United States
Department of
Agriculture

Roadmap for Alfalfa Research

Agricultural Research Service

June 2013

Key to Front Cover

1. Alfalfa is recognized for its many environmental benefits.

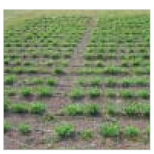
2. Alfalfa, the "queen" of forages, is an excellent source of both fiber and protein for dairy cattle.

3. New cropping systems using low levels of growth inhibitors will allow farmers to establish alfalfa during the last year of corn in a crop rotation. The yield advantage can be seen in the alfalfa on the left side of the picture.

4. Selection of alfalfa for high biomass yield compared to normal alfalfa.

5. Development and utilization of rhizomatous alfalfa (right side) in special situations may provide better management options over normal alfalfa (left side).

6. ARS researchers are currently working to understand how plants make special phenolics used to decrease protein degradation during ensiling.



7. A reduced-lignin alfalfa (shown in the nursery stage) was developed through a consortium with ARS and commercial researchers.

8. Selection of germplasm for resistance to Aphanomyces (seedlings on left).

9. A prototype harvester that separates alfalfa leaves from stems has been developed by university and ARS collaborators. This has the potential to lengthen the window of opportunity for harvest and reduce the number of harvests in a growing season.

10. The leaves separated at harvest, which are high in protein, could be ensiled and fed to dairy cows.

11. Juice could be extracted from the leaves, removing part of the protein (30% of total). The juice and leaf residue could be fermented and used for industrial purposes or as a protein source for other animals.

12. The stems separated at harvest, which are high in fiber, could be used as heifer and dry cow feed or as feedstock for cellulosic ethanol production.

Improved Alfalfa for 21st-Century Farms and Markets

Alfalfa is the most widely cultivated forage legume worldwide and is the fourth most produced crop in the U.S. In economic value, alfalfa ranks among the top three field crops in 26 states and is grown in all 50 states (Figure 1). Its value rests on both domestic and export markets. Alfalfa currently contributes more than $10 billion per year to the nation's farm economy, primarily through its use as an animal feed.

In addition, alfalfa provides many environmental services to farmers and to the public – benefits that are often overlooked. Those services diversify farming operations and help mitigate cropping system risk by providing nitrogen through biological fixation, reducing soil erosion, improving nutrient capture from annual crop fields, preventing nitrogen and phosphorus loss to surface and ground water resources, breaking of pest life cycles, and increasing soil carbon sequestration.

To capitalize on these benefits while improving alfalfa's value as a premier animal feed and also developing additional end uses, the Agricultural Research Service (ARS) will follow three routes: 1) genetic improvement of alfalfa, 2) innovations in harvesting, processing, and new products, and 3) quantifying environmental benefits of alfalfa. Research will be conducted at nine ARS research units (Addendum 2, page 11) across the nation with industrial, university and other collaborators. This "roadmap" was developed to clarify the USDA-ARS alfalfa research vision for the future, starting with current five-year project plans. (See Figure 2 for an overview of roadmap.)

The overall ARS national alfalfa research program goal is to expand the presence of alfalfa

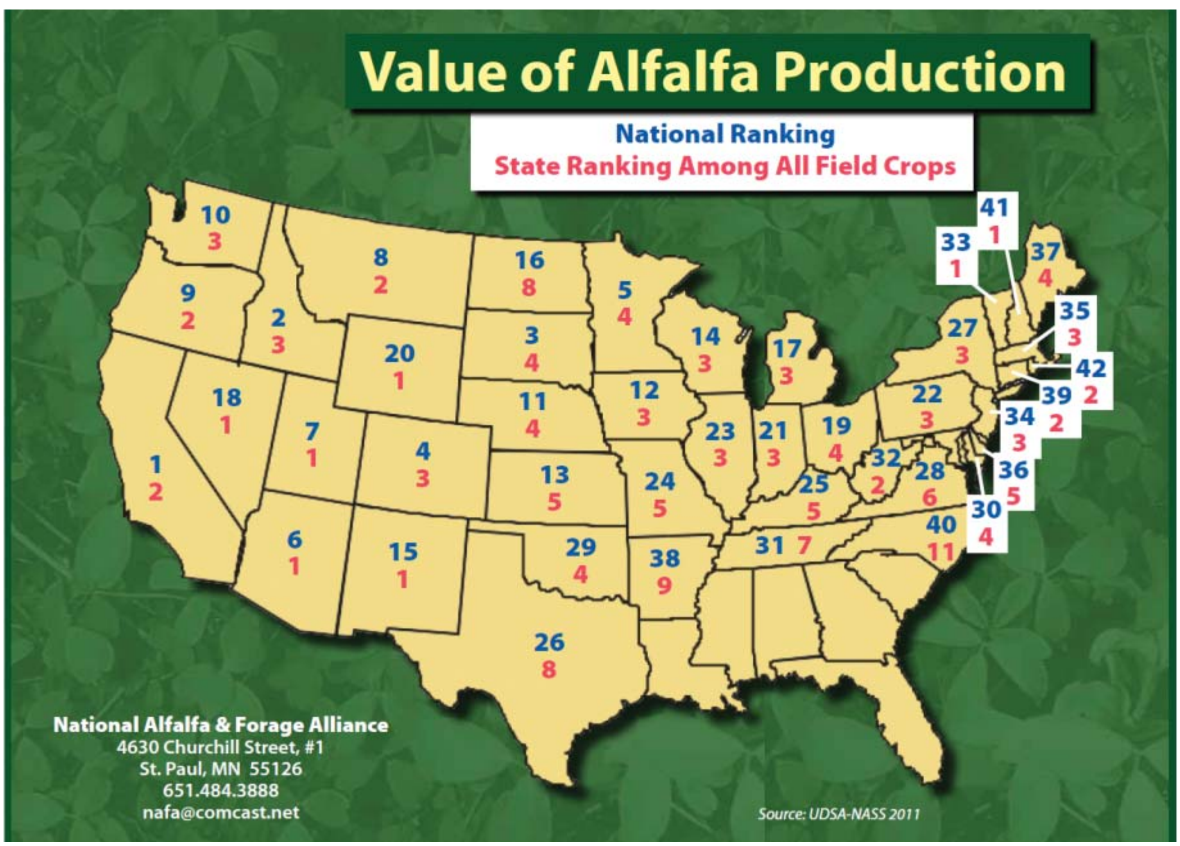


Fig. 1 Alfalfa is the fourth most produced crop in the U.S. In economic value, alfalfa ranks among the top three field crops in 26 states. This map shows the value of alfalfa production compared to other crops both on a national ranking (blue) and within individual states (red).

across the landscape by increasing yield, reducing labor requirements for harvest and storage, enhancing utilization by animals, developing new uses, and amplifying alfalfa's environmental services through improved nutrient management and other conservation benefits. This goal will be achieved through: 1) alfalfa improvement using new tools that accelerate and enhance existing breeding programs focused on protecting and improving forage yield; 2) developing innovative harvesting and utilization systems to change the perception that alfalfa is a labor-intensive, single use crop while uncoupling forage quality from yield – a factor limiting greater use of this highly productive crop; 3) developing new markets for co-products; and 4) quantifying a broader suite of environmental benefits from more reliable and resilient alfalfa-based agricultural systems. The remainder of this "roadmap" provides more details for each of the three research routes. Addendum 1 provides and an overview of specific research objectives, and Addendum 2 the locations of personnel conducting the research.

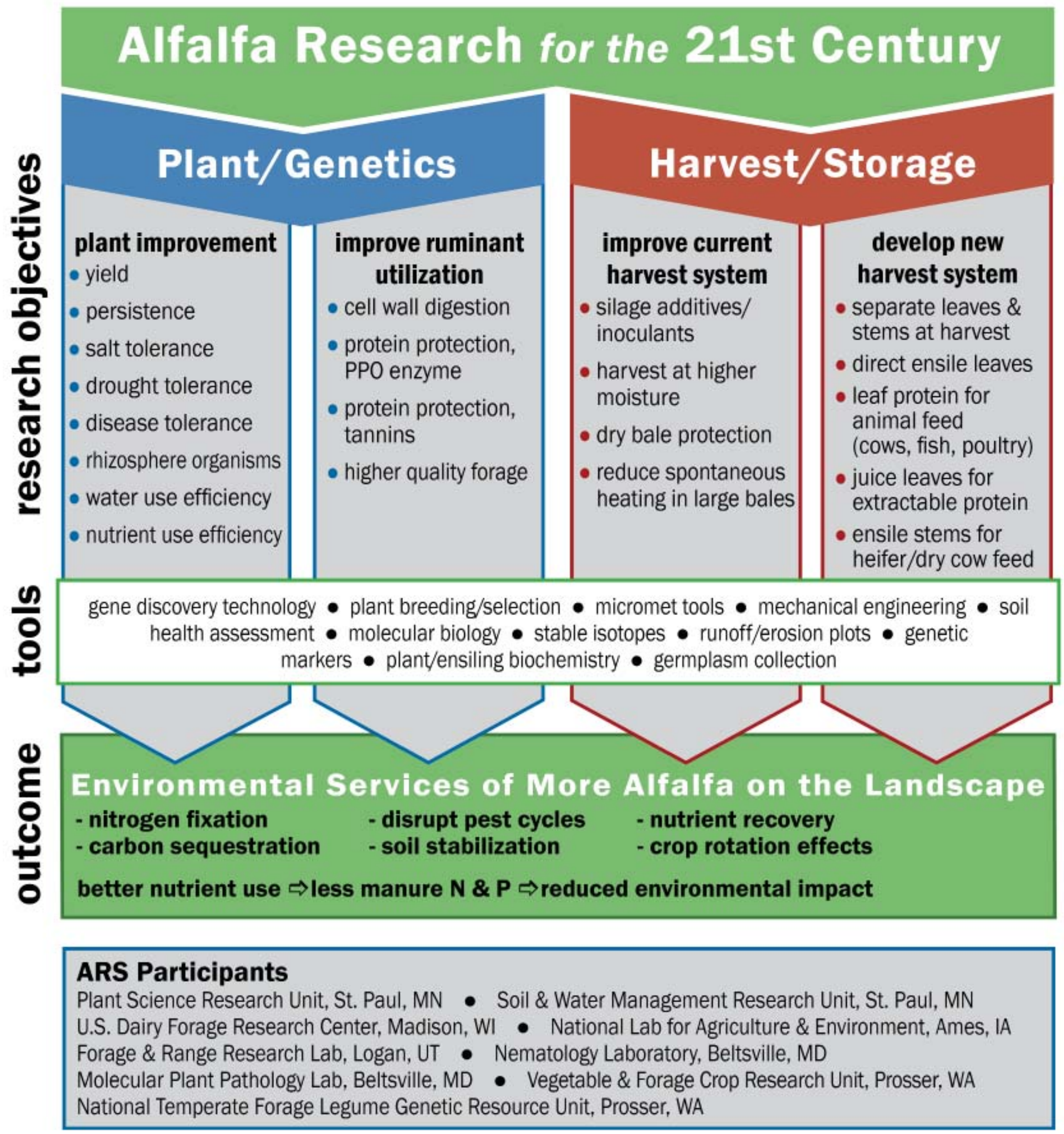


Fig. 2 The USDA-ARS *Roadmap for Alfalfa Research* is a comprehensive look at improvements needed in the alfalfa plant and its production, along with the routes, tools and personnel that will be used to achieve these improvements. The end goal is to increase the amount of alfalfa on the landscape to take advantage of its unique environmental services for improved agricultural sustainability.

Route A: Genetic Improvement of Alfalfa

Objective

Use genetic strategies to improve alfalfa and its utilization to increase farm and ranch sustainability and profitability (Addendum 1).

Genetic improvement of alfalfa is difficult due to its complex genome and general intolerance of inbreeding. Alfalfa varieties are typically constructed as synthetic populations as opposed to the development of individual hybrids. As a result, alfalfa has lagged behind other field crops in yield and other complex trait gains over the past several decades (Figure 3). Although alfalfa yields have increased since the late 1950's, yield gains have not kept pace with grain crops.

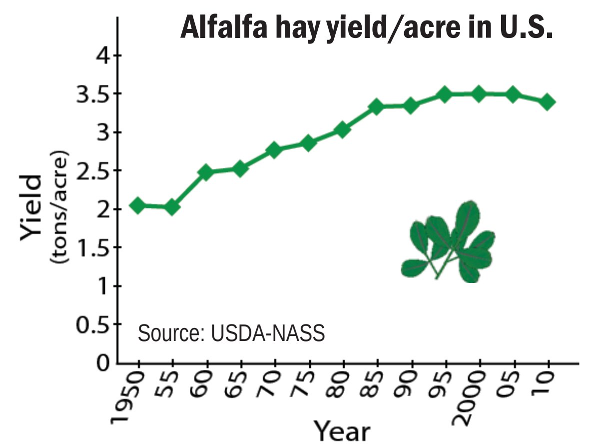


Fig. 3 Yield gains of alfalfa per acre have been small over the last 60 years, especially in the past 20.This is largely because breeders have selected for higher quality over yield.

In many cases, forage production has not reflected the current genetic potential of modern alfalfa varieties due to: selection of varieties poorly suited to specific conditions on a grower's farm; poor weed, pest, harvest, and soil fertility management; and growing on poor quality land with soil compaction or filtration issues. Higher alfalfa yields can be achieved through use of better management practices and also through genetic selection of quantitative traits that increase yield.

Despite widespread use in other crops, the development and utilization of genetic and genomic tools that support marker-assisted selection have been slow in alfalfa. Such tools are needed to accelerate breeding approaches to achieve the improved crop yields and stand persistence desired by alfalfa producers. These tools complement gene transfer approaches used for proof-of-concept, as well as gene transfer of value-added traits that are not currently available in alfalfa.

Molecular Markers to Facilitate Breeding

An advanced "breeder's tool box" is needed that integrates phenotypic, genotypic gene, and molecular marker data to accelerate evaluation of parents and breeding strategies through marker-assisted selection. Single nucleotide polymorphisms (SNPs) and single sequence repeats (SSRs) have been used extensively in other crops to greatly improve the efficiency and speed of plant breeding.

ARS scientists will sequence DNA and RNA from genetically diverse lines of alfalfa to identify SNP and SSR markers that will serve as a resource for the alfalfa community to improve breeding approaches and to understand plant response to biotic (pathogens and pests) and abiotic (drought and salinity) stresses. Molecular maps and mapping populations will be developed. This information will be integrated into a breeder-friendly database with web-based tools for assimilating marker-assisted selection into breeding programs.

Exploit Genetic Diversity and Identify Genes Controlling Agronomic Traits

Utilization of DNA markers for simple and inexpensive paternity testing has the potential to double the breeding gains in this genetically complex out-crossing crop. Affordable paternity identification techniques could be the trigger to enhance breeding traits such as forage yield and stand persistence. Identification of both parents would enable breeders to pinpoint specific combining ability (hybrid vigor) between individuals and determine the best parents through offspring performance.

ARS scientists will utilize paternity testing to identify the best parents and to capture heterosis to increase forage yield and stand persistence. Determination of molecular mechanisms that underly valuable agronomic traits such as abiotic and biotic stress resistance, nutritive value, and yield has led to significant germplasm improvement in most major crops. Identification of these mechanisms has lagged in alfalfa, but the genomic tools developed for the model plant *Medicago truncatula*, a close relative of alfalfa, and the *Medicago* germplasm collection resources have great potential for application to alfalfa.

ARS scientists will use RNA sequencing of alfalfa plants with desirable agronomic traits to identify genes useful for improving alfalfa through breeding and genetic engineering. Molecular approaches will be used to introduce desirable genes or to silence appropriate genes, leading to improved functionality of alfalfa (e.g., protein protection, increased fiber digestibility).

Genetic Characterization of Alfalfa Nematodes and Pathogens to Benefit Diagnostic and Breeding Efforts

Development of alfalfa varieties with improved pest resistance is challenging due to ever changing nematode and pathogen populations. ARS scientists are applying modern molecular tools to characterize the genetic diversity and track geographic distribution of nematode and pathogen populations that impact alfalfa in the U.S. Phenotypic screening for alfalfa resistance to nematodes and pathogens currently requires tedious evaluation of symptoms in individual plants. ARS scientists will exploit nematode, pathogen and/or plant genes expressed during the early stages of infection as molecular markers to more clearly define resistant and susceptible germplasm. Molecular screening methods should improve the speed and accuracy of breeding efforts and lower the incidence of false-negatives or false-positives during germplasm evaluation. Research is also being conducted to characterize the association of nematodes and fungal endophytes on alfalfa to discover novel relationships with crop productivity or improved adaptability to arid sites.

Outputs

- Alfalfa with improved persistence under drought and saline conditions and resistance to nematodes and pathogens.
- Alfalfa with increased yield, maintaining a high proportion of leaves in the harvested biomass.
- Improved nutritive value parameters, i.e., protein quality and preservation and fiber digestibility.

Outcomes

Expand the production range of alfalfa into areas that are currently hampered by biotic and abiotic stresses, thereby broadening cropping alternatives to include alfalfa and improve agricultural sustainability.

Route B: Innovations in Harvesting, Processing and New Products

Objective

Develop harvest and storage technologies to enhance alfalfa feed quality and develop new products (Addendum 1).

Weather, labor, time, and other difficulties in managing alfalfa have resulted in an expansion of corn-based grain and silage into dairy and beef rations. Current alfalfa harvest systems are also hampered by the need to balance digestible fiber and protein accumulation. These factors have led

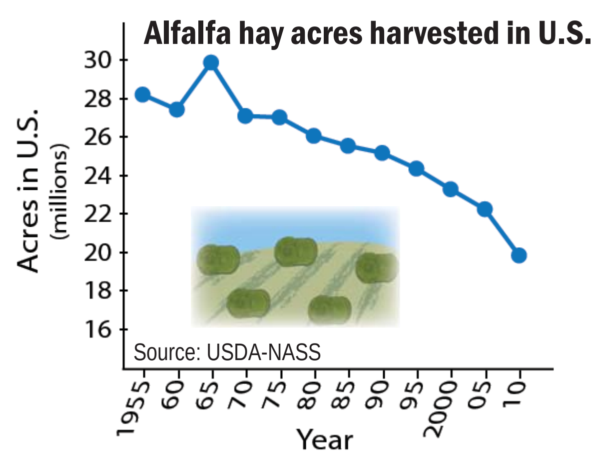


Fig. 4 The decline in acres of alfalfa produced in the U.S. has been significant as more land has shifted toward the production of row crops.

to a decline in the number of acres of alfalfa production over the last few decades (Figure 4).

A major innovation in alfalfa management and field harvesting is being developed that uses equipment to separate high-protein leaves from high-fiber stems. This strategy would optimize the use of both plant fractions in ruminant diets so that an appropriate and consistent nutrient supply could be delivered and fed to different animal groups. This novel approach reduces the risk of adverse weather on crop harvest and increases yield by capturing 30% of plant material that is typically lost with current harvest practices. This alternative strategy reduces the frequency at which the crop needs to be harvested by at least 25%, a potential major savings in labor and fuel.

New Harvesting System and Value-Added Products

Initial evaluations of an innovative prototype harvester successfully demonstrated that high protein leaves can be separated from high-fiber stems, thus optimizing the use of both plant fractions in animal diets (Figure 5).

Creation of two separate product streams (leaves and stems) widens the harvest window for farmers, and uncouples harvest time from stage of plant development. Routine ensiling practices may need to be modified to accommodate the higher moisture leaf material. It is anticipated that modifications would be minimal, as there should be high levels of sugar available in the leaf fraction to support rapid fermentation. The farmer can recombine the two fractions in optimal proportions for diet requirements of different animal groups such as high-producing dairy cows, dry cows, or heifers. Protein from leaves could also be used to produce supplements for poultry or possibly human diets. Moreover, this new harvest approach creates a new feedstock stream for producing value-added products. Leaf protein could serve as a raw material base for industrial uses, while stems could be used in various bioenergy or bio-product applications.

New bio-refinery facilities will soon begin producing liquid fuels from crop residues such as corn stover and switchgrass. Without proper land management practices, widespread corn stover harvest could have decidedly negative environmental impacts, particularly with regard to loss of soil organic matter and increased soil erosion. Alfalfa does not have this same challenge due to the large amount of carbon sequestered in its deep root system. The alfalfa harvest strategy that separates leaves from stems could also open the door for wider use of alfalfa across rural landscapes, thereby increasing carbon sequestration in soils and providing an additional source of biomass from stems for biofuel conversion facilities. These alternative yet complementary harvest strategies could further enhance environmental benefits of alfalfa and provide greater economic stability than do current corn or corn-soybean rotation production systems.

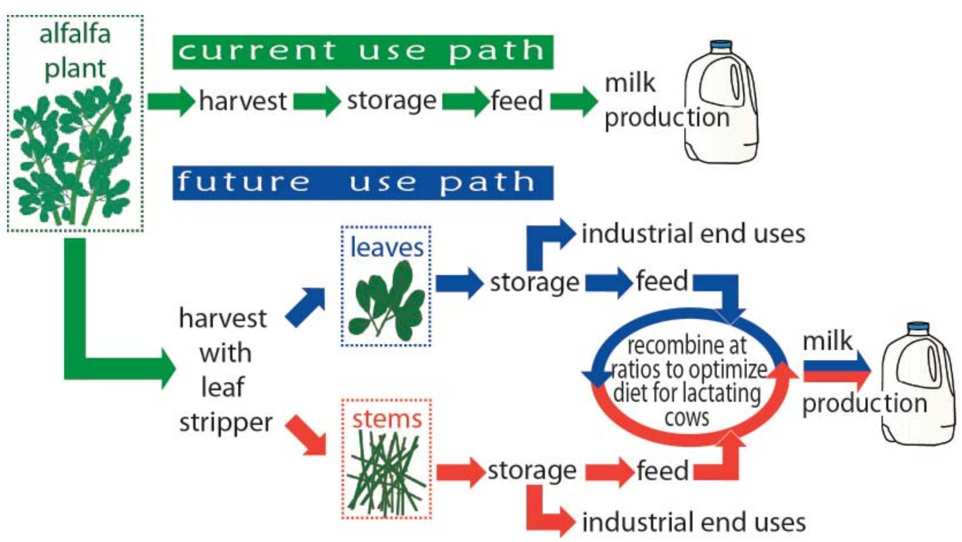


Fig. 5 A new system being developed for alfalfa harvest uses equipment to separate high-protein leaves from high-fiber stems. This strategy would optimize the use of both plant fractions in ruminant diets, reduce the risk of adverse weather on crop harvest, increase yield by capturing 30% of plant material that is typically lost with current harvest practices, and reduce the frequency of harvest by at least 25%.

Outputs

- Development and commercialization of an efficient new harvesting system that separates alfalfa leaves from stems during harvest.
- Development of new storage practices that allow direct ensiling of high-moisture leaf material.
- Development of high-protein leaf products for animal feed supplements and industrial products.
- Development of alternative uses and products for high-fiber stems.

Outcomes

Expanded use and efficient utilization of alfalfa on dairy farms and in sustainable agricultural systems that lead to increased acreage of alfalfa in crop rotation with grains to improve environmental and economic status of farming systems across the U.S.

Route C: Quantifying Environmental Benefits of Alfalfa

Objective

Develop and evaluate farming systems that strategically incorporate alfalfa on the landscape to reduce the negative environmental impacts of row crop and livestock agriculture (Addendum 1).

Alfalfa provides a variety of critical environmental benefits, including a "rotation effect" which increases subsequent crop production beyond what can be explained by enhanced nitrogen supply alone. A better understanding of these rotational benefits of alfalfa is a prerequisite to wider adoption of alfalfa-based cropping systems and development of novel agronomic practices that exploit the attributes of alfalfa to improve the environmental footprint of agriculture.

Cropping Systems for Enhanced Production

Crop rotation is the "black box" of agronomic science. Two or more years of alfalfa growth increases subsequent corn grain yields by 5 to 15% compared to corn grown with nitrogen fertilizer equivalent to that provided by alfalfa, but the underlying mechanism for yield improvement is unknown (Figure 6).

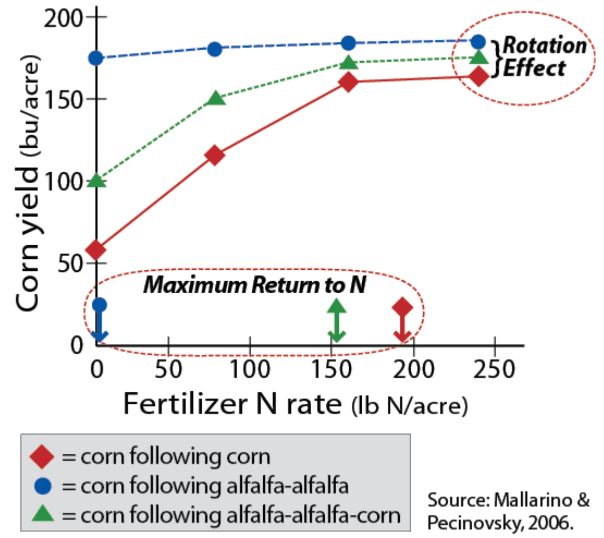


Fig. 6 First-year corn grown after alfalfa may have 10 to 15% higher yield portential due to factors other than the nitrogen supplied by alfalfa; this is known as the 'rotation effect' and is shown on the upper right corner of the graph. The graph also shows the yield response to fertilizer nitrogen for continuous corn and corn following alfafla (lines) and the maximum return to nitrogen (arrows at bottom).

ARS scientists will investigate the role of microbial partners that contribute to the rotational effect and thus develop new land management strategies to optimize the benefits of growing alfalfa. Metagenomic approaches will be used to identify microbial populations that are associated with alfalfa and corn roots grown in rotation, but are not enhanced in continuous corn or corn-soybean rotation systems.

Living mulches have been shown to have economic and environmental benefits. Alfalfa and other legumes will be tested and developed as living mulches into which annual crops like corn can be planted with the aid of zone tillage. Such systems will allow harvest of both grain for feed and industrial uses and crop residues for livestock feed or energy production while providing erosion protection, maintaining soil organic matter, and supplying nitrogen for subsequent corn crops. These types of cropping systems are already in use for corn silage production and have been shown to produce silage yields equivalent to conventional corn while significantly reducing nitrate-leaching losses.

An additional advantage of these integrated systems is that they combine the spring and fall growth of perennial legumes with the high mid-season photosynthetic capacity of corn, and they are potentially capable of achieving a much higher annual productivity than either system alone. However, broad-scale adoption of these systems has been slow because they present new management challenges and need additional research to develop economically viable production strategies.

Greenhouse Gas Reduction and Climate Change Mitigation

It has been suggested that nitrogen fixed by legumes is much less susceptible to gaseous loss as nitrous oxide than fertilizer nitrogen. This is critical because the global warming potential of nitrous oxide is 300 times that of carbon dioxide. There is evidence that alfalfa sequesters more carbon dioxide as soil carbon than annual row crops because of its longer photosynthetic season and deeper root system. ARS scientists will conduct definitive, comparative measurements of nitrous oxide and soil carbon changes for both alfalfa and annual row crops to document their relative greenhouse gas footprints.

Water Quality Improvement

Alfalfa can prevent and remediate nitrate contamination of ground water, but there are also instances where significant nitrate leaching has occurred following an alfalfa production cycle. Another problem with some perennial legumes is that much of the fresh or preserved feed nitrogen is not fully utilized by livestock and is therefore excreted as waste. Increasing the concentration of enzymes (i.e., polyphenol oxidases, *o*-diphenols) and polyphenols (i.e., tannins) could protect plant proteins and reduce loss of plant nitrogen in livestock excrement. ARS scientists are pursuing molecular, genetic, and selection strategies to increase the presence of these compounds, with the goal of improving nitrogen use efficiency and reducing manure nitrogen losses.

Outputs

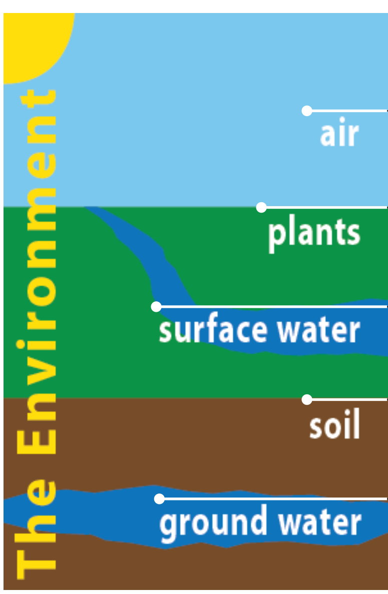
- Identification of microbial communities and plant traits that contribute to positive benefits of alfalfa in rotation with other crops.
- Determination of the extent and value of carbon sequestration and decreased nitrous oxide emissions from alfalfa-annual grain crop rotations.
- Cropping systems to improve production capacity while maintaining soil health, especially when using corn stover for bioenergy production.

Outcomes

Increased use of alfalfa in crop rotations to improve soil health, decrease soil erosion, and increase environmental and economic sustainability of farming operations.

Environmental Benefits of Alfalfa

(compared to row crops such as corn and soybeans)



air	**Captures more sunlight/more photosynthesis/more carbon. Captures carbon for a longer time period in the growing season.**
plants	**Provides nitrogen/improves nutrient uptake for subsequent crops. Breaks pest life cycles when used in rotation with other crops.**
surface water	**Less surface runoff. Less phosphorus lost to surface water.**
soil	**Less soil erosion. More soil carbon sequestration.**
ground water	**Less nitrogen leached to ground water.**

Addendum 1

Route A Objective:

Use genetic strategies to improve alfalfa and its utilization to increase farm and ranch sustainability and profitability.

Sub-Objective	Sub-Sub-Objective	Personnel/ Collaborators *(see Addendum 2 for explanation of acronyms)*	Anticipated Product(s)
1-1. Develop molecular genetic resources, techniques and tools to improve environmental adaptation, persistence, production, and animal feed quality, as well as new products for alfalfa.  	1-1-1. Investigate expression and regulation of genes associated with alfalfa development. Develop markers to identify tolerance to abiotic stresses including: drought, salinity, and temperature extremes (heat and cold).	FRRL MPPL PSRU VFCRU *(Need ARS Minn. position to link SNPs SSRs to traits.)*	Genetic markers for tolerance to drought, salinity, heat, and cold.
	1-1-2. Develop markers to identify resistance to biotic stresses including Verticillium wilt, Aphanomyces root rot, and stem nematode.	MPPL NL PSRU VFCRU	Markers to identify pest species; markers for resistance to pests and pathogens.
	1-1-3. Develop markers for increased forage yield components.	FRRL PSRU	Markers for forage yield components: large stems, robust crowns, delayed leaf senescence, rhizome development, and persistence.
	1-1-4. Develop markers for increased metabolizable energy, reduced proteolysis, and increased microbial protein in alfalfa for dairy.	PSRU DFRC	Markers for polyphenol oxidase, polyphenols (tannin), rumen undegraded protein, cell wall cellulose, soluble carbohydrates and pectin.
	1-1-5. Identify trait markers for new uses for and new products from alfalfa.	DFRC	New products from alfalfa: proteins for industrial use (paper coatings, films, additives, etc.)
1-2. Use traditional approaches, including screening the *Medicago* germplasm collection, and marker assisted plant breeding methodologies to identify parents with improved environmental adaptation, persistence, production, and animal feed quality, as well as traits for new products for alfalfa. 	1-2-1. Increase tolerance to abiotic stresses including: drought, salinity, heat, cold, and pH in alfalfa.	FRRL VFCRU NTFLGRU	Germplasms that persist and yield more when exposed to heat, cold, salinity, drought, and acidic soils.
	1-2-2. Increase resistance to biotic stresses including stem and root knot nematodes, Aphanomyces root rot, and Verticillium wilt.	MPPL NL PSRU VFCRU	Germplasms resistant to stem and root knot nematodes, Aphanomyces root rot and Verticillium wilt.
	1-2-3. Increase forage yield. *(Utilize new mgmt. strategies discussed in Objective 2.)*	PSRU	Germplasms with increased yield.
	1-2-4. Increase metabolizable energy, reduced proteolysis, and increased microbial protein in alfalfa for dairy.	Consortium for Alfalfa Improvement DFRC PSRU	Germplasms with increased cell wall digestion, decreased protein degradation in the rumen, and with sufficient carbohydrate available to capture/produce additional microbial protein.
	1-2-5. Develop alfalfa for new uses and industrial products.	DFRC	New products from alfalfa: proteins for industry (paper coatings, films, additives).

Addendum 1, *cont.*

Route B Objective: Develop harvest and storage technologies to enhance alfalfa feed quality and develop new products.			
Sub-Objective	**Sub-Sub-Objective**	**Personnel/ Collaborators** *(see Addendum 2 for explanation of acronyms)*	**Anticipated Product(s)**
2-1. Optimize harvest conditioning equipment and ensiling techniques to stabilize nutrient value for feed and new industrial compounds.	2-1-1. Machinery improvement and technology development for extraction of new products from alfalfa forage	DFRC Case-New Holland	Development of new prototypes for harvesting leaves separately from stems, new ensiling processes.
	2-1-2. Ensile and juice alfalfa forage to enhance the extraction of value added industrial chemicals.	DFRC	New products from alfalfa: proteins for industrial use (paper coatings, films, additives, etc.).
	2-1-3. Ensile forage to preserve and enhance the protein profile for dairy feed.	DFRC	High-protein value material for supplementing dairy diet rations.
2-2. Optimize recently developed harvest technology that segregates leaves and stems to enhance alfalfa feed quality and develop new products.	2-2-1. Machinery improvement and technology development for separation of leaves and stems and production of new products.	DRFC Case-New Holland	Development of new prototypes for harvesting leaves separately from stems, new ensiling processes.
	2-2-2. Ensile leaves to preserve and enhance protein profile, extract protein for refined markets requiring low fiber content.	DFRC Rick Barrows (ARS Aberdeen, ID)	Alfalfa protein as a substitute for corn or soybean in other animal systems --poultry, beef, swine, aquaculture.
	2-2-3. Utilize leaves and/or stems for new chemical products (industrial application of protein, cosmetics, nutraceuticals).	DFRC Gordon Selling (ARS Peoria, IL) Mila Hojilla-Evangelists (ARS Peoria, IL)	Industrial use proteins (coatings etc), protein extraction for new products, lignin for phenolic compounds.
 	2-2-4. Develop alfalfa stems as an alternative high fiber feed source or energy feedstock.	PSRU DFRC	Lower-protein diets for dry cows, heifers, beef cattle, sheep production, or energy feedstock.

