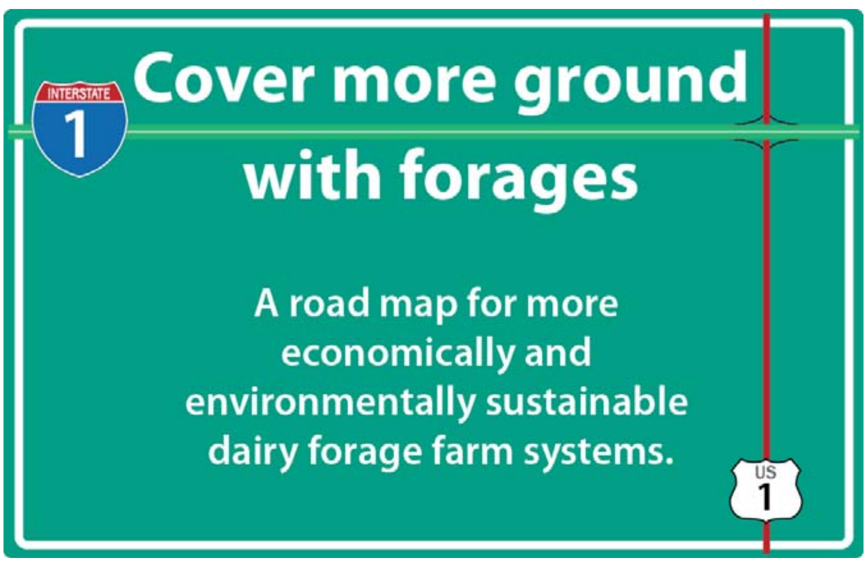
United States
Department of
Agriculture

National Dairy Forage Road Map



U.S. Dairy Forage Research Center

Agricultural Research Service
Madison, Marshfield, and Prairie du Sac, Wisconsin

March 2013

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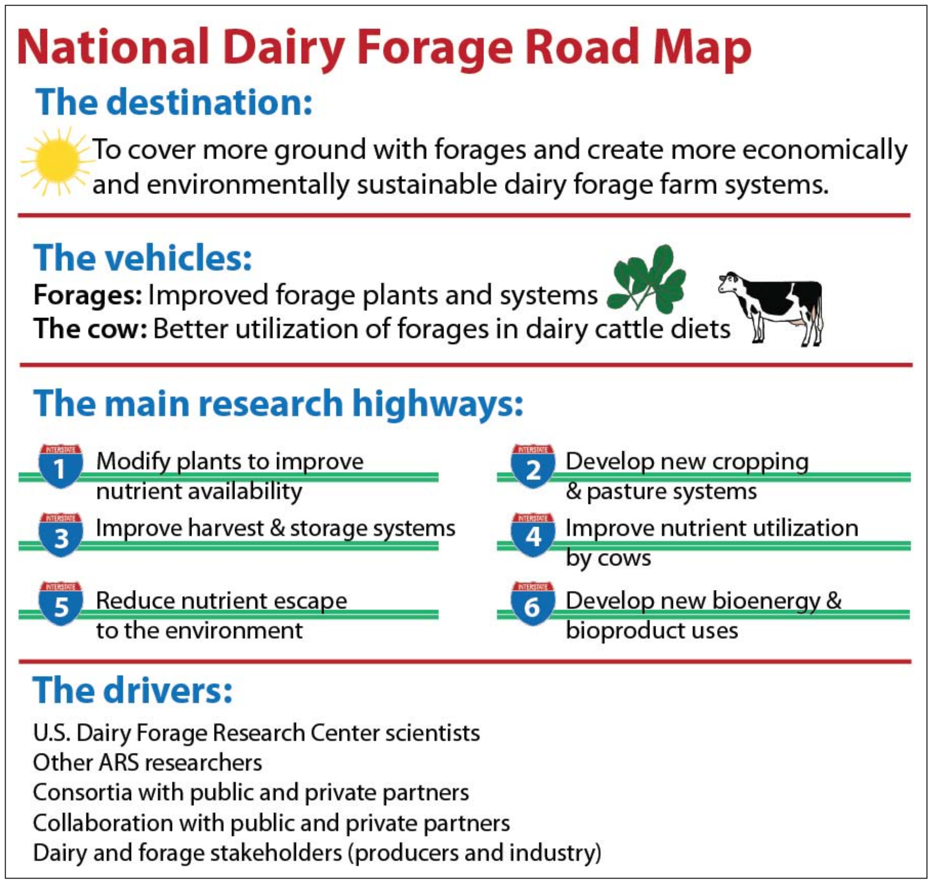
National Dairy Forage Research Road Map

Since 1981, ARS researchers at the U.S. Dairy Forage Research Center (USDFRC), Madison, WI, have been developing 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. The USDFRC is the only ARS unit with the mission of improving forage use by dairy cattle.

