of reducing nitrogen in dairy manure by improving protein utilization. The Center continues to cooperate with other scientists and farmers to improve utilization of forage with dairy cows. Added focus and interest from California producers will assist research and development to make improvements faster.
**RECENT RESEARCH ACCOMPLISHMENTS**

- Proper roasting of soybeans for dairy cow diets generates $20 to $40 million annually in added value.
  
  A field macerator has been developed which could potentially reduce drying time of alfalfa hay by 2 days, increase dry matter digestibility, and improve protein utilization.
  
  Reducing P in dairy cattle diets (20 % less) does not affect milk production, but reduces P levels in manure by 25-30%.

- We have developed a dairy forage systems model (DAFOSYM) to strategically evaluate forage crop growth, harvest, storage, and feeding while measuring milk and manure production (nutrient loads).
  
  Increased persistence, longevity, yields, and disease resistance of red clover varieties annually saves $140/acre/year.

- Improved germplasms of birdsfoot trefoil and kura clover have been developed.
  
  Lignin chemistry and phenolic-carbohydrate cross-linking, which impact cell wall digestibility, have been characterized in forages.
  
  Annual leaching of nitrate is negligible in intensively grazed grass pasture fertilized with 50 lbs N per acre.
  
  Alfalfa germplasms that ineffectively fix N$_2$ absorb 30% more nitrates than a standard alfalfa variety from nitrate-contaminated soil.

**CURRENT RESEARCH THURSTS**

**Integration of cropping systems and nutrient management on dairy farms.**

Cropping and pasture systems are being developed to combine optimal nutrient utilization in soil, manure, and feed for profitable dairy production with minimal environmental impacts. We are studying forage legumes that are productive, pest resistant, persistent, non-estrogenic, high quality and compatible in mixtures with grass for silage, hay, or grazing.

- **Identification of factors that affect the indigestibility and digestion kinetics of cell walls and limit forage utilization.** Plants with genetically modified lignification will be characterized to develop novel approaches for improving forage utilization.
  
  The extrinsic role of rumen environment upon forage digestion, fermentation efficiency, and the formation of indigestible residues will be studied.

- **Utilization of site-specific estimates of nutritive value of feeds to improve the sustainability of dairy farms.** Critical parameters that affect the nutritive value of feeds will be identified, including feed characteristics, crop genetics, growing conditions, harvesting, storage, processing, ration formulation, and animal type. A computer expert system will be designed to integrate feed information and provide farm-specific estimates of nutritive value.

- **Improving efficiency of nitrogen utilization in dairy products.** Methods are being developed to reduce protein breakdown to nonprotein N in silage, provide rapid and accurate means of quantifying ruminal protein degradation, and employ practical strategies to optimize ruminal balance between protein degradation and synthesis.
Evaluation of value-added products from perennial legumes and manure.

Systems of fractionation and subsequent processing of perennial legume herbage to extract industrially valuable substances from transgenic plants will be developed. Alternative processing pathways are evaluated for the production of various agricultural and industrial feedstocks, as well as fuels, construction materials, and consumer goods.

TECHNOLOGY TRANSFER

USDFRC scientists continue to work cooperatively with research and extension faculty in land grant Universities, industry research and development specialists, and farmers to improve utilization of forage crops by dairy cattle. Scientists participate in Symposia such as this to learn more about research and education needs. Our research summaries are published annually, available via mail, or are also available on the Center web site: www.dfrc.ars.usda.gov or www.dfrc.wisc.edu. Visit the web site or stop-by and visit our campus laboratory and/or research farm.

SELECTED REFERENCES:

