Novel Forages and Novel Research

Neal Martin, Director
U.S. Dairy Forage Research Center
USDA-Agricultural Research Service

December 8, 2009

Midwest Dairy Expo, St. Cloud, MN

Greener Horizons for Crops, Cows, and Communities

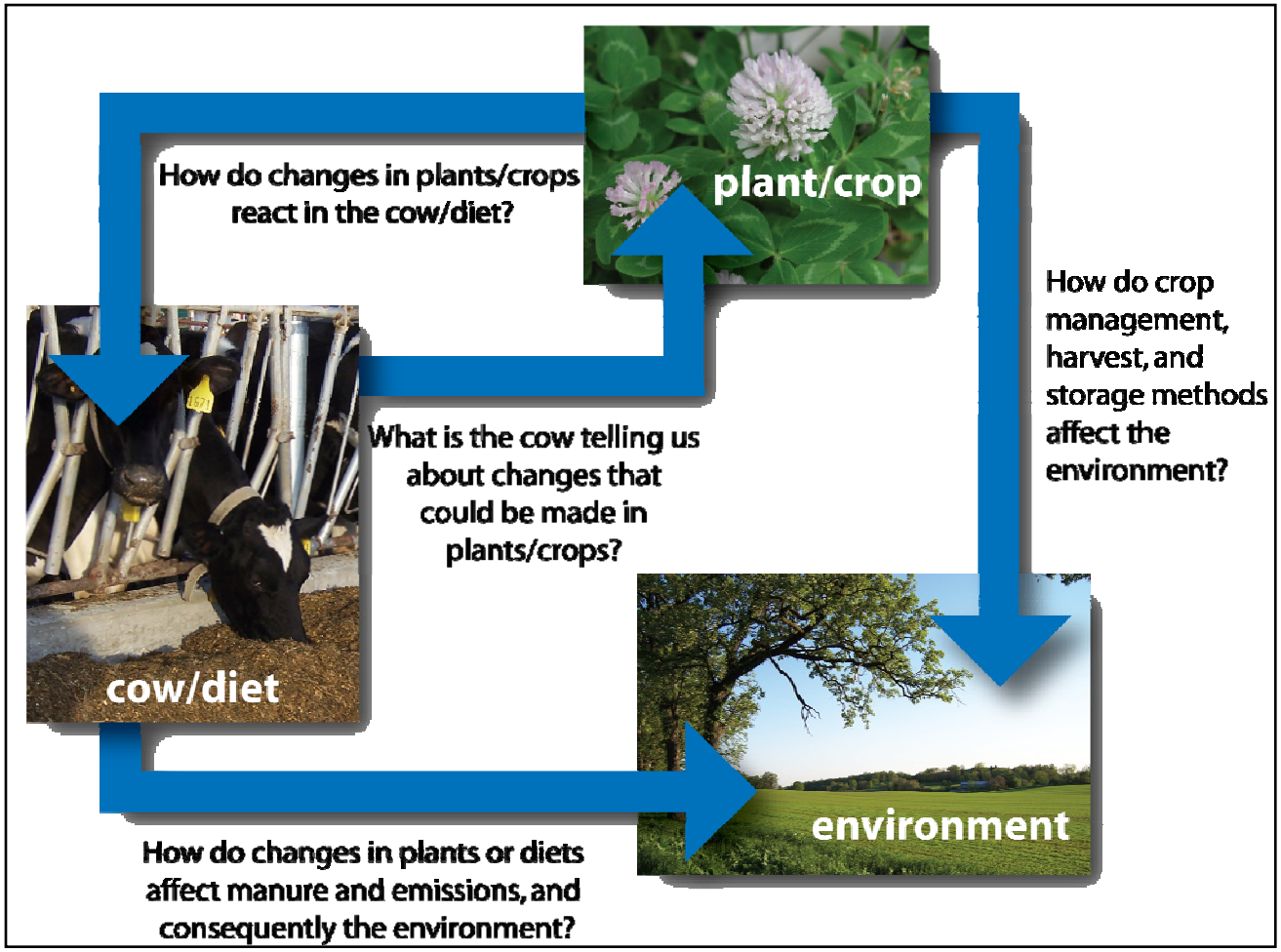
This talk will report. . .

- U. S. Dairy Forage Research Center
- Production of perennial forage crops
- Redesigning alfalfa for livestock diets – CAI
- Potential of alfalfa as cellulosic ethanol feedstock
- Forage legume breeding - USDFRC
- Forage grass breeding - USDFRC

Unique Mission

- **One of about 100 units in the USDA-ARS.**
- **Only ARS unit with the mission of improving forage use by dairy cattle.**
- **Mission:** *To develop knowledge and tools to enhance sustainable and competitive dairy forage systems that protect the environment, promote animal health, and ensure a safe, healthy food supply.*

Unique multidisciplinary Approach



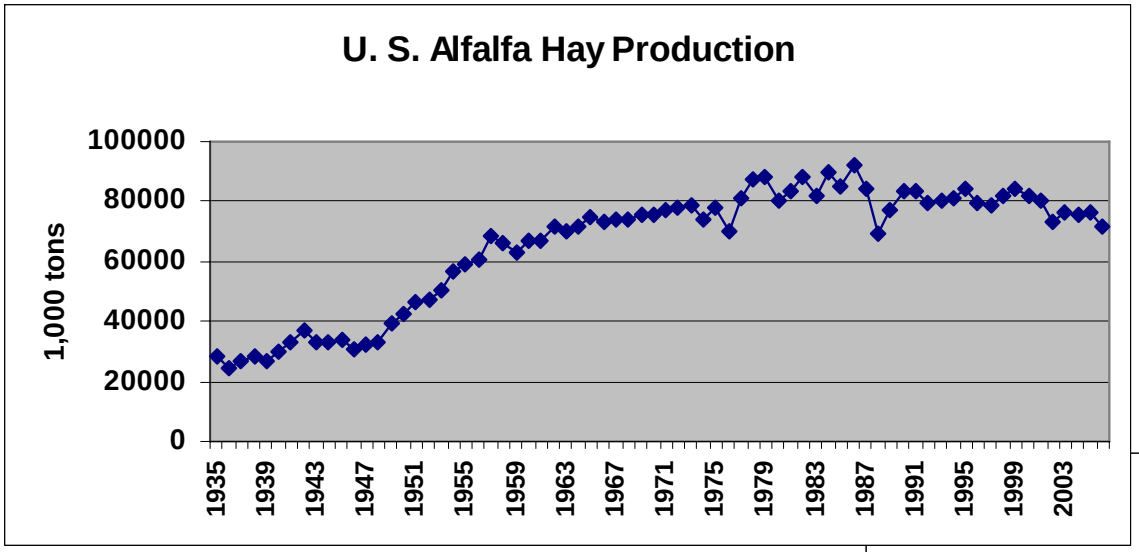
3 Locations

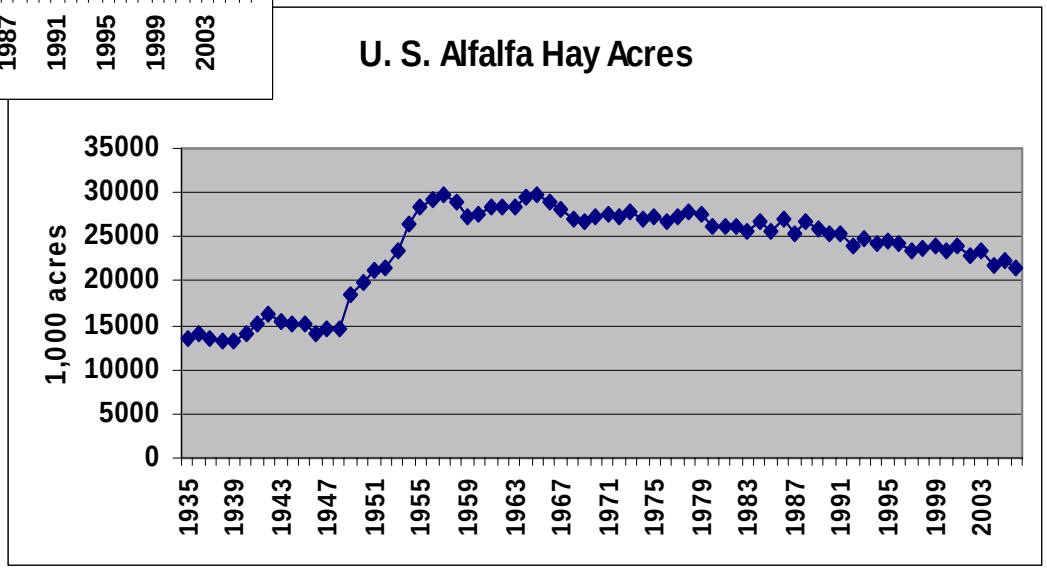
Prairie du Sac, WI – research farm; 2,006 acres, 325 cows, since 1980.

Madison, WI – main office and laboratories for 12 scientists, since 1981.

Marshfield, WI – Institute for Environmentally Integrated Dairy Management – laboratory (south), since 2009; and research farm (north), soon to be completed.

Alfalfa Hay Trends . . .



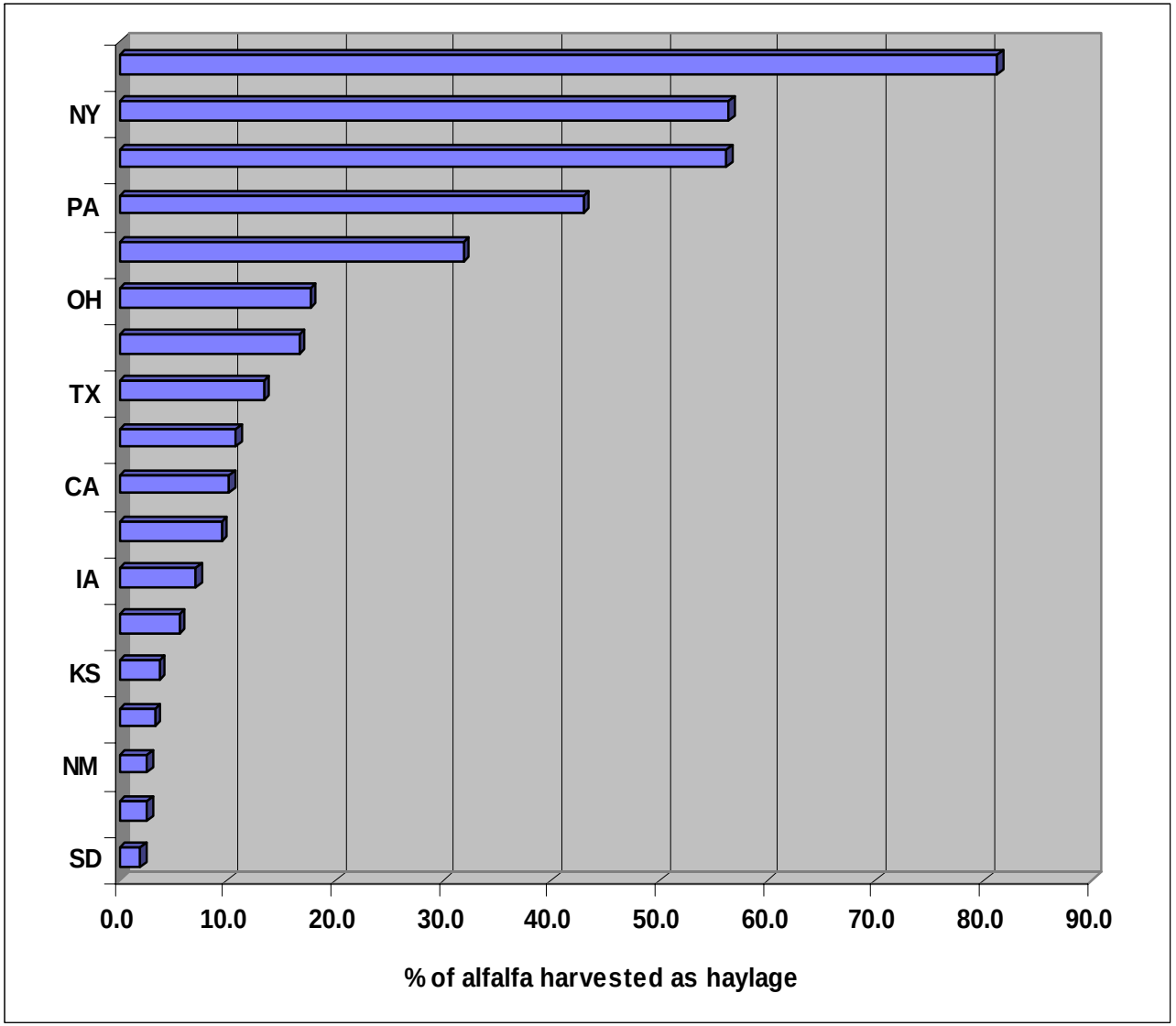


Forage Trends . . .

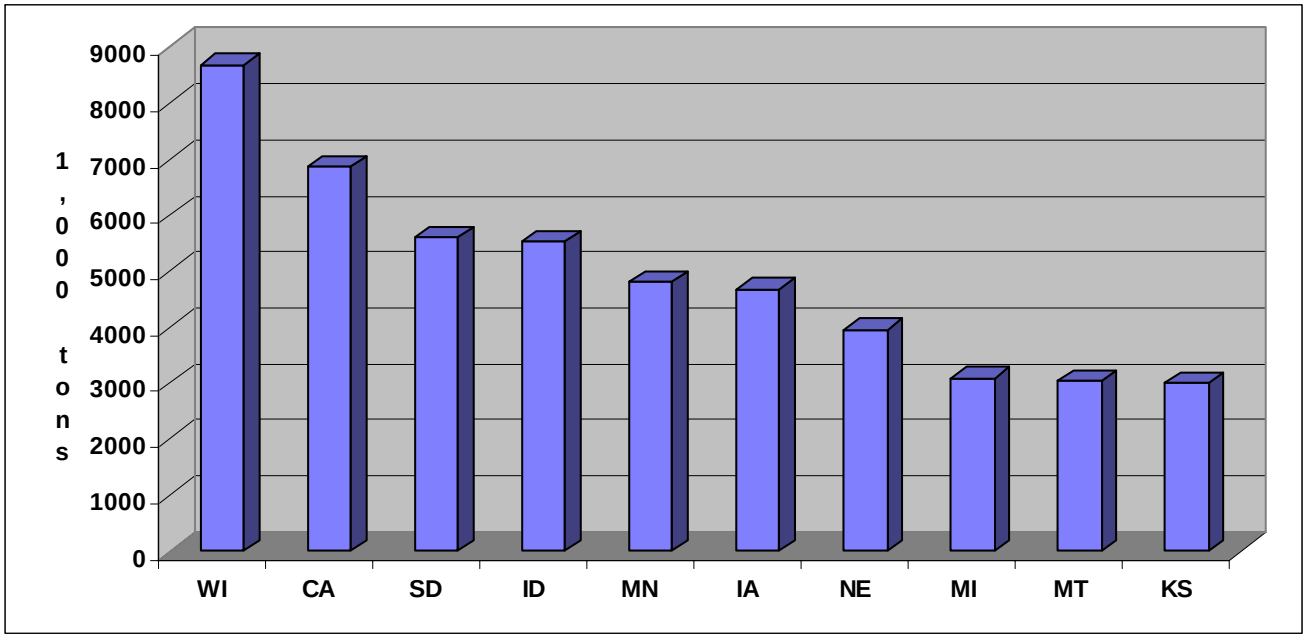
2008 U.S. Alfalfa Production

- **Hay**
  - **69.6 million tons**
  - **21.0 million acre**
  - **$10.8 billion**
  - **4th following corn, soybeans & wheat**
- **Forage**
  - **80.7 million tons**
  - **23.1 million acres**
  - **~$13.9 billion**

Trends . . . Alfalfa Silage



Leading Alfalfa Forage States, 1,000 tons, 2008

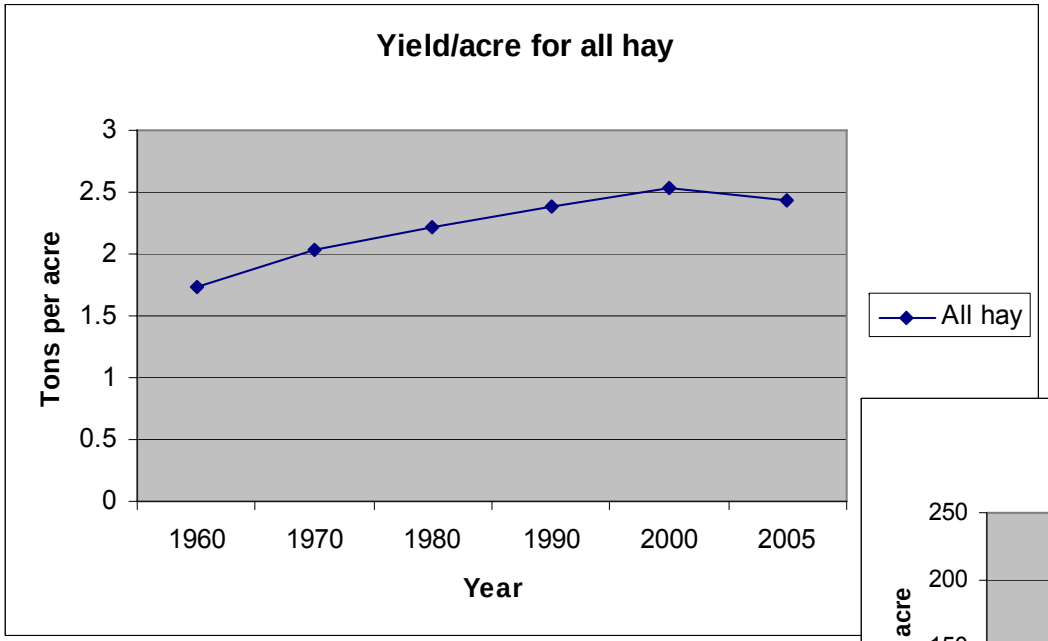


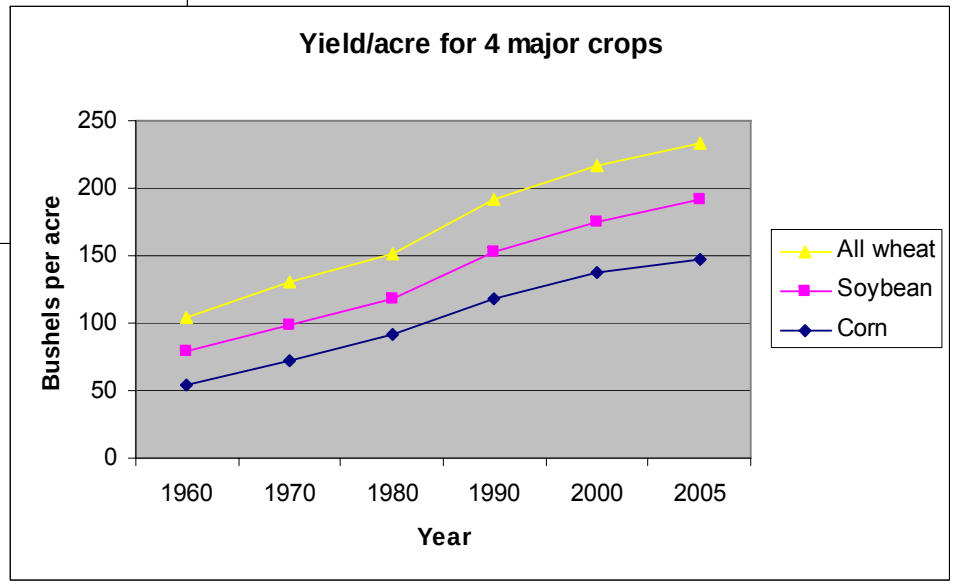
Top 10 States

- 61 % of U. S. tons
- 60 % of acres
- 7 states NC
- 3 states West
- 5 Lead Dairy

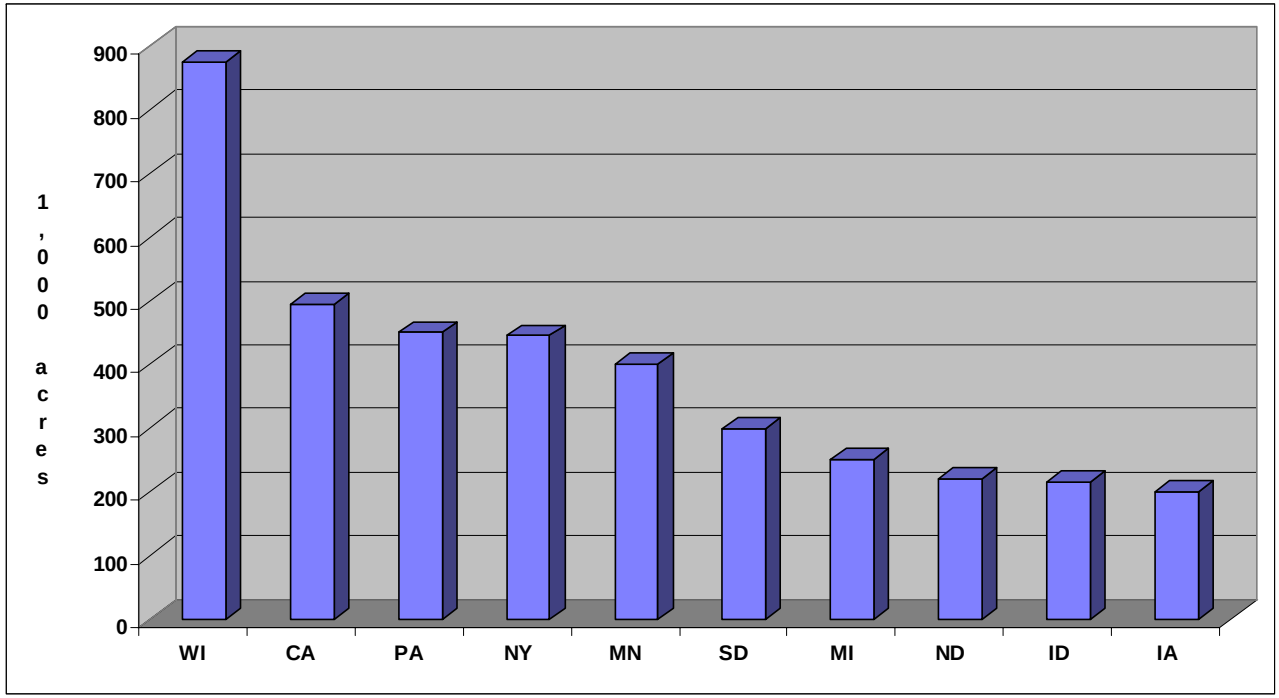
Forage trends . . .

Least aggressive in yield increases





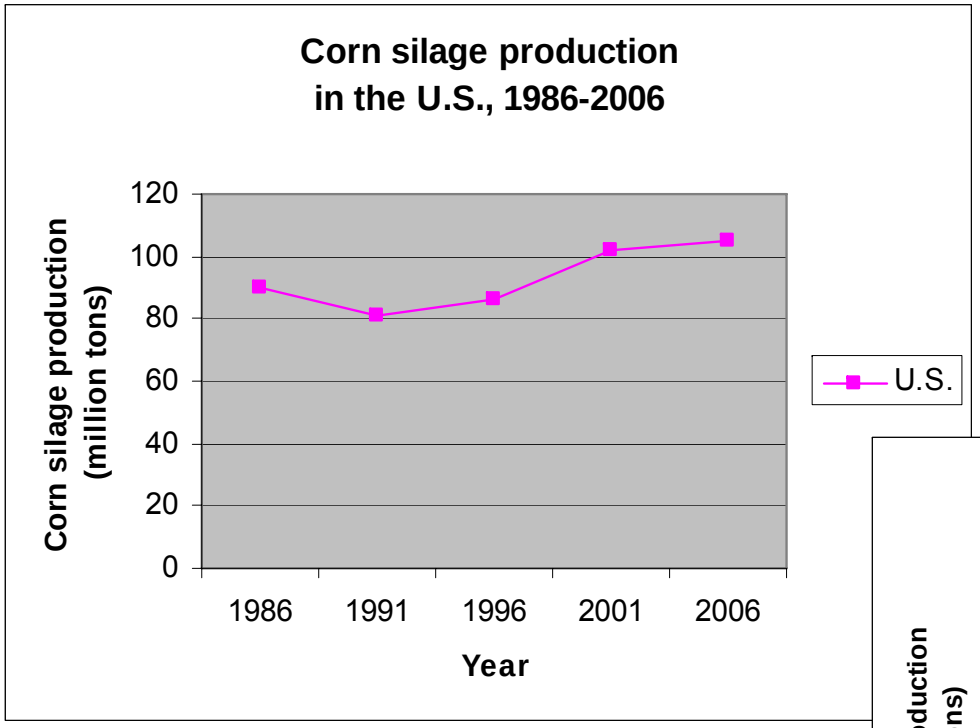
Leading States in Corn Silage production 1,000 tons, 2008

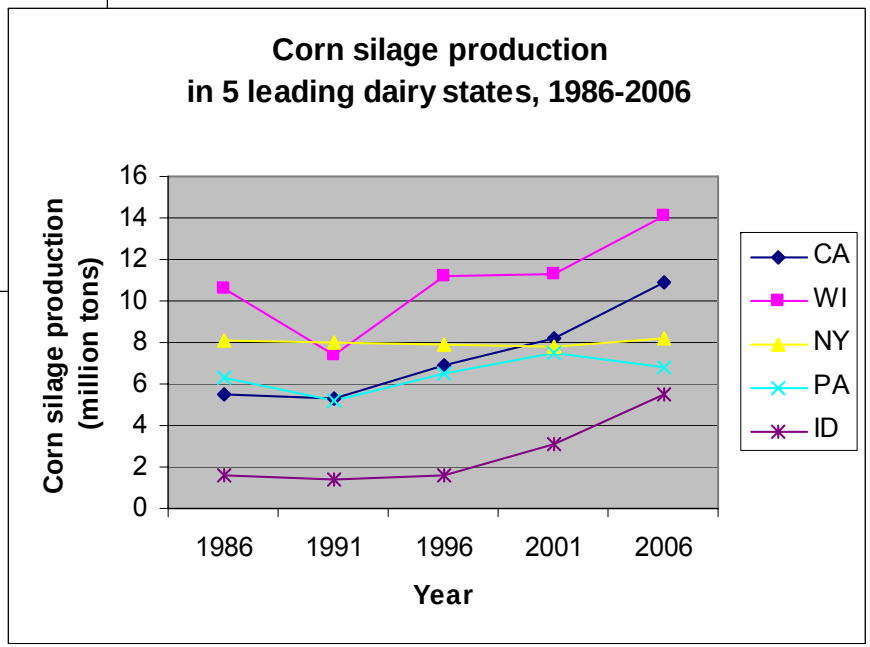


Top 10 States

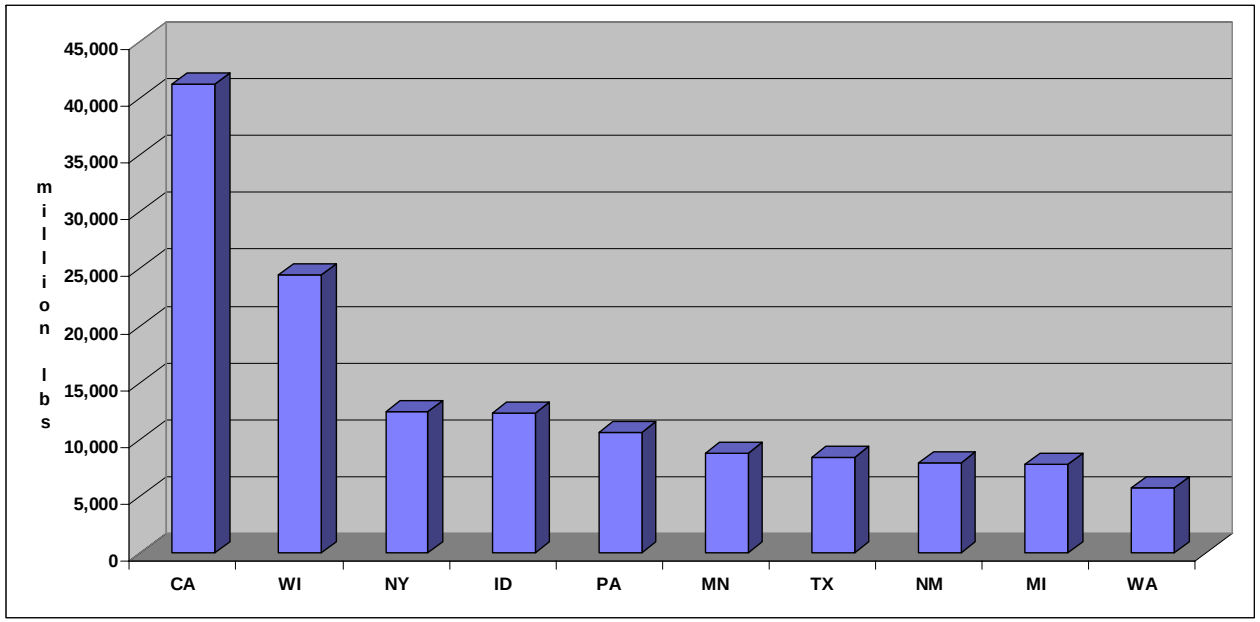
- 64 % of U. S. acres
- 64 % of tonnage
- 6 NC
- 2 West
- 2 states NE
- 7 Lead Dairy

Forage trends . . .





Leading Dairy States, million pounds of milk, 2008



Top 10 States

- 73 % of U. S. prod
- 71 % of cows
- 5 west
- 3 NC
- 2 NE

Forage Trends . . .

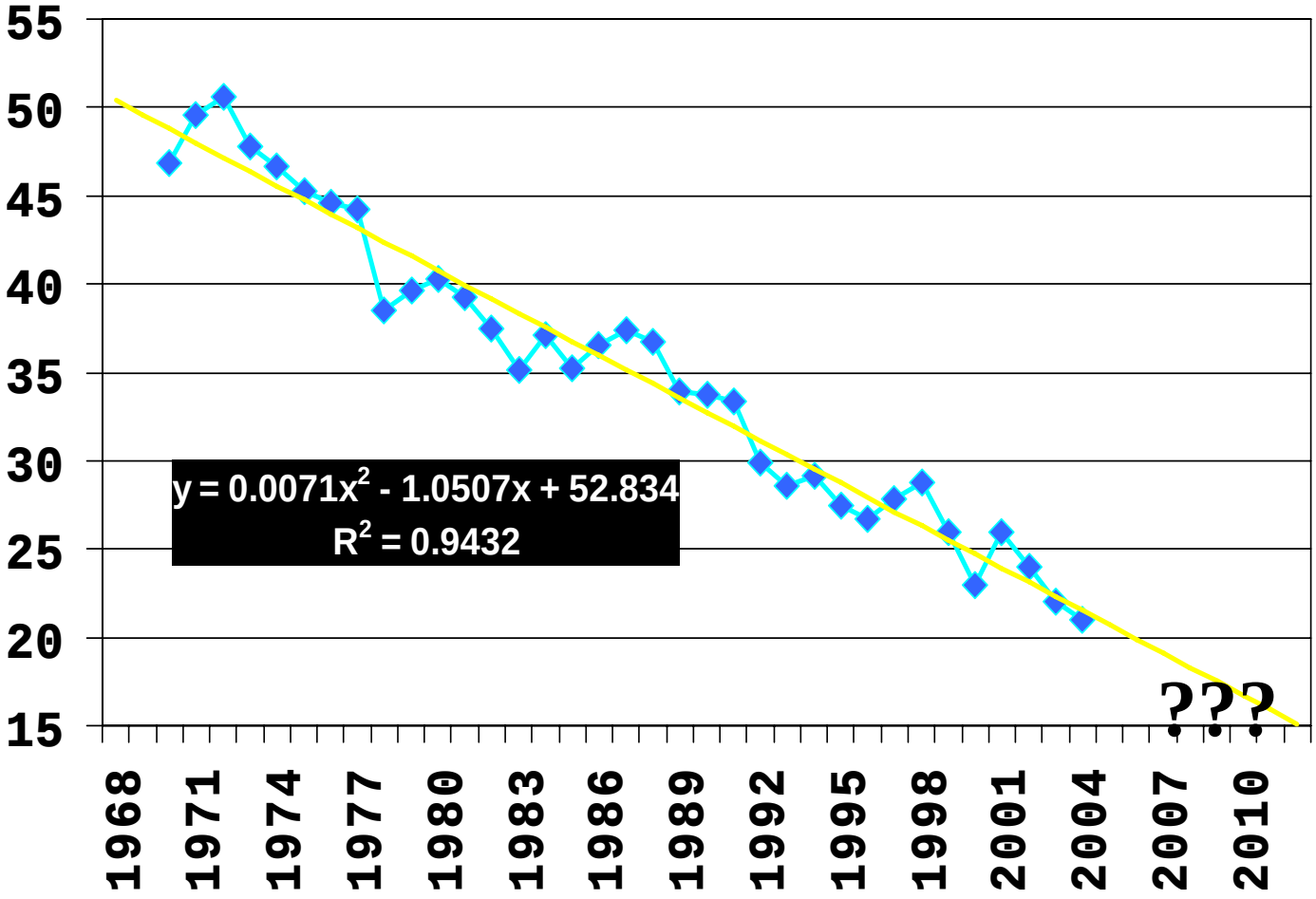
	million acres, 2007
Cropland harvested	406,424,909
Cropland pastured	35,771,154
Woodland pastured	370,297
Permanent pasture & rangeland	408,832,116

Between 2007 & 2002 acreage harvested for hay and haylage declined by 4 %

Acreage grazed declined by 28 %

2007 U.S. Census of Agriculture

CA Hay Production Per Dairy Cow (lbs alfalfa/cow/day)



Source: Dan Putnam, 2005 Consortium for Alfalfa Improvement

Trends . . .

- **Hay acreage remains unchanged**

- **Dairy cattle feeding – declining amounts**

Barriers to increasing alfalfa usage . . .

- **Increasing use of corn silage**
- **Forage quality of alfalfa haylage, alfalfa hay and corn silage**
  - **Low fiber**
  - **Excessive crude protein resulting in excessive ruminal degradable protein**
  - **Less consistent quality of hay and haylage**
- **Relative to corn, alfalfa yields have lagged**

We don’t want to see reduced perennial forage crops in rotation because . . .

- **Perennial forage crops are good for environment**
- **Good for cow health**

Forage & Livestock Industries Need

Perennial Legumes and Grasses

- **Increased yield and persistence**
  - **Improved forage digestibility of legumes**
  - **Enhanced protein utilization of alfalfa**

Redesigning Alfalfa

Two goals:

1. **Reduce the amount of protein degraded in silage and in the rumen.**
2. **Increase the availability of carbohydrates in the plant cells.**

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**

Consortium *for* Alfalfa Improvement

Research Challenge/ Opportunity

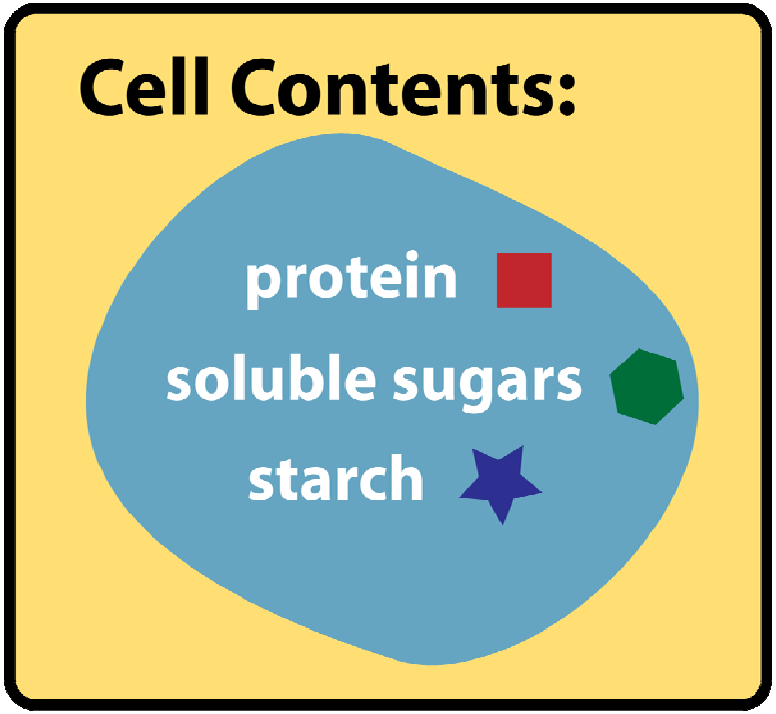
. . . fiber digestion

Redesigning alfalfa . . .

First: A lesson on cell walls

Cell contents are completely digestible.

But sometimes intact cell walls keep them from being available to the cow.



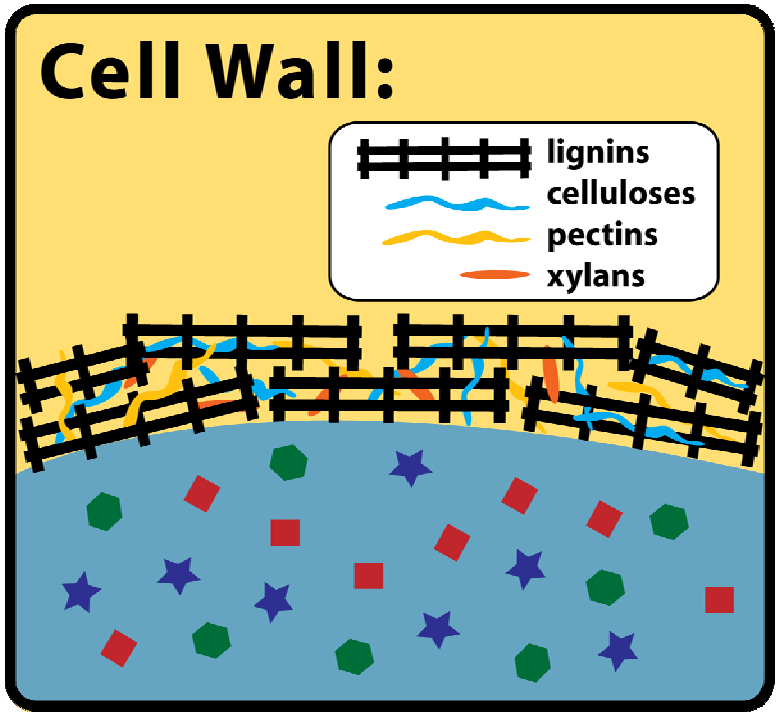
Redesigning Alfalfa

Cell walls contain carbohydrates such as:

- **celluloses**
- **pectins**
- **xylans**

that are partially available to the cow.

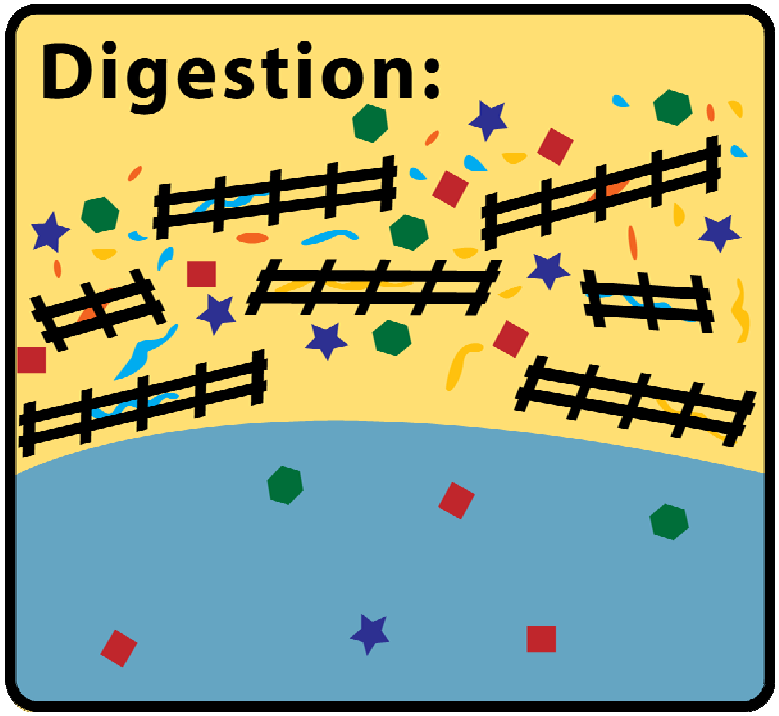
Cows cannot digest lignin.

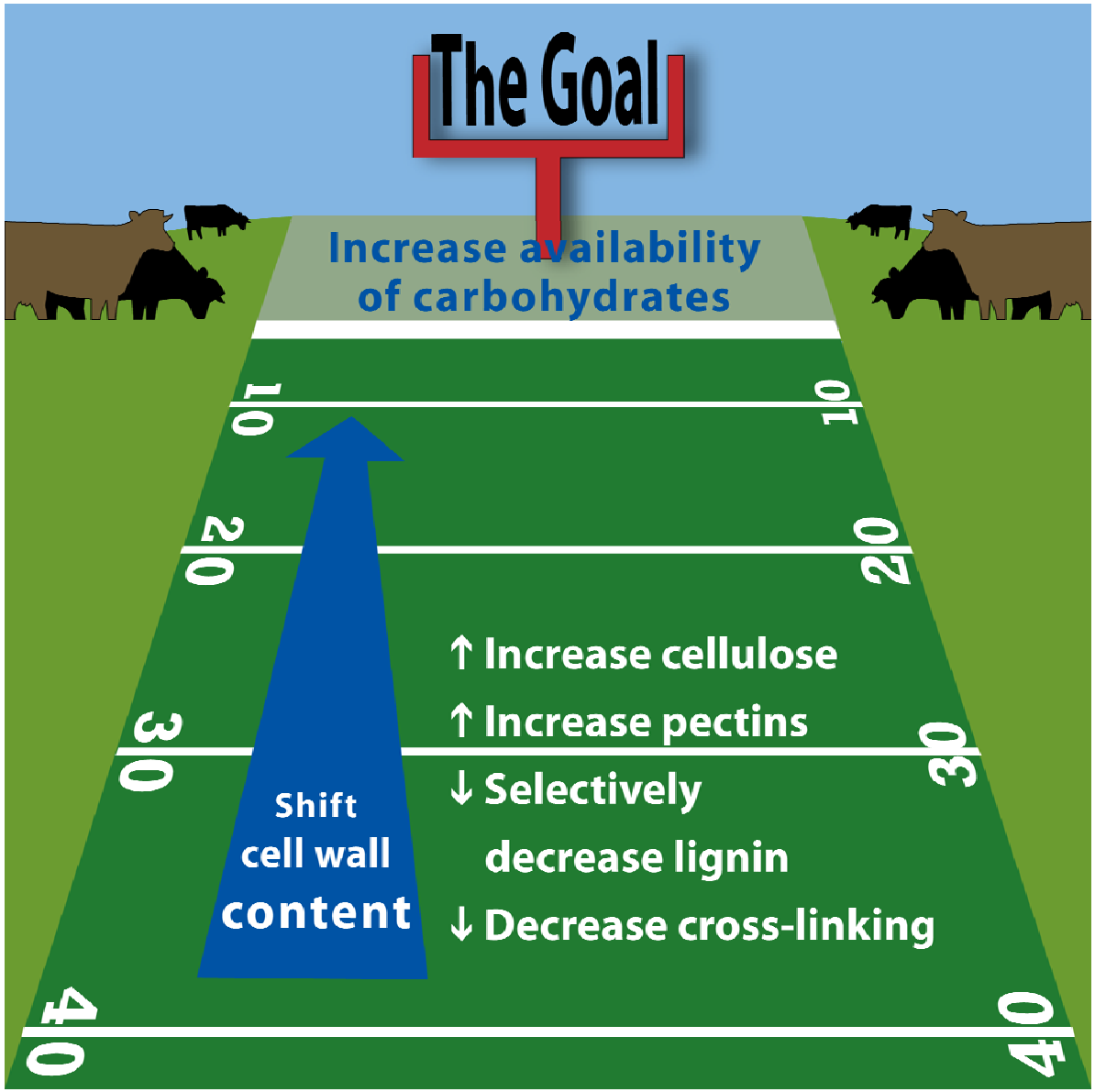


Redesigning Alfalfa

During digestion, lignin remains intact. But enzymes and microbes eat away at the other carbohydrates which break up and become available to the cow.

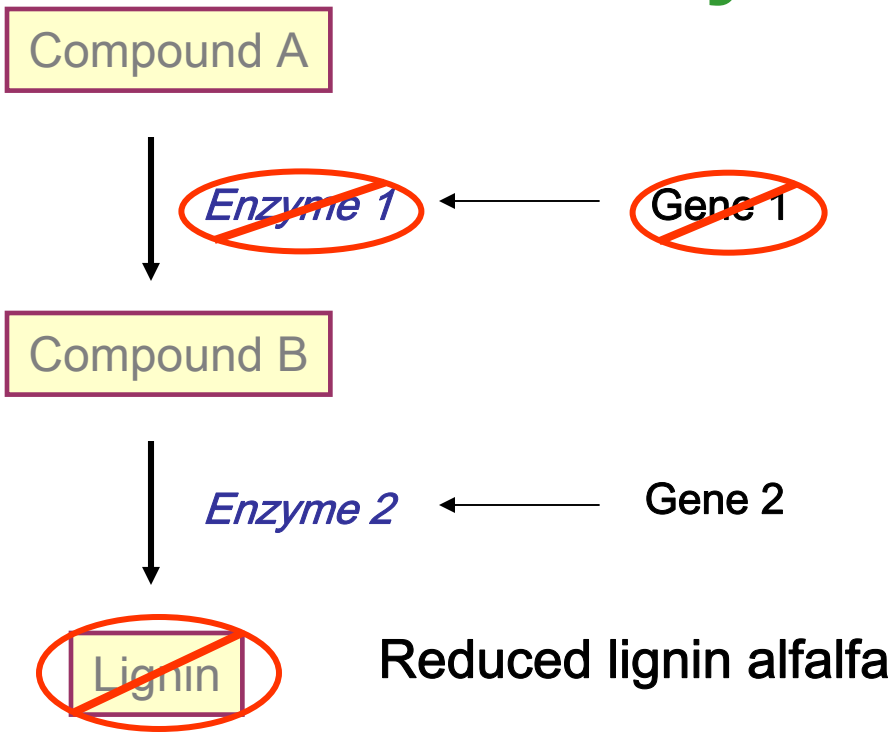
This also weakens the foundation around the lignin allowing the cell wall to break open so that cell content nutrients can be utilized by the cow.





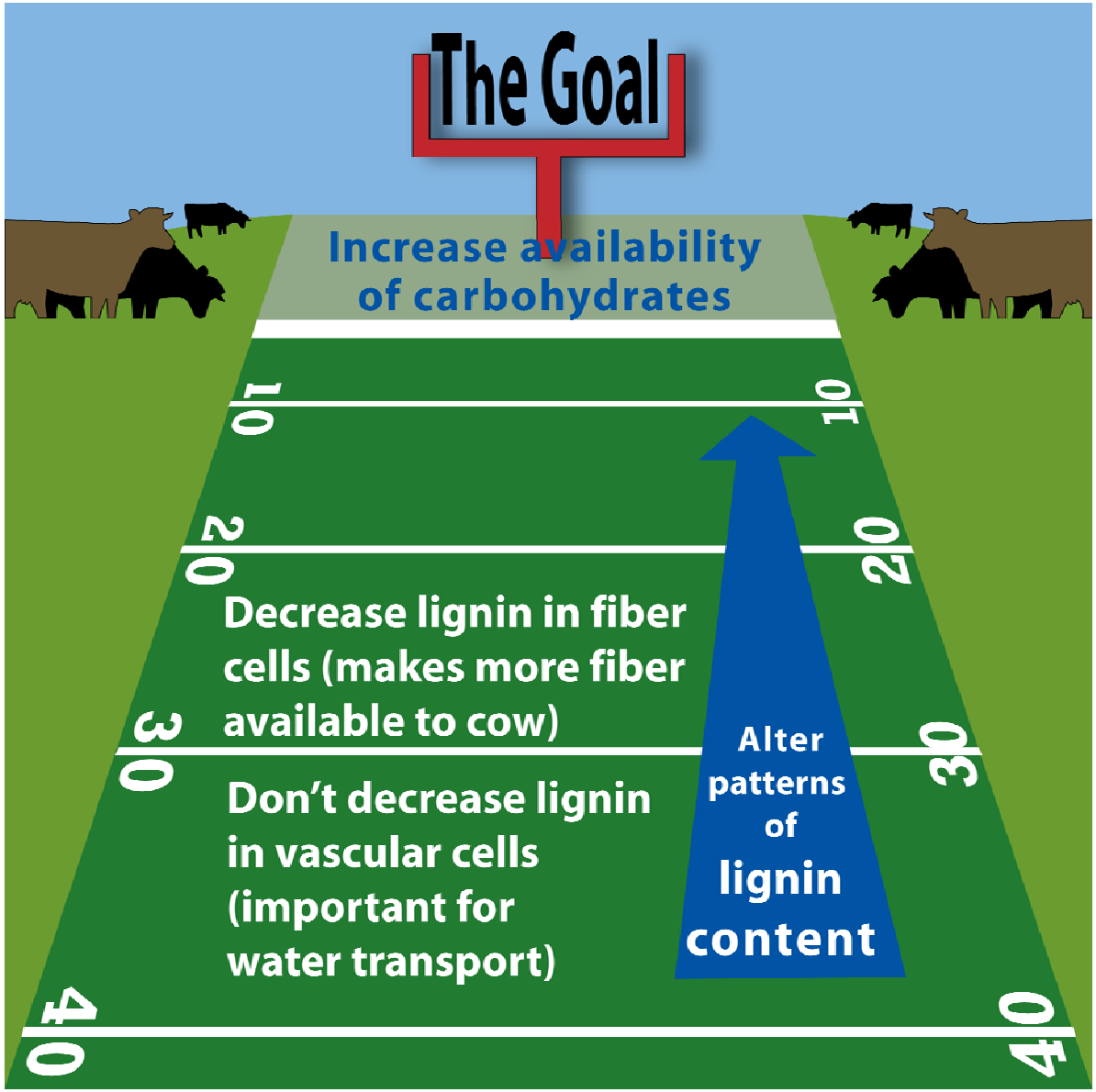
Can't get rid of lignin . . . So research goal is to decrease the percentage of it in the cell wall by increasing celluloses and pectins.

Lignin biosynthesis can be reduced by “silencing” genes for one or more key enzymes

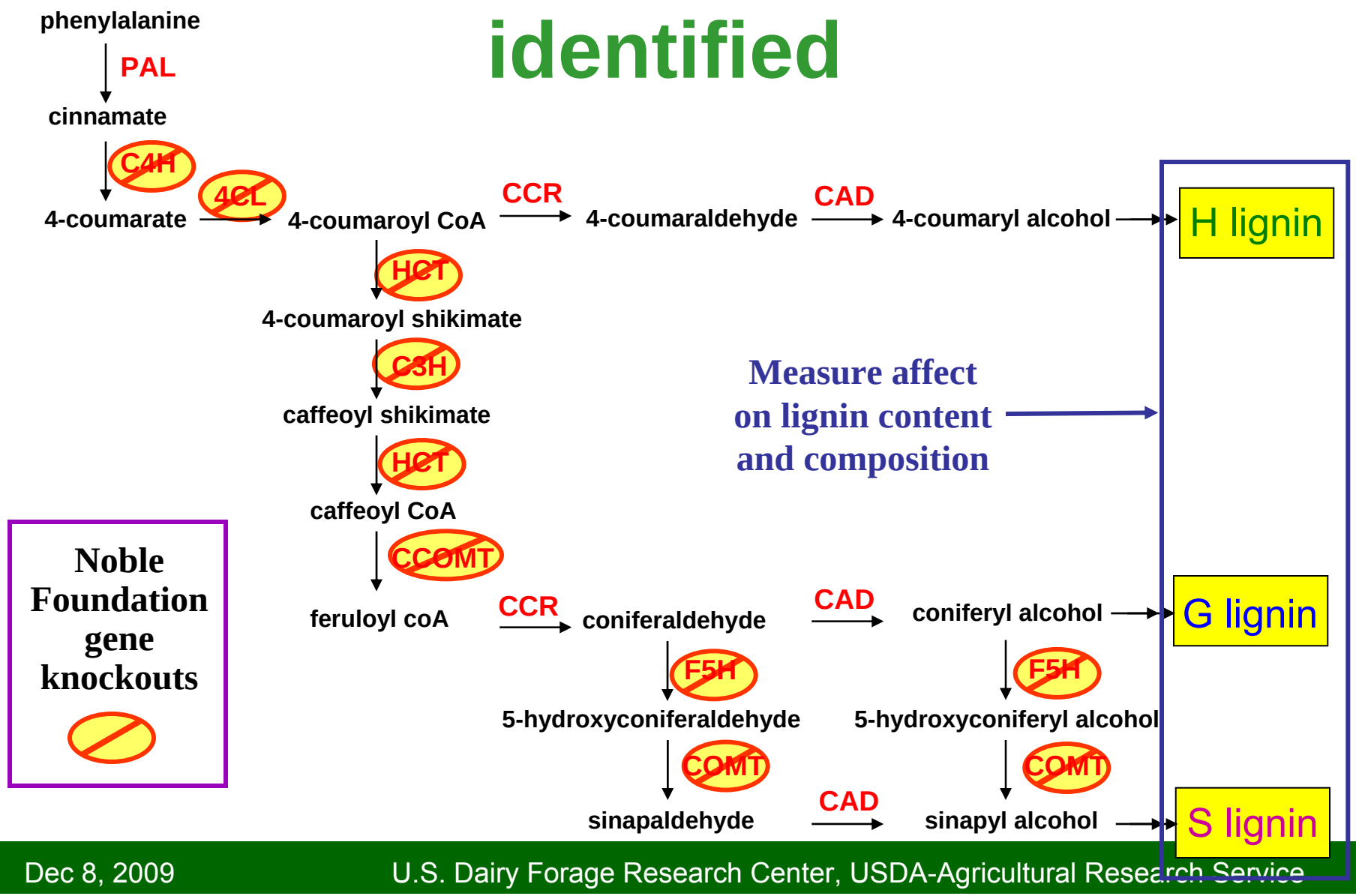


Use genetic engineering to knockout/silence “lignin gene(s)” in alfalfa

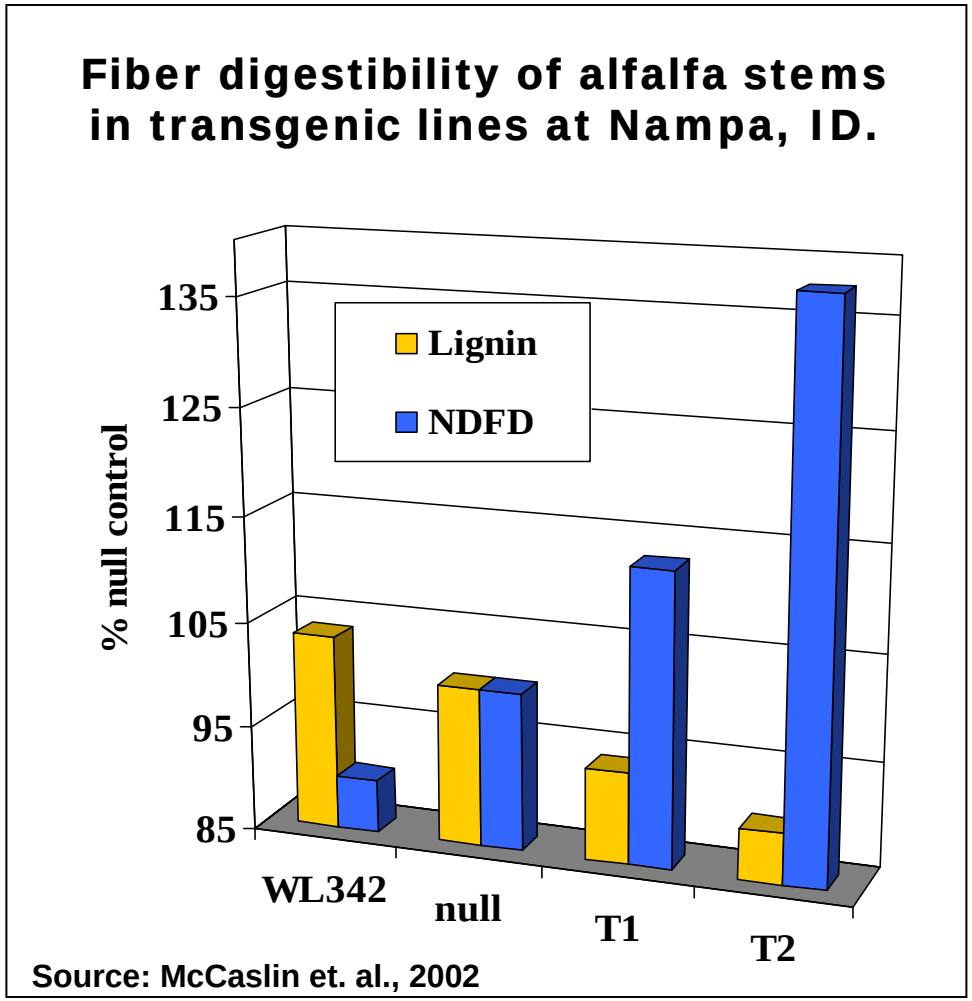
Lignin is more crucial in some cells than others . . . So research goal is to selectively decrease lignin in some cells and leave it intact in others.