Addendum 1, *cont.*

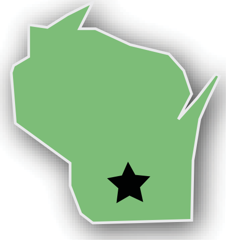
Route C Objective:

Develop and evaluate farming systems that strategically incorporate alfalfa on the landscape to reduce the negative environmental impact of row crop and livestock agriculture.

Sub-Objective	**Sub-Sub-Objective**	**Personnel/ Collaborators** *(see Addendum 2 for explanation of acronyms)*	**Anticipated Product(s)**
3-1. Use alfalfa to reduce the negative environmental footprint of dairy farming systems while improving profitability.	3-1-1. Utilize strip cropping, green mulches, timing of harvest to impact nutrient cycling and utilization (N/P/K/C).	PSRU SWMR	Development of improved management practices to better utilize soil nutrients.
	3-1-2. Quantify and contrast the life cycle, economic, and environmental benefits of alfalfa and corn silage in dairy rotations.	DFRC PSWRU SWMU Alan Rotz (ARS University Park, PA)	Development of improved analytical frameworks (IFSM) to determine best management strategies that enhance the sustainability of farming.
	3-1-3. Reduce losses of manure nutrients and movement of pathogens with strategic application to established alfalfa.	DFRC SWMU	Optimized combinations of alfalfa germplasms and manure application methods to protect water quality.
3-2. Quantify the performance of alfalfa in reducing the negative environmental impacts of bioenergy feedstock production systems.	3-2-1 Determine the feasibility of using alfalfa in rotation with energy crops to improve environmental conditions and increase profitability.	NLAE SWMU	Improved sustainability of bioenergy feedstock production systems.
3-3. Improve the amount and reliability of the estimated fertilizer N replacement value of alfalfa to following crops.	3-3-1. Determine whether stand decline due to root and crown diseases reduces the alfalfa N credit to first-year corn.	PSRU SWMU Jeff Coulter (Univ. of MN)	Improve the value of disease resistant alfalfa cultivars in crop rotations by enhancing yield of alfalfa forage and reducing the need for purchased fertilizer N for subsequent crops.
	3-3-2. Improve and validate new method(s) of predicting the fertilizer N replacement value of alfalfa.	PSRU SWMU Jeff Coulter (Univ. of MN)	Greater reliability of estimated fertilizer N replacement value of alfalfa, with improved economic and environmental outcomes on farms with alfalfa-corn rotations.

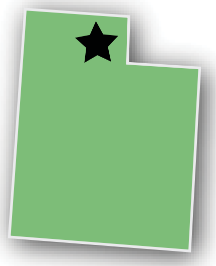
Addendum 2

Current ARS locations, units, and personnel involved in the Roadmap for Alfalfa Research



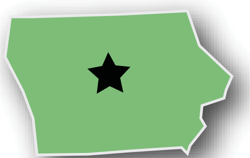
Dairy Forage Research Center (DFRC), Madison, Prairie du Sac, and Marshfield, WI

Geoffrey Brink, Research Agronomist
Mark Borchardt, Research Microbiologist
Wayne Coblentz, Research Agronomist/Dairy Scientist
John Grabber, Research Agronomist
Mary Beth Hall, Dairy Scientist
Ronald Hatfield, Plant Physiologist
William Jokela, Research Soil Scientist
Richard Muck, Agricultural Engineer
Michael Sullivan, Molecular Biologist (Plants)
Vacant, Dairy Scientist
Vacant, Agricultural Engineer



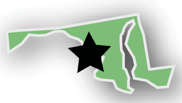
Forage and Range Research Laboratory (FRRL), Logan, UT

Michael Peel, Research Geneticist (Plants)
Ivan Mott, Research Geneticist (Plants)



National Laboratory for Agriculture and the Environment (NLAE), Ames, IA

Douglas Karlen, Supervisory Research Soil Scientist

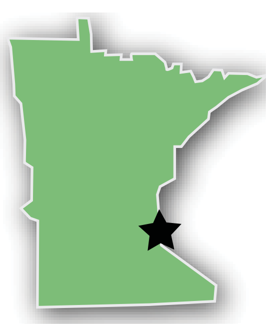


Molecular Plant Pathology Laboratory (MPPL), Beltsville, MD

Lev Nemchinov, Research Molecular Biologist

Nematology Laboratory (NL), Beltsville, MD

Andrea Skantar, Research Molecular Biologist



Plant Science Research Unit (PSRU), St. Paul, MN

John Gronwald, Plant Physiologist
JoAnn Lamb, Research Geneticist (Plants)
Michael Russelle, Research Soil Scientist
Deborah Samac, Research Plant Pathologist
Carroll Vance, Plant Physiologist

Soil and Water Management Research (SWMR), St. Paul, MN

John Baker, Research Soil Scientist

National Temperate Forage Legume Genetic Resource Unit (NAFLGRU), Prosser, WA

Stephanie Greene, Plant Geneticist

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