Two key genes in the lignin biosynthetic pathway were identified



Redesigning Alfalfa



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

Forage Genetics International

Consortium for Alfalfa Improvement

Lactating Cow Response

Alfalfa hay in diet!	CP	NDF	NDFD	Milk
	----%DM----		-%NDF-	lb/day
COMT Inactive	18.1	31.1	53.5**	84.7*
COMT Active (Control)	18.4	29.3	42.5	82.1
CCOMT Inactive	18.1	31.2	48.6**	84.5
CCOMT Active (Control)	18.3	31.1	44.5	86.7

! TMR diets - 50 % alfalfa hay, 10 % corn silage, 40 % concentrate
***Significant, P < 0.10; ** significant P <0.01**
SOURCE: Weakley et al. 2008. J. Dairy Sci. Supple. 1

Digestibility in Lambs

100% Alfalfa Hay Diet	aNDF	ADL	NDFD	DMD
	-----%DM	-----	-%NDF-	-%DM-
COMT Inactive	38.2	5.3	57.5*	67.5*
COMT Active (Control)	39.0	5.8	49.1	64.5
CCOMT Inactive	39.4	5.2	50.1*	65.3*
CCOMT (Control)	39.4	5.9	46.4	63.7

***Significant, P < 0.05**

SOURCE: Mertens et al. 2008. J. Dairy Sci. Supple. 1

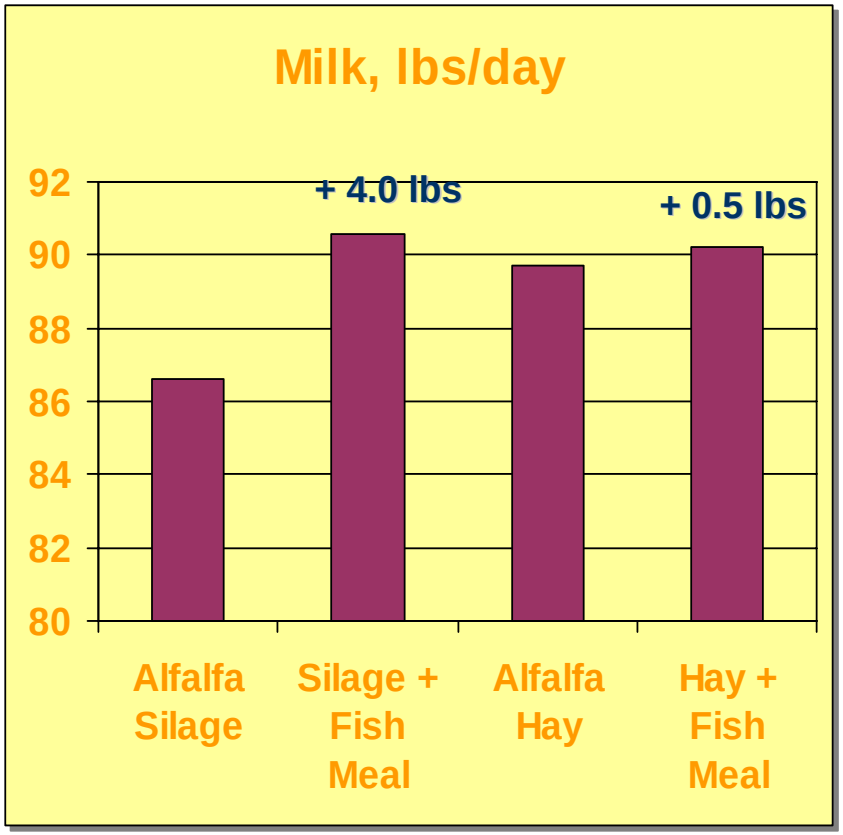
Lignin Composition - Analysis

Test	Null	COMT	CCOMT
NIRS breeder equation	---------- % ----------		
ADL, DM	12.5b	11.2a	10.9a
NDFD, NDF	31.8a	35.8a	35.3a
Chemical analysis			
ADL, DM	10.2c	9.6b	7.9a
T. Thioacidolysis, DM	6.1c	3.8a	5.0b
S-lignin, DM	2.7b	0.7a	2.7b
G-lignin, DM	3.3b	3.1b	2.2a
H-lignin, DM	0.7a	0.7a	0.9b
NDFD, NDF	30.6c	41.0a	36.2b

Values within row differ significantly, $P < 0.05$

SOURCE: Riday et al. 2008. Abstract. Proceedings Joint Meeting of the 41st North American Alfalfa Improvement Conference & 20th Trifloium Conference, June 1-4, 2008. Dallas, TX. Abstract # 18.

Milk Yield from Alfalfa Silage and Hay Diets

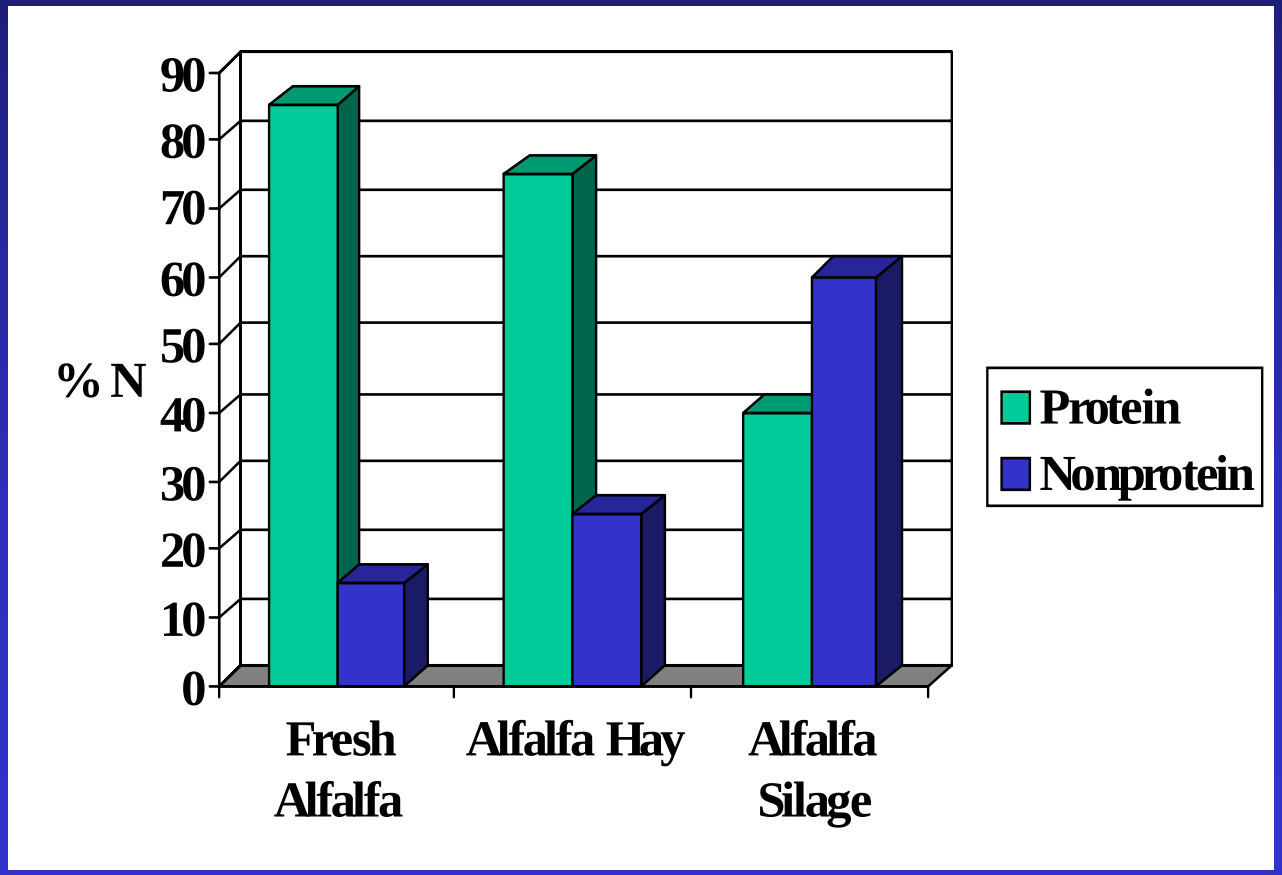


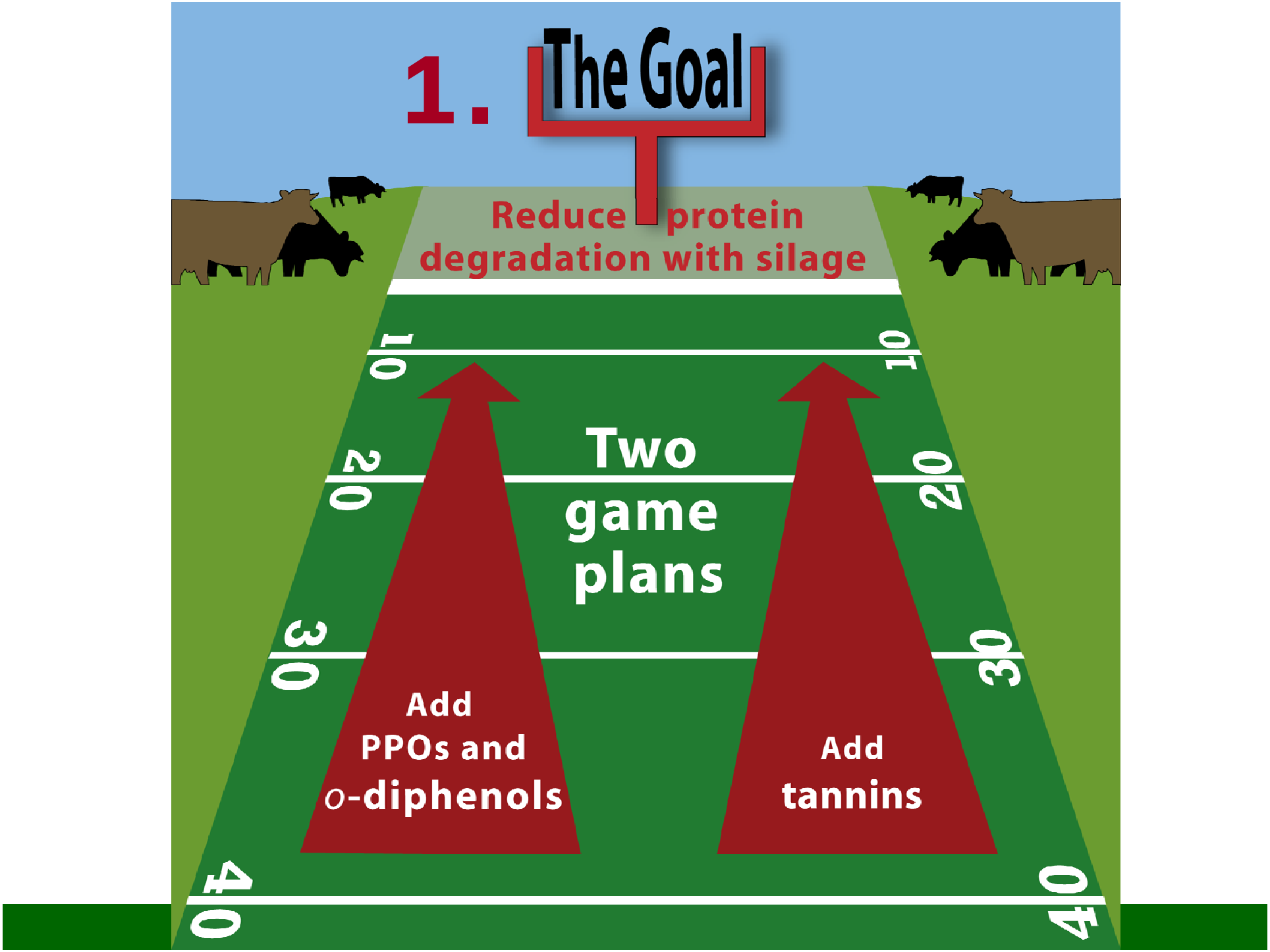
- **Fish meal is beneficial in alfalfa silage diets, but not alfalfa hay diets.**
- **Bottom line: alfalfa silage nitrogen is not efficiently used by the cow**

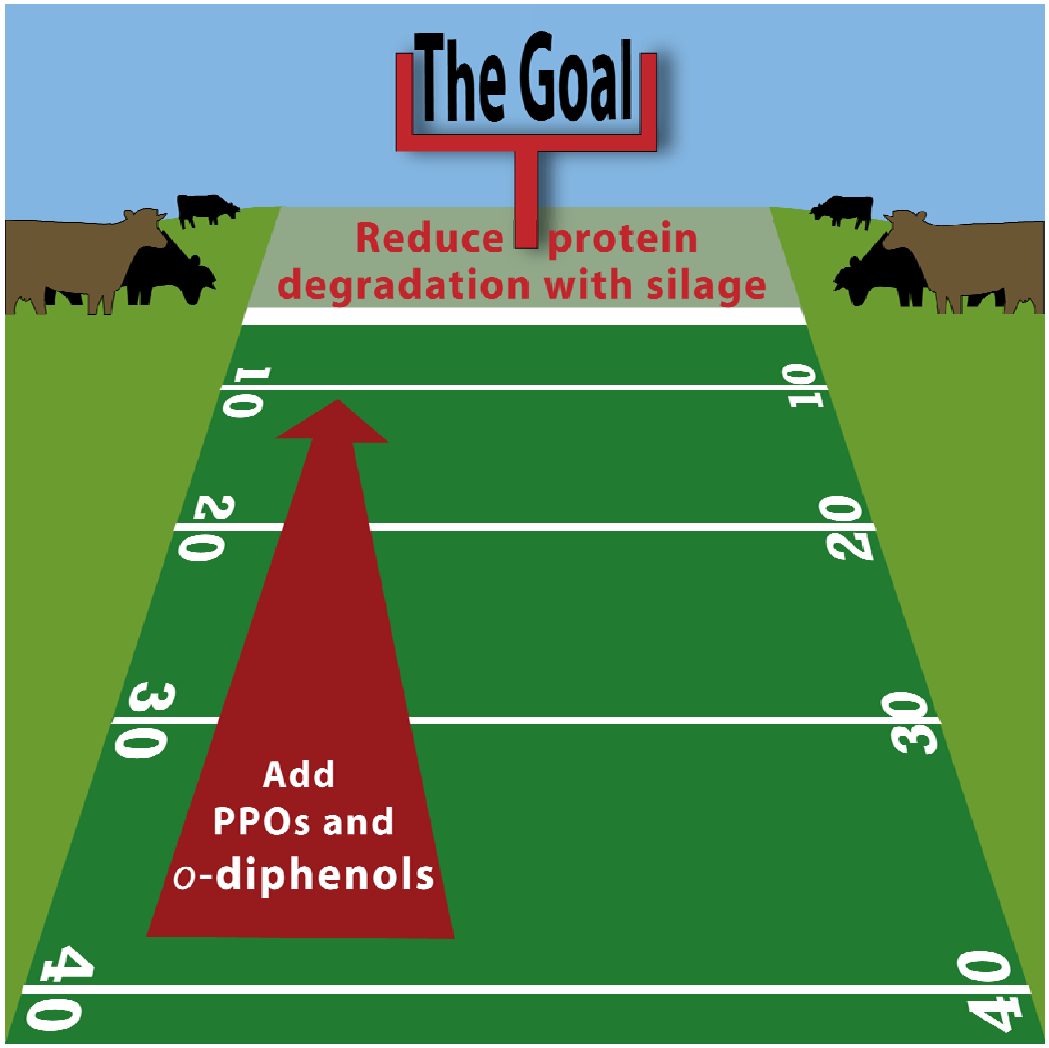
Source: Vagnoni and Broderick, 1997

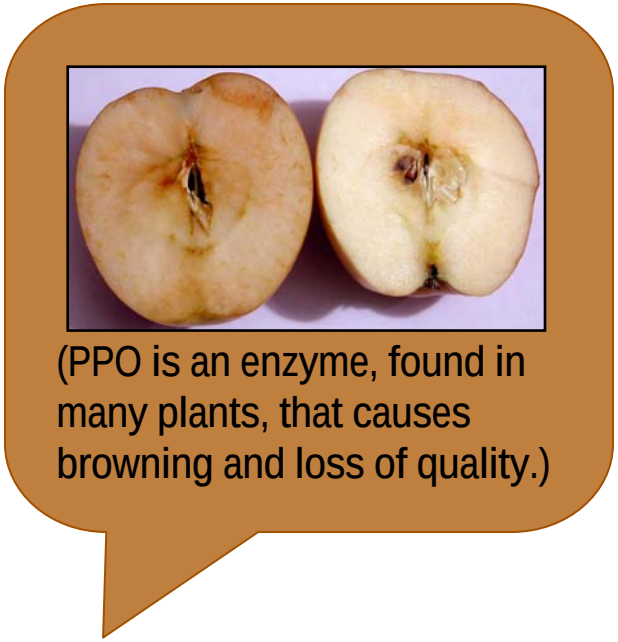
Feed Storage Problems

- However in alfalfa, our primary forage:




1.
The Goal
Reduce protein degradation with silage
Two game plans
Add PPOs and o-diphenols
Add tannins
10
20
30
40





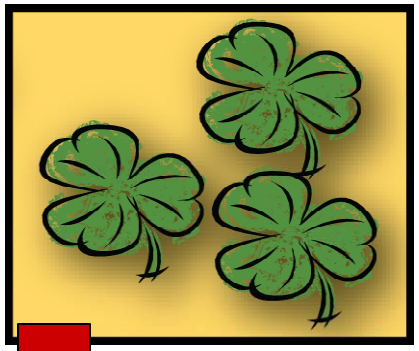
Consortium *for* Alfalfa Improvement

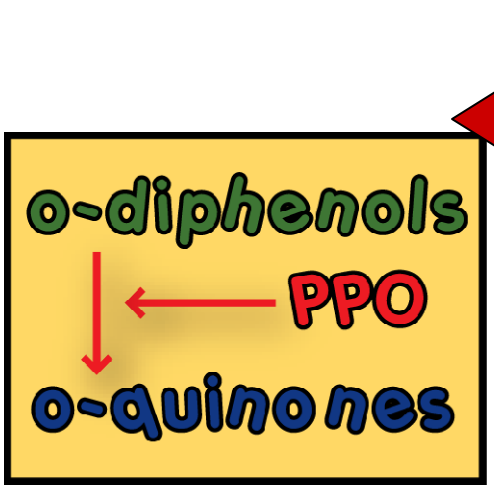
Redesigning Alfalfa

Goal #1: Reduce protein degradation

Save protein

Unlike alfalfa, red clover contains PPOs (polyphenol oxidase) and *o*-diphenol.





The PPO acts on the *o*-diphenols to produce *o*-quinones.

Redesigning Alfalfa

Goal #1: Reduce protein degradation

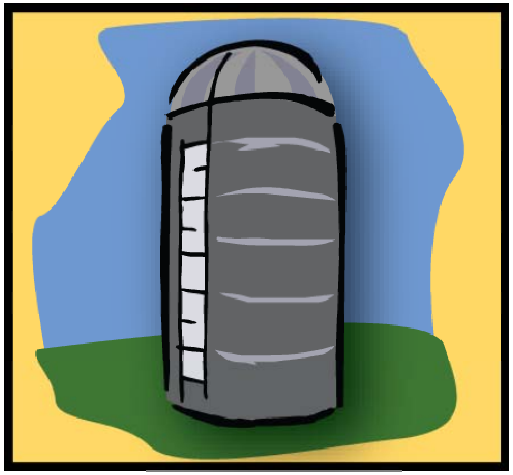
The highly reactive *o*-quinones bind with protein.

Proteases, which want to degrade protein, cannot do this when *o*-quinones are bound to the protein.

Redesigning Alfalfa

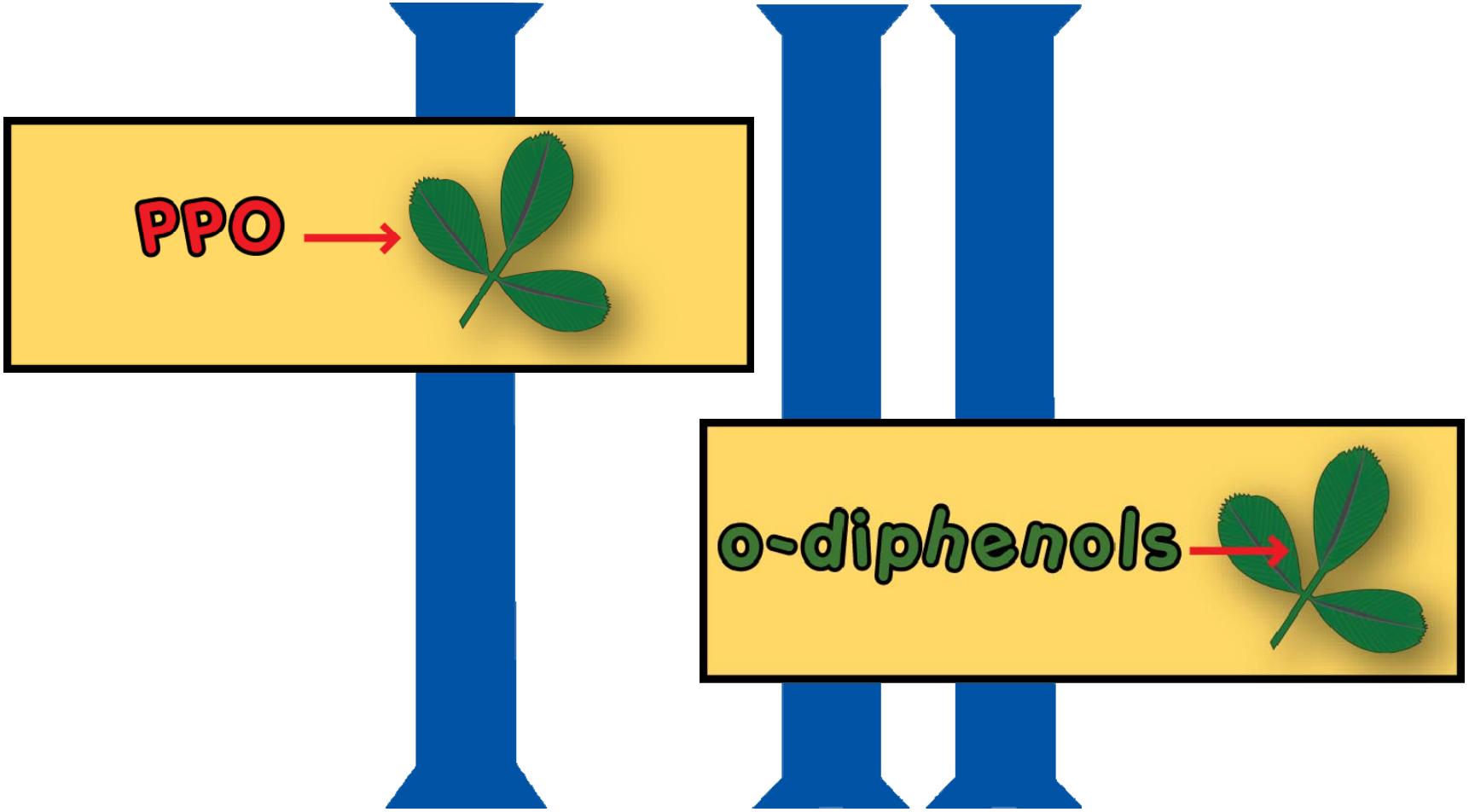
Goal #1: Reduce protein degradation

Therefore, red clover, compared to alfalfa, loses much less protein when ensiled.

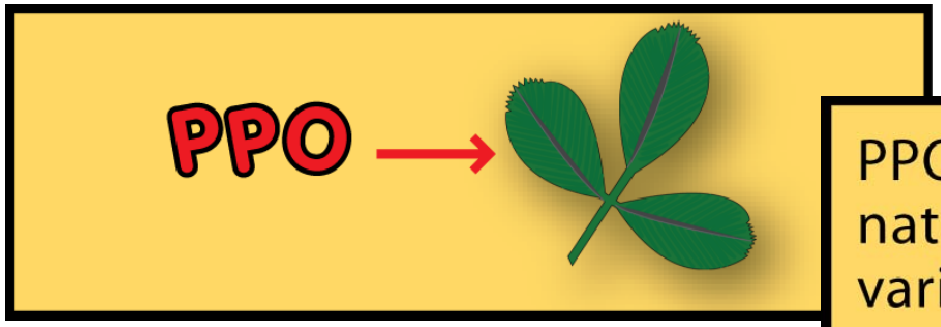


Can we take what works in red clover and transfer it to alfalfa?

Redesigning Alfalfa



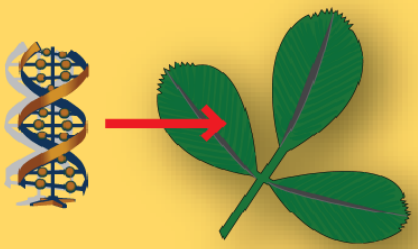
Redesigning Alfalfa



PPO genes occur naturally in some variety of alfalfa?

NO.

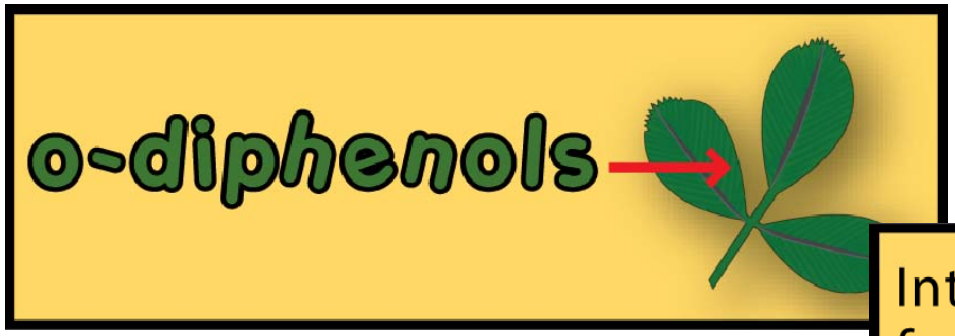
Insert red clover gene into alfalfa?

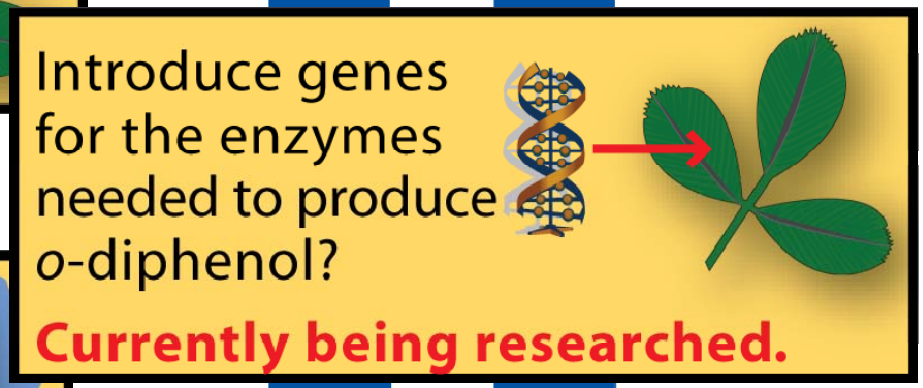


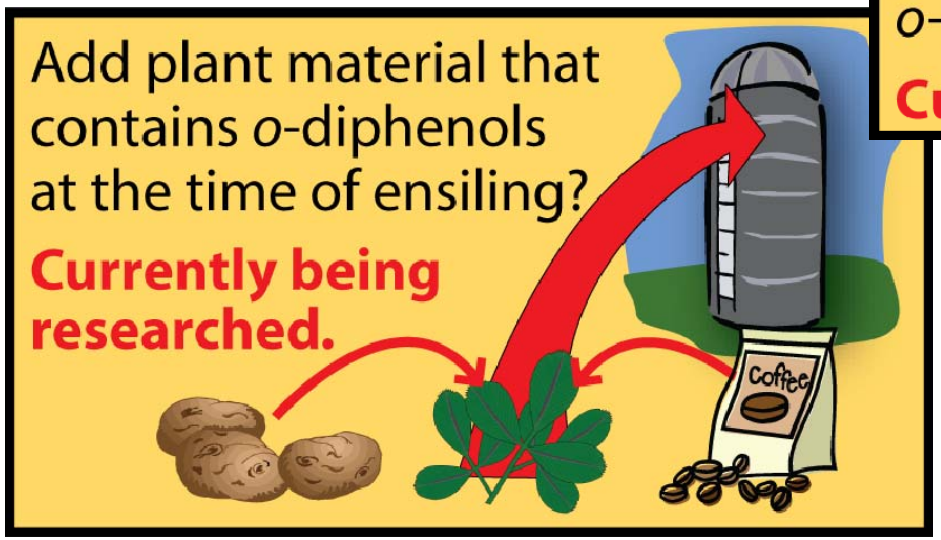
YES.

DFRC has successfully done this.

Redesigning Alfalfa







Redesigning Alfalfa

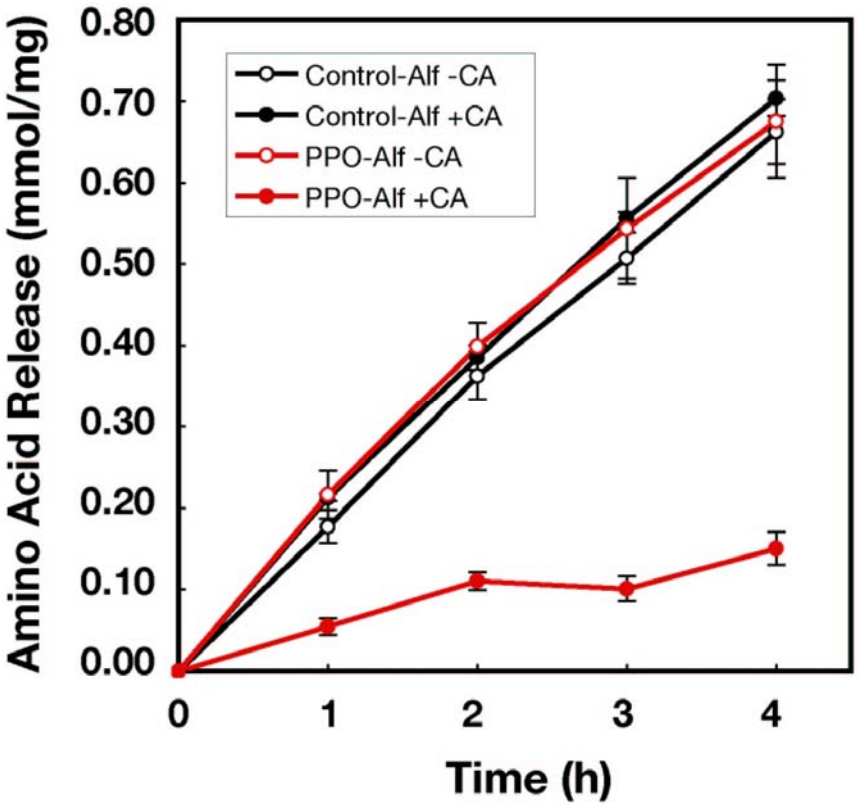
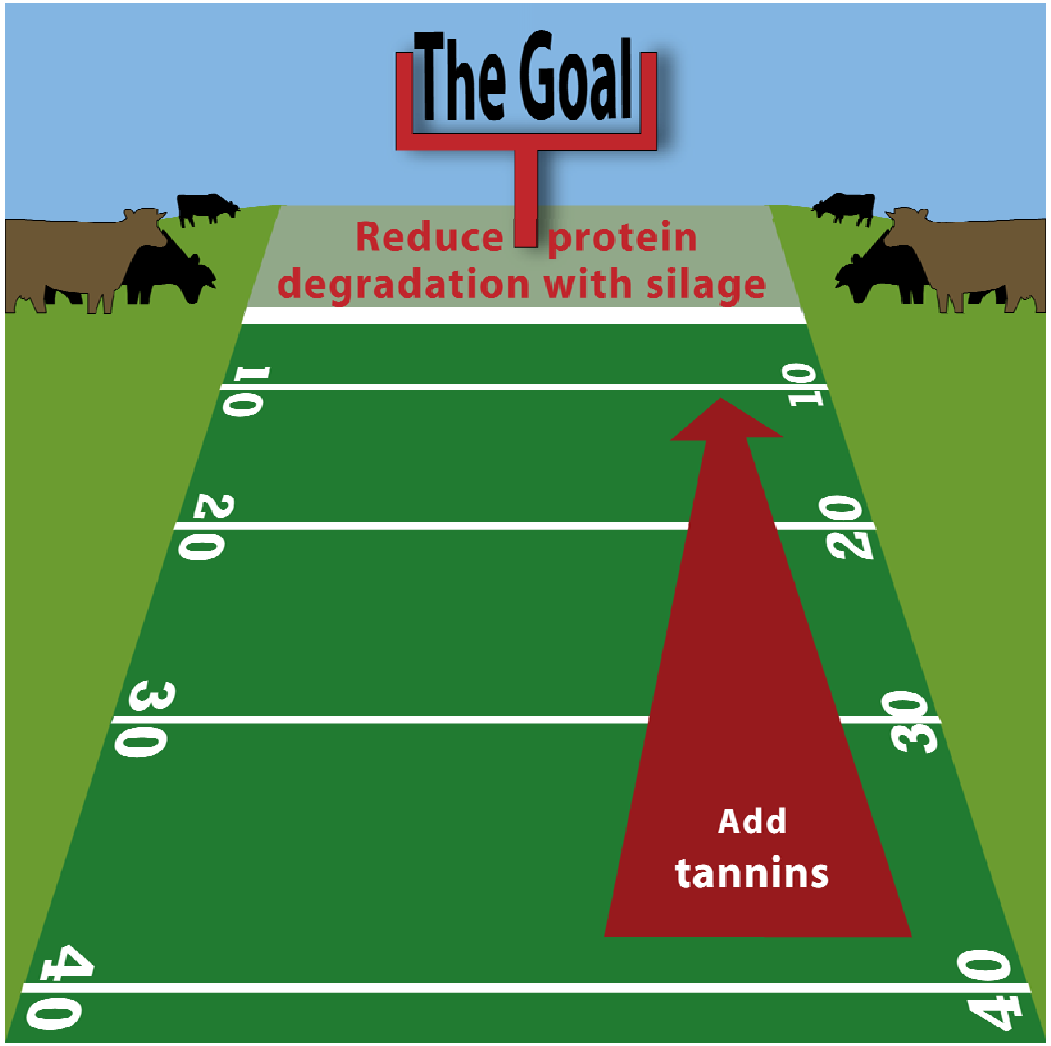


Chart shows how much less protein is degraded in alfalfa silage when alfalfa has PPO gene and *o*-diphenol* is added at time of ensiling.

***caffeic acid in these studies**

Tannin is found naturally in some forages such as birdsfoot trefoil.

Tannins bind to protein and protect it during ensiling and in the cow's rumen.



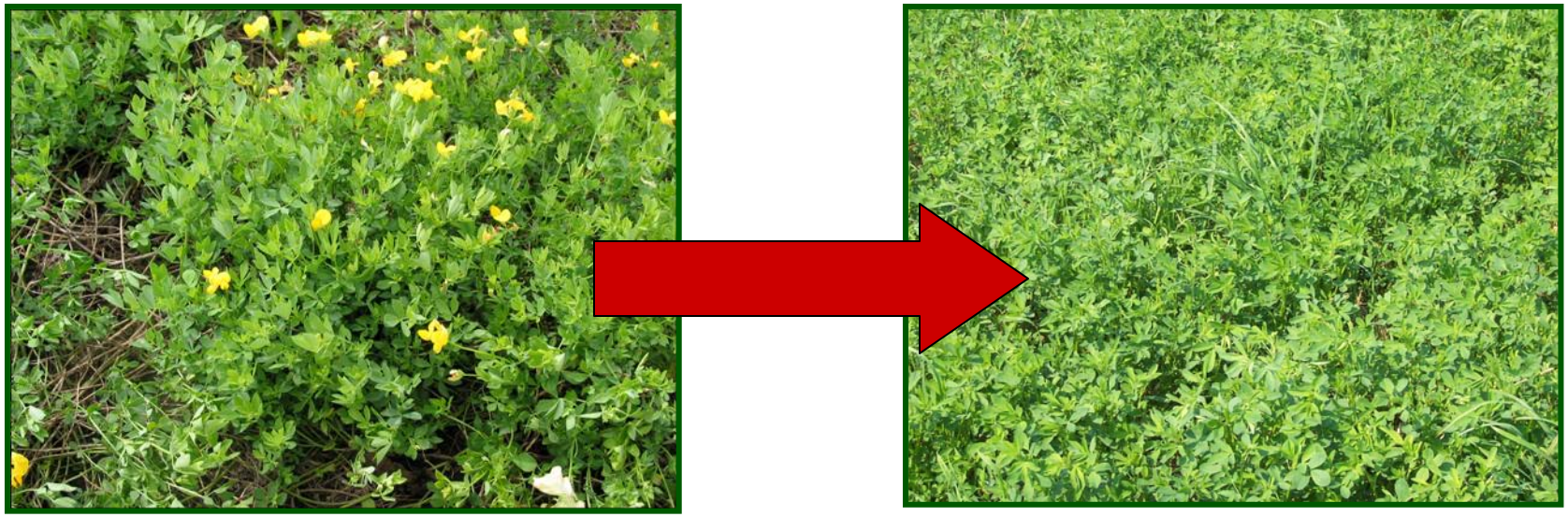
Consortium for Alfalfa Improvement

THE SAMUEL ROBERTS NOBLE FOUNDATION

Redesigning Alfalfa

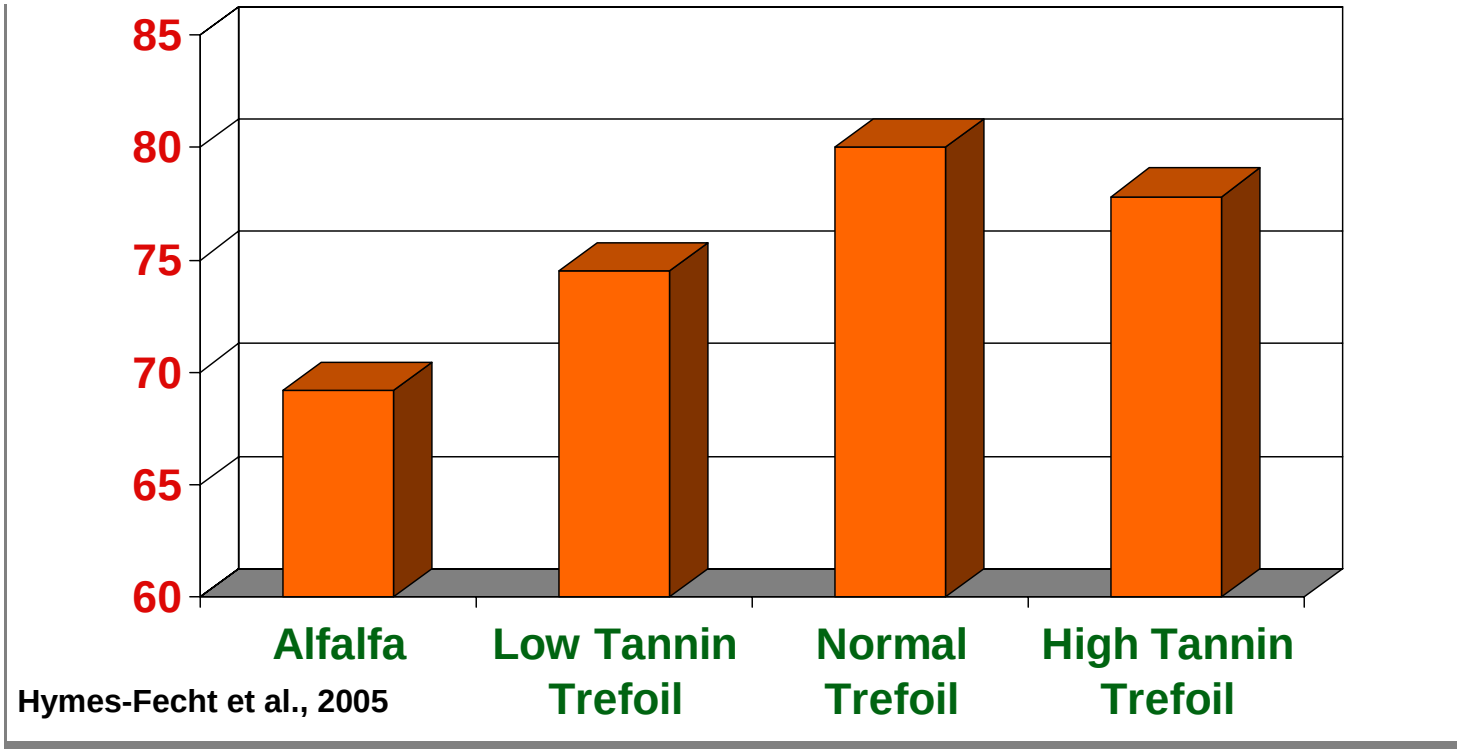
Research efforts:

- Can we insert a tannin gene into alfalfa?
- Can we grow and ensile birdsfoot trefoil with alfalfa and have an effect?



Redesigning Alfalfa

Milk yield (lbs/day)-alfalfa and birdsfoot trefoil silages



Hymes-Fecht et al., 2005

Redesigning Alfalfa

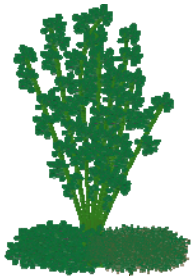
Potential high value alfalfa

1. Allow us to feed lower protein diets
2. Allow for digestion of complex carbohydrates – new feeding approach
3. Reduce the number of cuttings per season

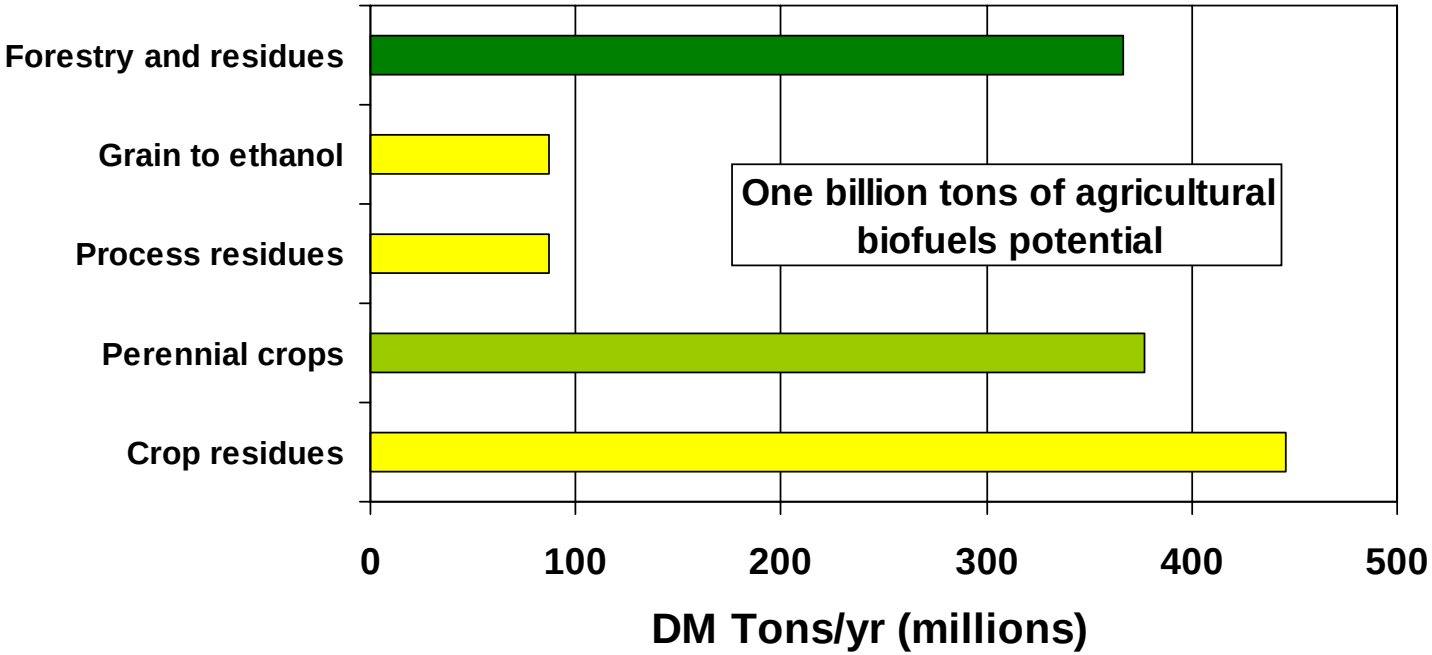
Corn Is Ethanol's Present

Cellulose Is Ethanol's Future

Cellulosic Ethanol: Feedstocks

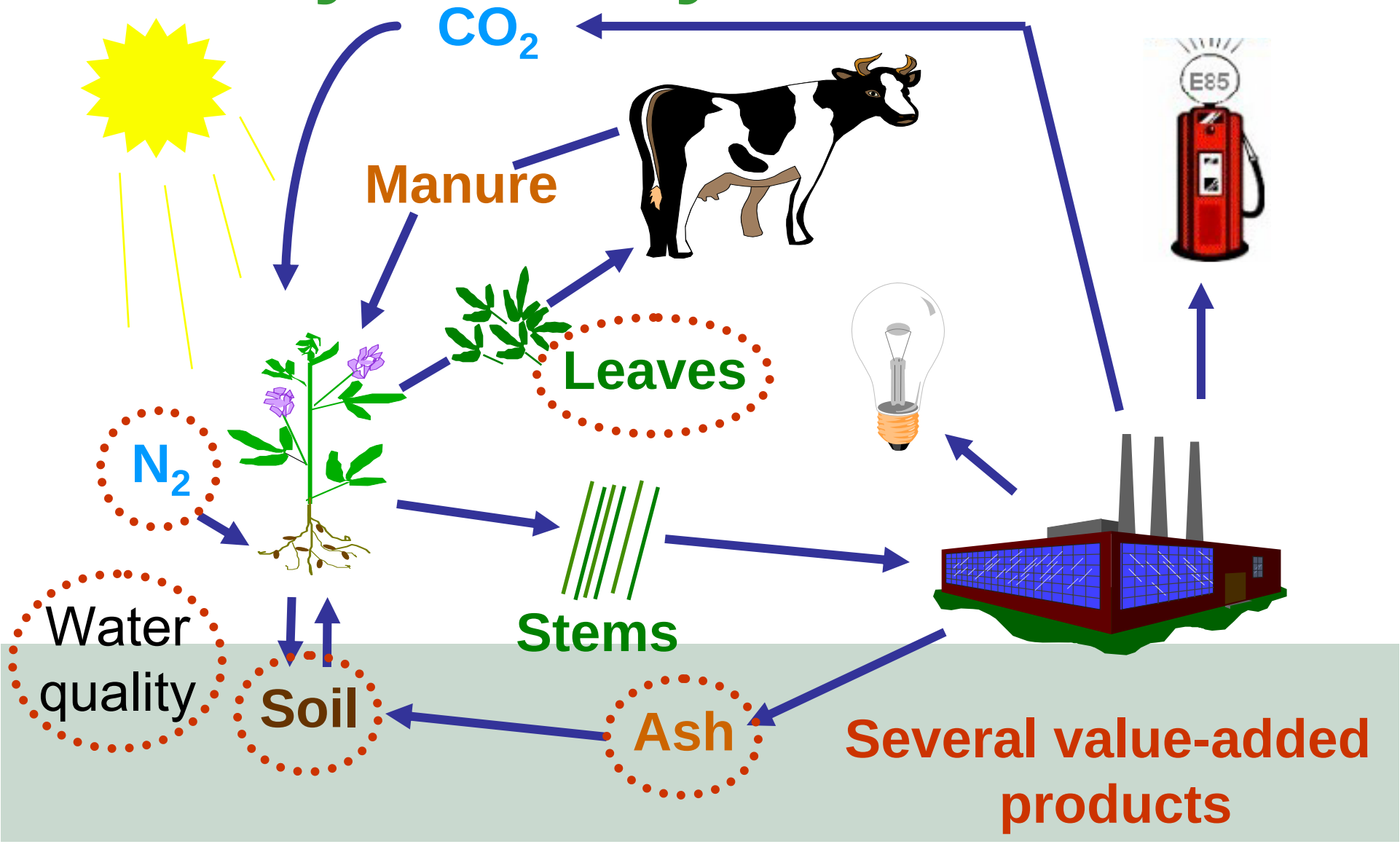


DOE Billion Ton Vision - 2030



Ethanol from corn grain is expected to provide only a portion of a biofuels solution.
Forestry and process residues, perennial crops, crop residues, and other designated energy crops will provide the bulk of a biofuels solution longer term.

Cellulosic Ethanol: A Dairy Farm System



Cellulosic Ethanol: Feedstocks-Alfalfa

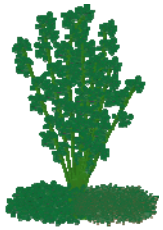
Biomass-Type Alfalfa

Developed by USDA-ARS

Traits Incorporated:

- **Large, lodging resistant stems**
- **Maintenance of leaf yield**
- **Winter hardiness**
- **Disease / pest resistance**
  - **Root rot**
  - **Leaf hopper**

Cellulosic Ethanol: Feedstocks- Alfalfa



Alfalfa Biomass Production Practices

First Production Year Stand

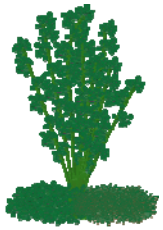
Traditional
42 plants/ft^2

Biomass
17 plants/ft^2

Modify production practices to maximize both leaf and stem yield.

1. **<u>Bigger Plants</u>: Decrease stand density to give plants more room to grow.**

Cellulosic Ethanol: Feedstocks-Alfalfa



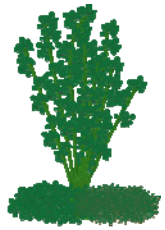
2. <u>More Stem Biomass</u>: Delay harvest from early bud stage to late flower/green pod stage to get longer stems. Lodging increases at later maturities.

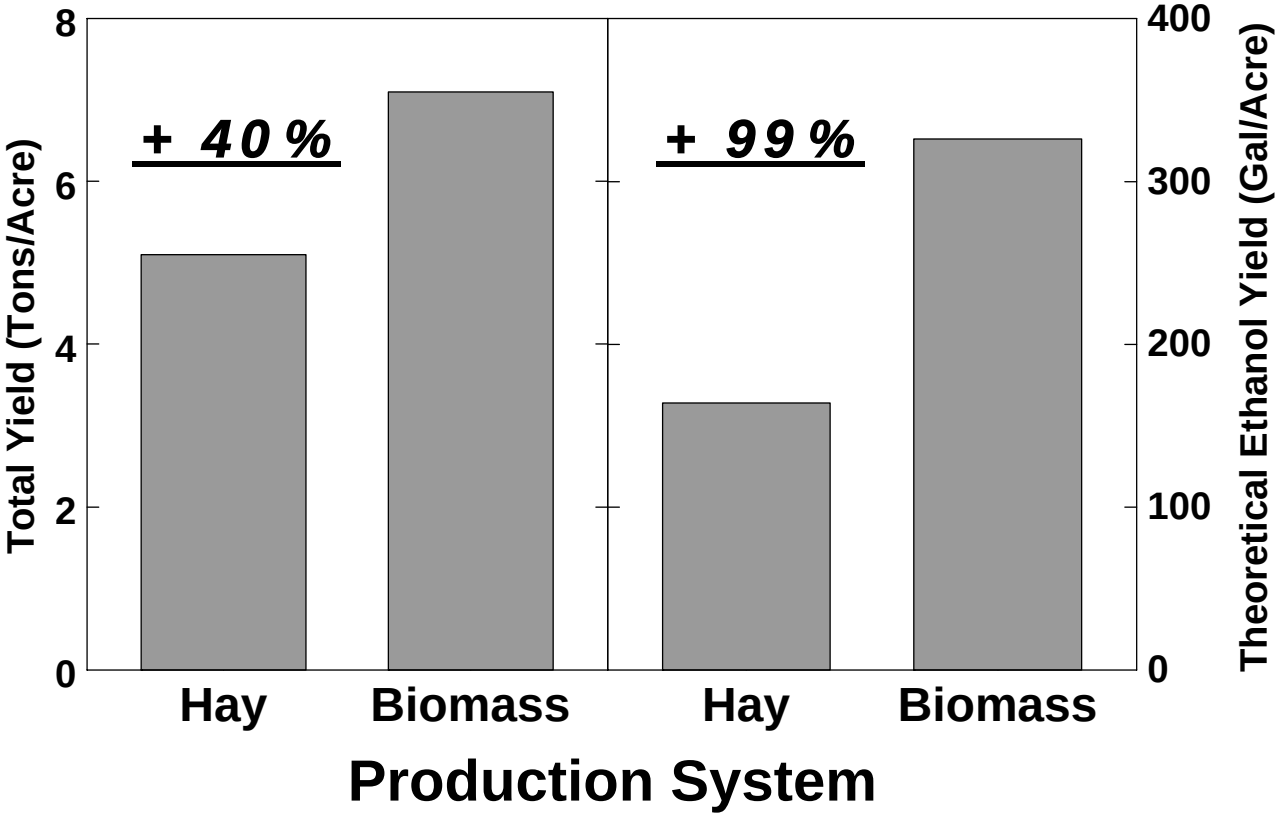
Full Bloom Maturity Stage

Dairy Hay Type

Biomass Type

Cellulosic Ethanol: Feedstocks - Alfalfa





Source: Lamb et al. 2007. Crop Sci. 47:1407-1415.

Biomass-Type Alfalfa + Biomass Management Doubles Ethanol Yield

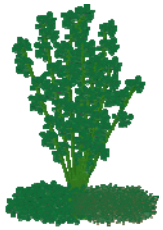
Cellulosic Ethanol: Feedstocks-Alfalfa

Research to design equipment to separate alfalfa leaves and stems in-field; ongoing at the University of Wisconsin

Kevin Shinners and Matt Digman

MILLER
PRO

Cellulosic Ethanol: Feedstocks - Alfalfa



Efficient separation of stem and leaf material is technically feasible

Stripped Leaves

- **Leaf Fraction: 60% ***
- **Purity: 90% leaves**
- **Protein: 27%**
- **Fiber: 20%**

Remaining Stems

- **Stem Fraction: 40% ***
- **Purity: 90% stems**
- **Protein: 13%**
- **Fiber: 50%**

Ratio of leaves to stems can be adjusted by changing rotor speed

Bio-based products from alfalfa

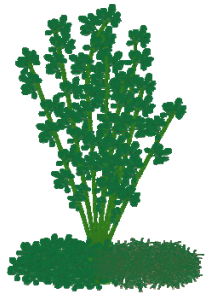
Products from fermentation of fiber from wet fractionation, or of stems from dry fractionation

- **Ethanol**
- **Butanol**
- **Adhesives**
- **Methane from anaerobic digestion**

Products from transgenic alfalfa

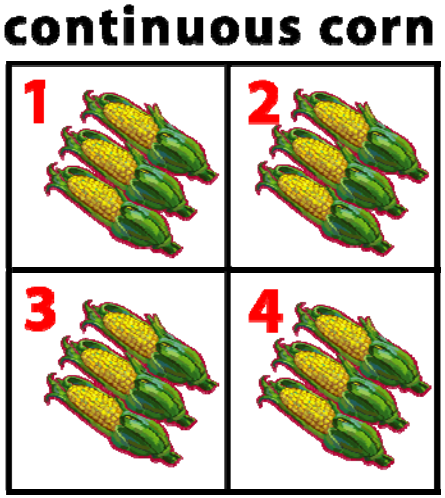
- **Enzymes (phytase, a-amylase)**
- **Plastics (poly-b-hydroxybutryate)**

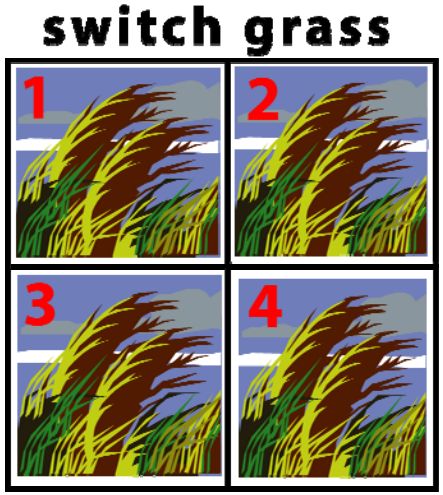
Cellulosic Ethanol: Sustainability

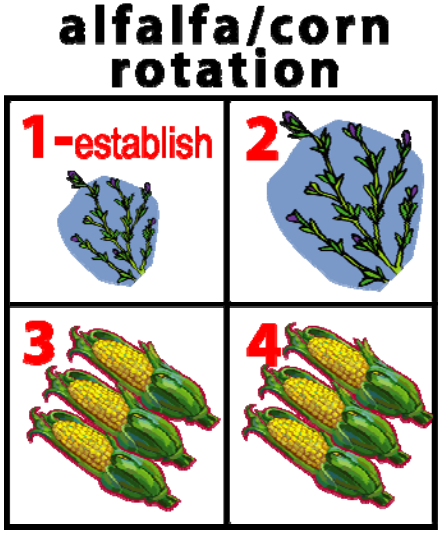


ARS Scientist:
Peter Vadas
Madison, WI

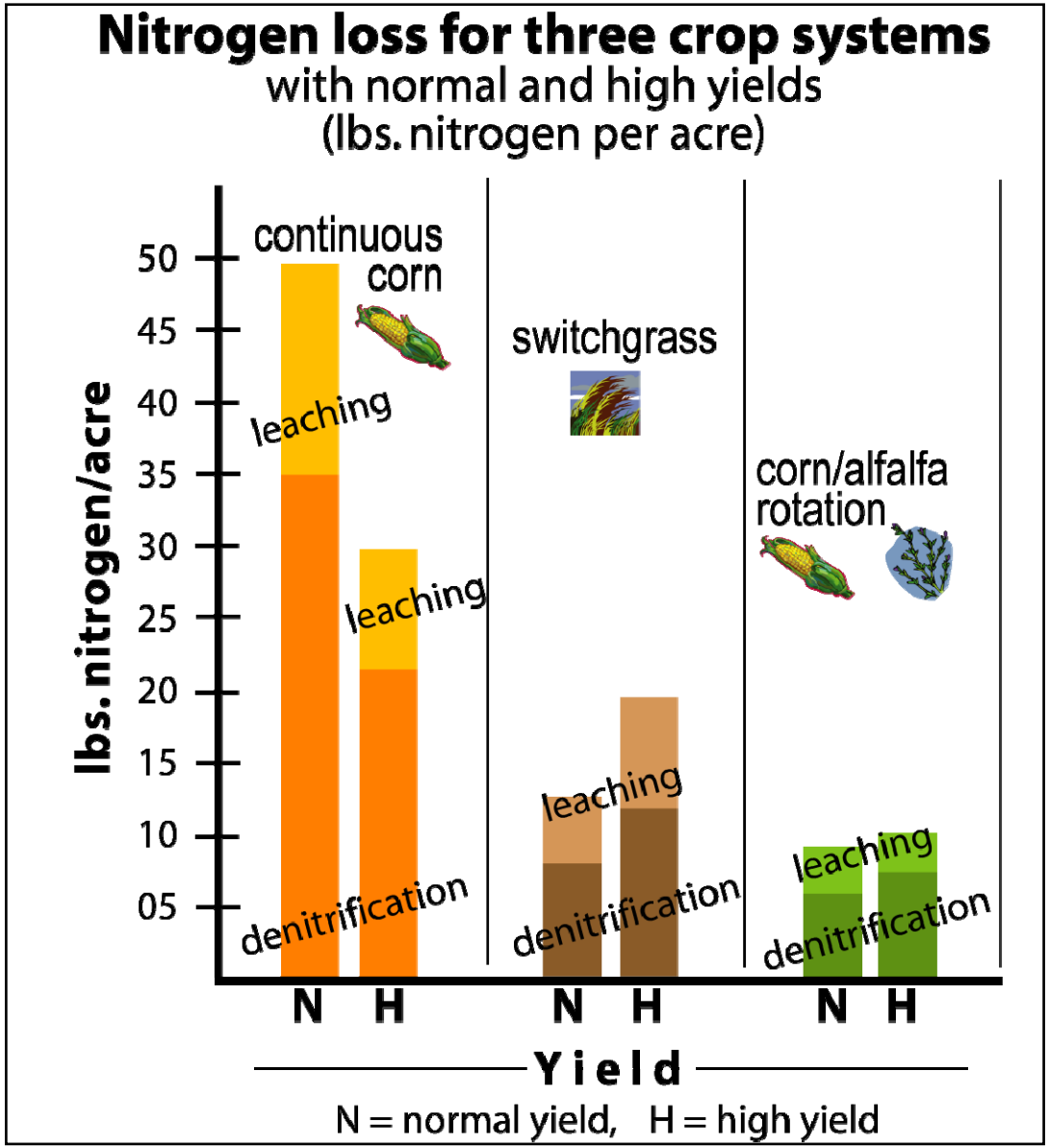
Comparison of three systems



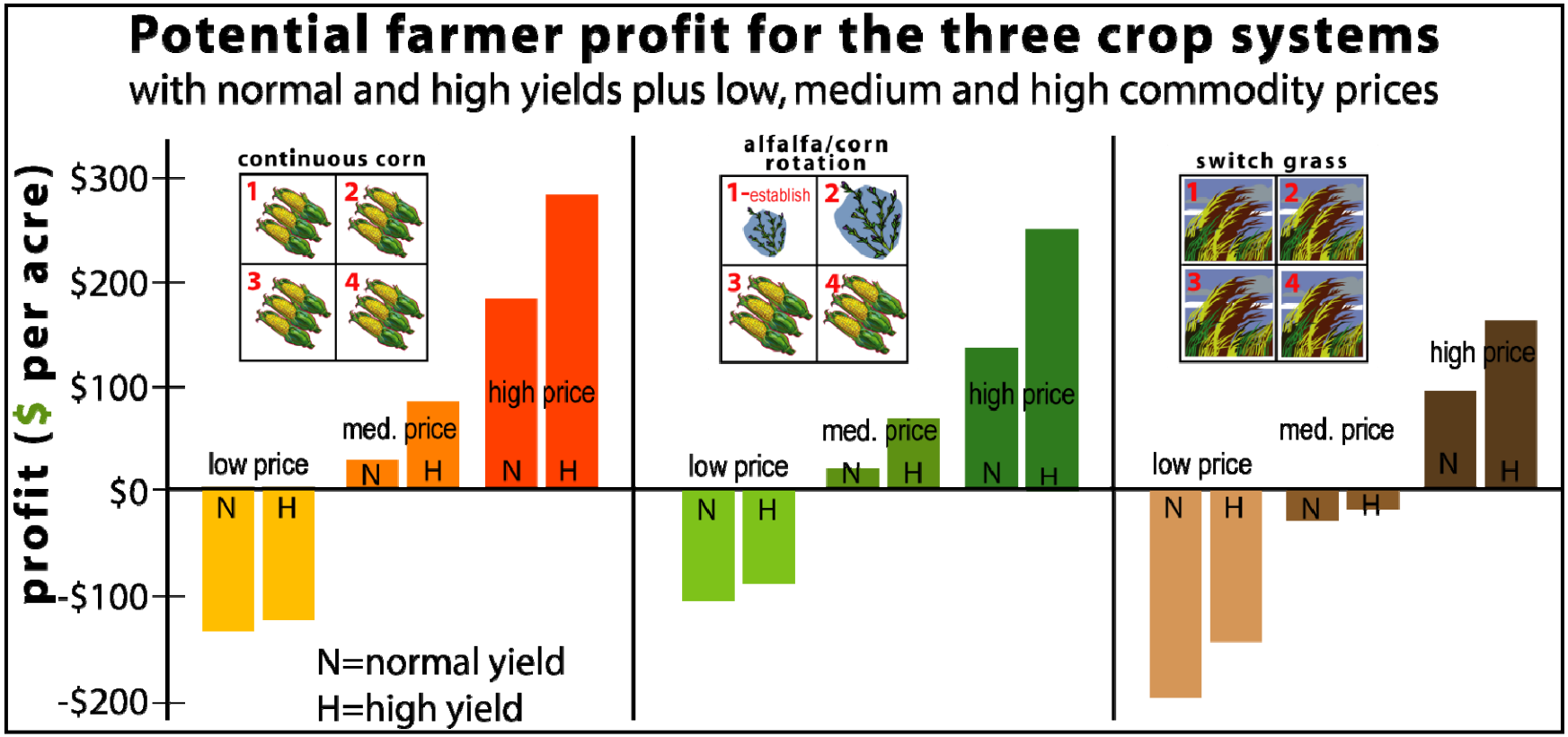




Cellulosic Ethanol: Sustainability



Cellulosic Ethanol: Sustainability



ARS and bioenergy research:

Focus on feedstock

- development
- production
- conversion

Redesigning forages: Grasses

While genetic engineering is used with alfalfa, it is not used with other legumes and grasses. Why?

- **Small market and very small profit margins with each individual grass species makes it difficult for company to recoup R&D costs.**
- **The traits that are most desired – better yield and persistence – are not easy traits to genetically engineer by 1 gene.**
- **A lot of producers who want to grow grasses are philosophically opposed to genetic engineering.**

Red Clover Breeding

Red Clover

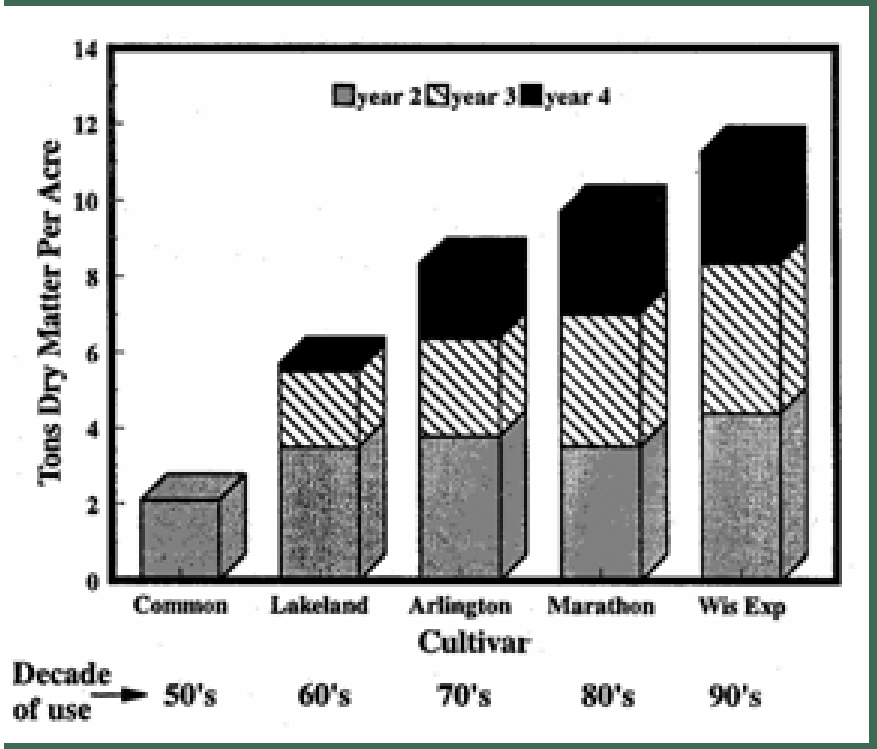
- Establishment and Management Versatility
- Less Persistent

Breeding Targets

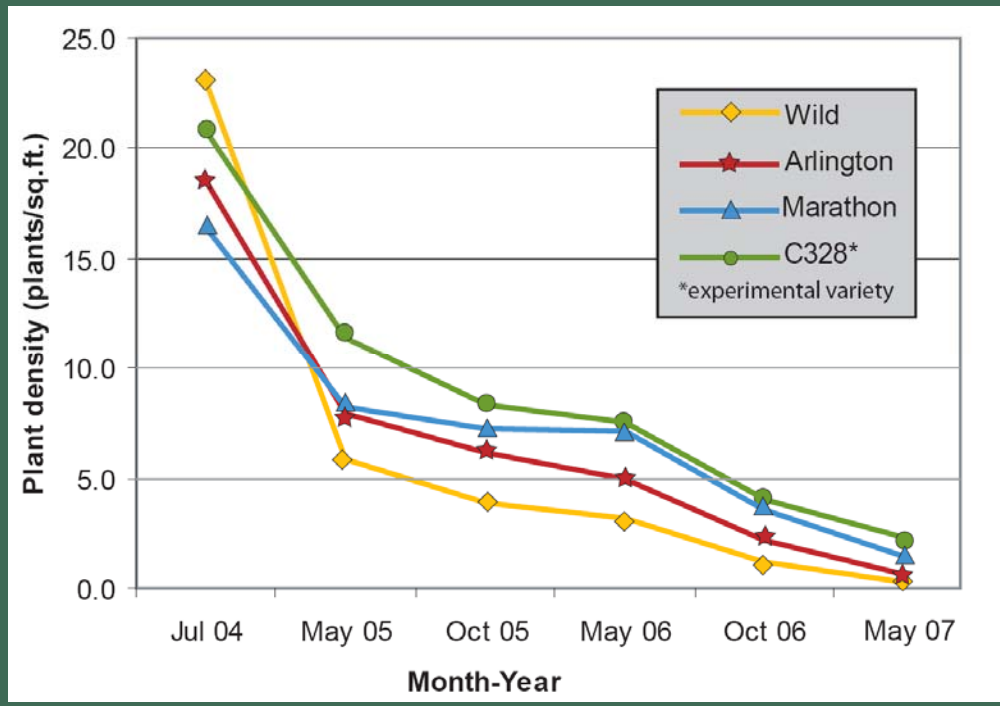
- Increased Persistence
- Increased Yield
- Plant Vigor

Red Clover Breeding Results

50+ years of breeding at USDFRC has dramatically increased red clover persistence



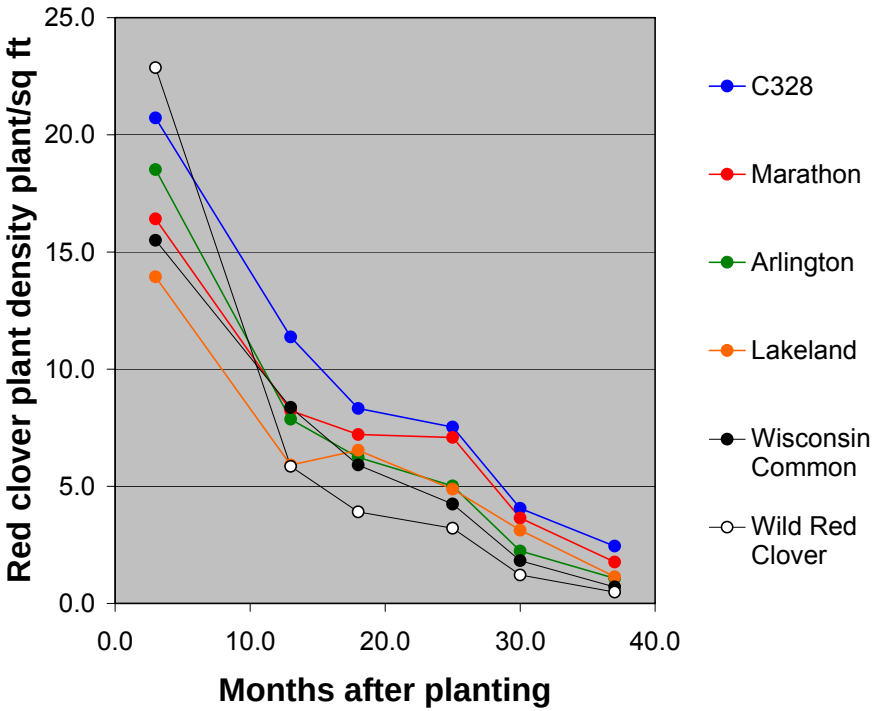
Hay Management
(Smith, 2000)

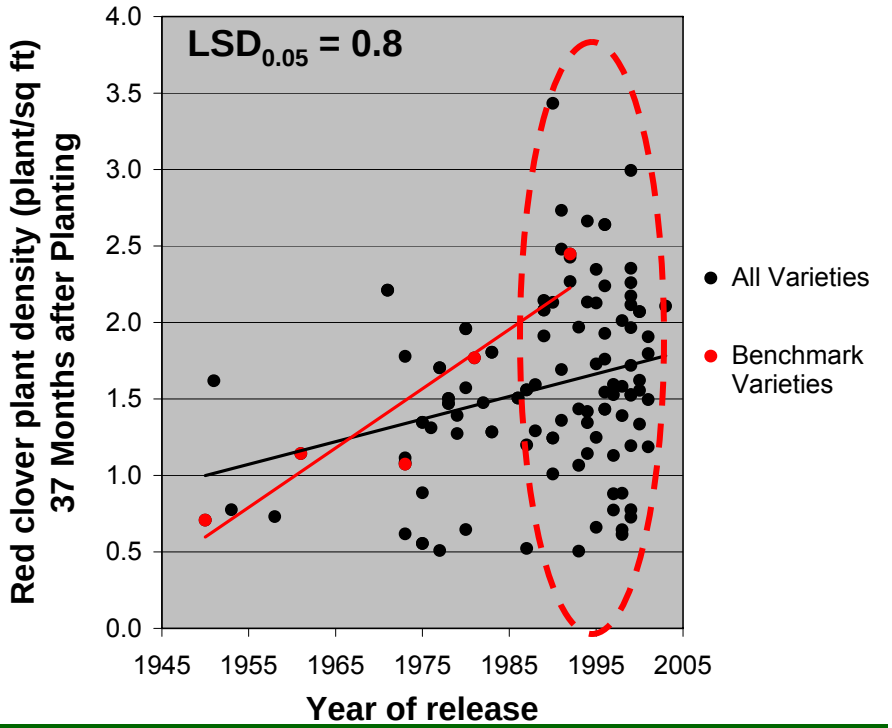


Rotationally Grazed in Grass Pasture (Riday, 2009)

Grazing Red Clover

- **Newer red clover more persistent**
  - **100% red clover ground cover at 9 or more plants per sq. ft**
  - **Not all new red clover varieties are equally persistent**





Kura Clover Breeding

Prairie du Sac, WI – Breeding Nursery

Kura Clover

- Very Persistent
- Difficult to Establish

Breeding Targets

- Seedling Establishment
- Seed Production and Yield
- Plant Vigor

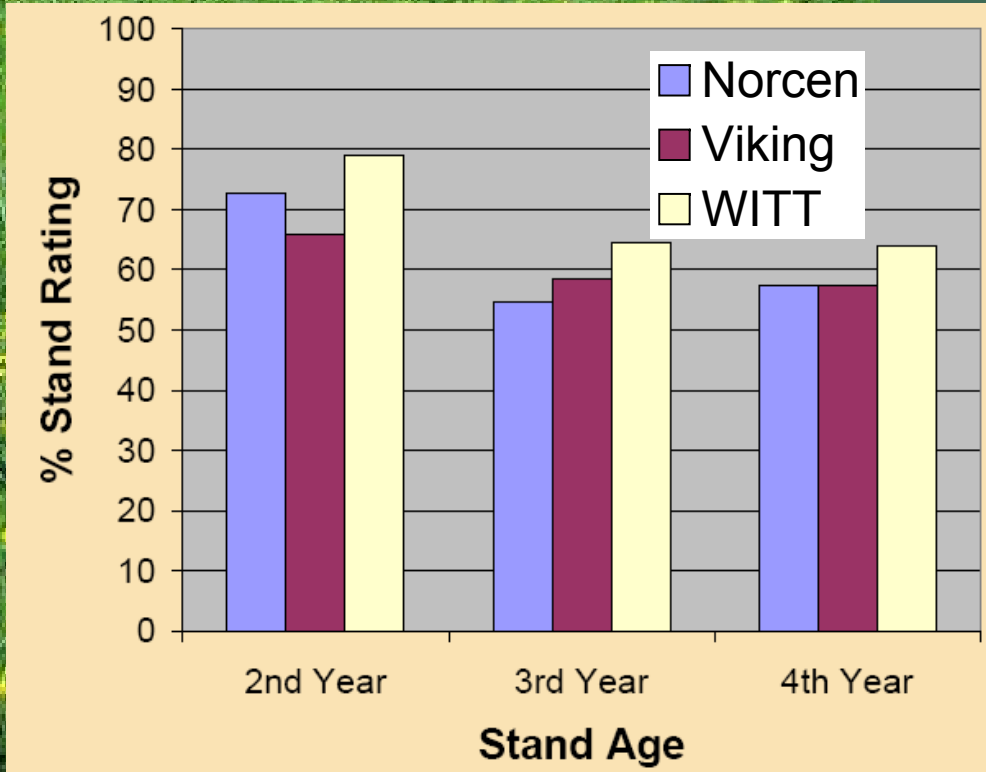
Birdsfoot Trefoil Breeding

Birdsfoot Trefoil - Non Bloating Legume

New Cultivar 'WITT'

- Commercial License Granted to Allied Seed
- Seed to Market in 2-3 Years

'WITT' had Superior Persistence Across 16 MN & WI Variety Trials



Redesigning forages: Grasses

Recent pasture/grazing research

Geoff Brink, DFRC Agronomist

Agronomic potential of meadow fescue

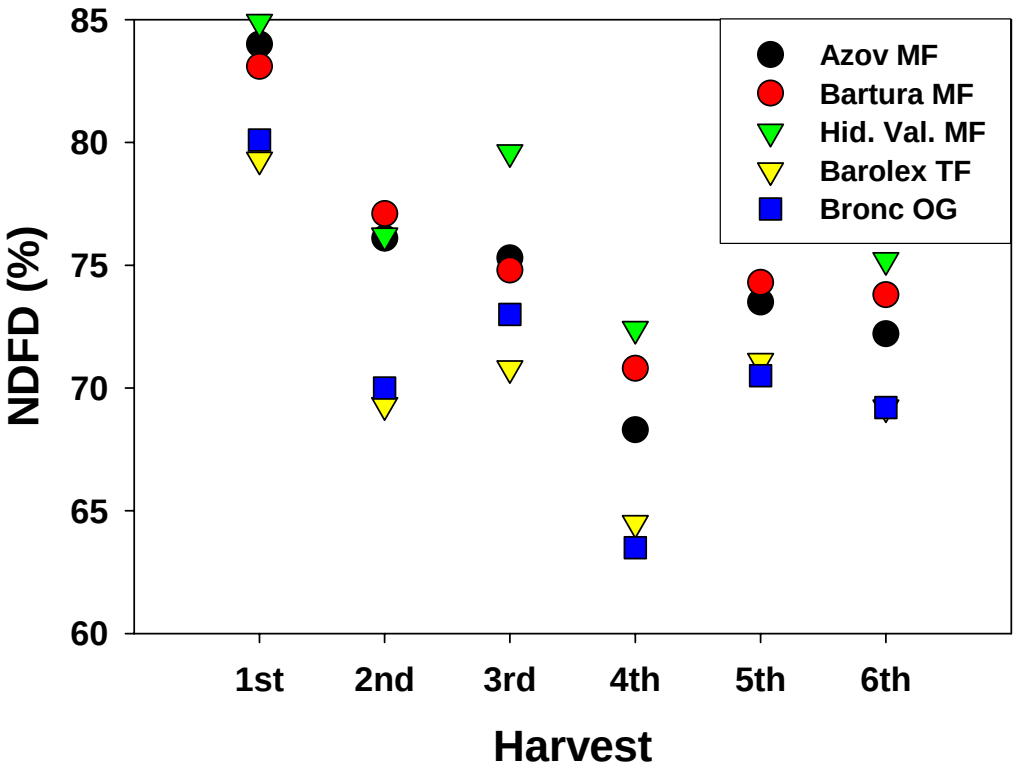
Response to N rate and defoliation management at grazing maturity by:

Bronc orchardgrass

Barolex soft-leaf tall fescue

Azov, Bartura, and Hidden Valley meadow fescue.

Redesigning forages: Grasses

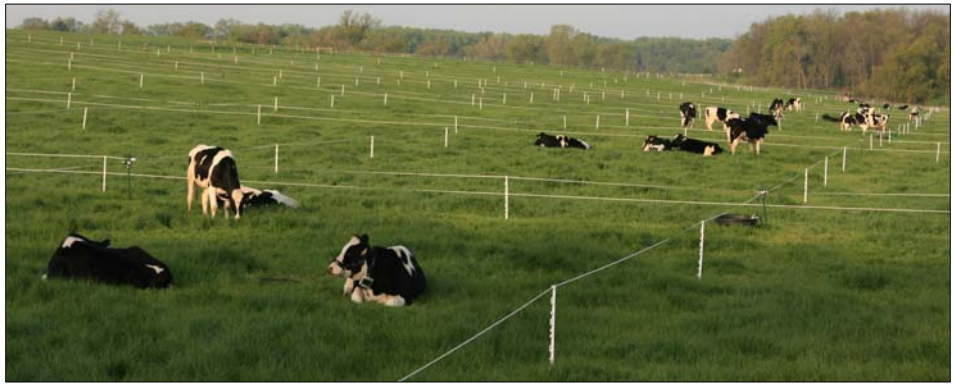


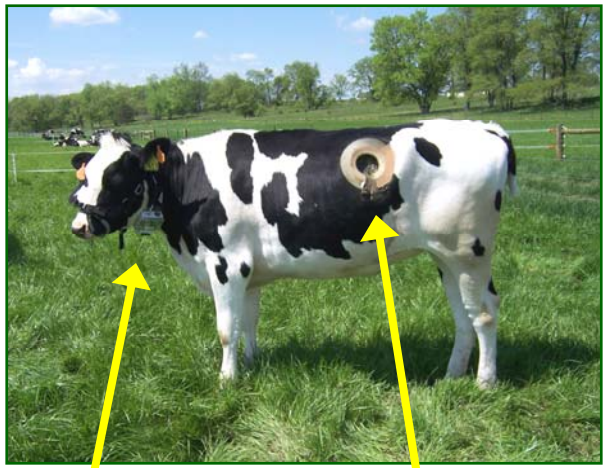
- Tall fescue and orchard-grass yielded 500-1000 lb DM / acre / year more than meadow fescue.
- NDFD of meadow fescue > tall fescue and orchardgrass through-out growing season at similar maturity.

Redesigning forages: Grasses

Animal response to meadow fescue

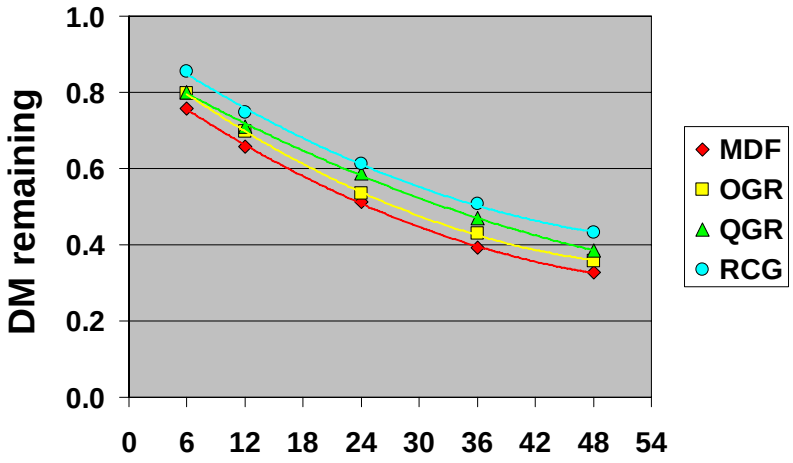
Compare intake, digestibility, and behavior of bred dairy heifers grazing meadow fescue, orchardgrass, reed canarygrass, and quackgrass (grasses that differ in sward structure and quality).



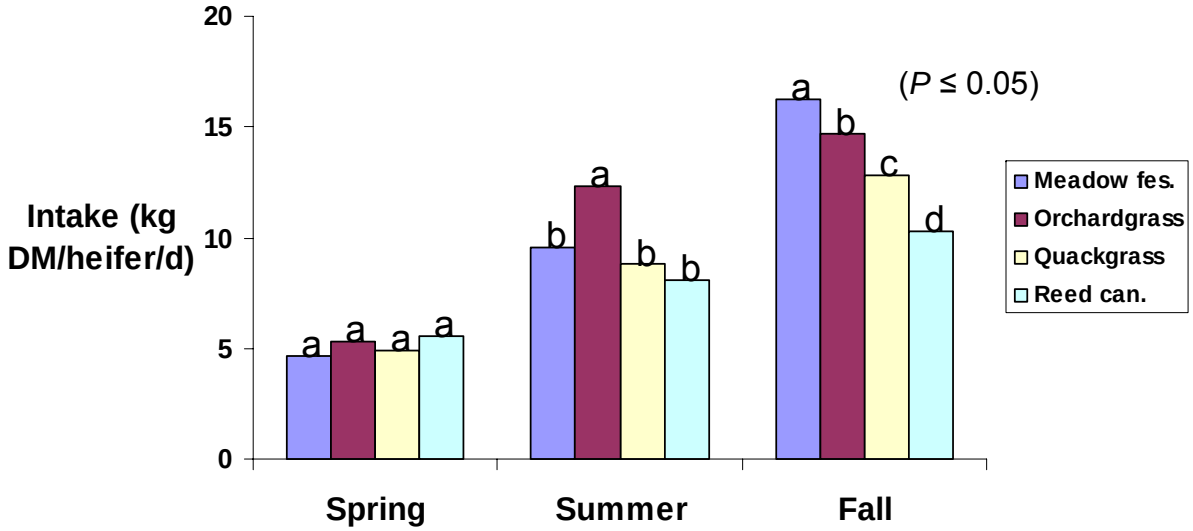


Collaborative with Dr. Kathy Soder, USDA-ARS Pastures Systems and Watershed Management Research Unit.

Redesigning forages: Grasses



- **Meadow fescue had greater *in situ* digestibility than tall fescue or orchardgrass, but greater intake in fall only.**



Redesigning forages: Grasses

Targets for Grass Breeding

- **<u>The past:</u> hay/silage production**
  - **The focus of grass breeding since its beginning.**
  - **Many excellent, well-adapted varieties exist.**

Redesigning forages: Grasses

- **<u>The present:</u> management-intensive grazing & pastures**
  - **Virtually no grass breeding efforts until 1990.**
  - **Most breeding programs have shifted toward this goal.**
  - **The best hay types are not necessarily the best pasture types and vice versa.**

Redesigning forages: Grasses

Recent grass breeding activities

(Mike Casler, ARS-U.S. Dairy Forage Research Center, Madison, WI)

- **Timothy and bromegrass:**
  - **Breeding grazing-tolerant varieties**
- **Reed Canarygrass:**
  - **New cultivar with improved establishment by selection and breeding**
  - **Determining the mechanism for improved establishment**

Original germplasm taken from natural, undisturbed locations such as cemeteries and ditches.

Redesigning forages: Grasses

- **'Spring Green' Festulolium**
  - **Meadow fescue x perennial ryegrass hybrid**

X

  - **Quality & establishment similar to ryegrass**
  - **Drought tolerance similar to fescue**
  - **Selected for winter survival on-farm**

Redesigning forages: Grasses

- **'Spring Green' Festulolium**
  - **Tested in 8 states from Minnesota and Iowa to New York and Virginia . . .**
  - **. . . and compared to previous fescue x rye varieties, Tandem and Kemal**
  - **Spring Green showed a 31% increase in survival (52 vs. 40%). . .**
  - **. . . and a 2% increase in tons/ acre (3.98 vs. 3.91)**

Redesigning forages: Grasses

- **Meadow Fescue:**
  - **New cultivar, 'Hidden Valley,' selected from Charles Opitz farm, WI**
  - **Drought tolerance and highly palatable**

Opitz Farm, Wisconsin

Redesigning forages: Grasses

- **Non-heading Orchardgrass**
  - **A management technique, not breeding**
  - **Designed to simplify grazing management in the spring**
  - **Orchardgrass flowering genes turned off in cold weather, but not in warm weather**
  - **Take seeds produced in warm Oregon and plant them in hardiness zones 3, 4, and 5 where winters are cold.**

Redesigning forages: Grasses

Grass and legume breeding summary:

- **We have changed the focus of our grass and legume breeding program from hay harvesting to grazing.**
- **We are developing new varieties with unique traits that will simplify and enhance the grazing operation.**
- **There is a growing interest and market for these varieties.**

Team Plant Modification - targeted

- **Use conventional and molecular breeding where appropriate**
- **Target breeding at dairy cattle intake, nutrient digestion and nutrient metabolism**
- **Use multi-disciplinary approach within unit and with partners**
- **Benefit of high risk research with partners in alfalfa is dependent on acceptance genetic modification by customers**