Through the years the USDFRC has successfully navigated through a changing landscape by updating CRIS projects, adding staff, and building the Environmentally Integrated Dairy Management Research Unit, Marshfield, WI. More recent changes have prompted the USDFRC to ask, “Is it time to create a new road map to help us navigate through these changes and beyond?” This is an attempt to do that – to create a road map for dairy forage research based on what we know are critical concerns facing the industry at this time – realizing that this road map will need to change, too, as the years advance.



This new road map is also being designed to include other drivers. The USDFRC has had several collaborative relationships with universities, other ARS units and private industry in the past. As updated research goals are placed on this new map, there is a concerted effort to find research partners who can leverage the work of the USDFRC and help provide the dairy forage industry with additional research results in a more timely manner.

The structure and goals for the road map

With a destination of more economically and environmentally sustainable dairy forage farm systems, forages and dairy cows are the vehicles. Based on past, current and future research at the USDFRC, six main highways have been identified as the routes to the final destination:

1. Modify plants to improve nutrient availability.
2. Develop new cropping and pasture systems.
3. Improve harvest and storage systems.
4. Improve nutrient utilization by cows.
5. Reduce nutrient escape to the environment.
6. Develop new bioenergy and bioproduct uses.

Who will drive the research?

It will take a team effort to complete all of the research needed to improve the economic and environmental sustainability of dairy forage farm systems. The USDFRC begins by identifying these key team members:

1. USDFRC researchers
2. Other ARS researchers
3. Consortia with public and private partners
4. Collaboration with public and private partners
5. Dairy and forage stakeholders (producers and industry)

First, follow the farm road map

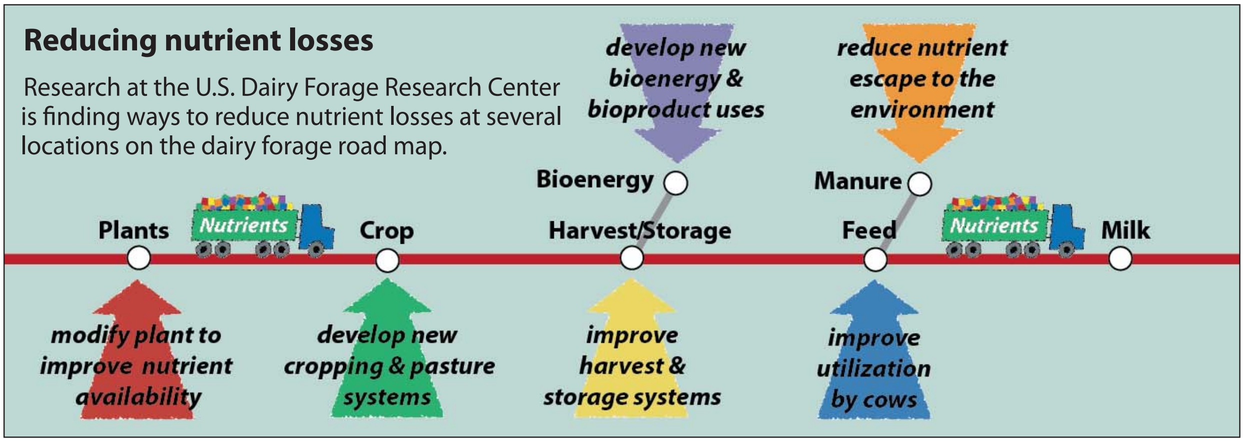
The National Dairy Forage Road Map is based on the road map that the nation's dairy and forage producers follow (see figure below). They plant some seeds, grow a crop, and harvest and store the crop for feeding to livestock, for sale to other livestock producers, or for

On-farm road map and fate of nutrients

The goal of an economically and environmentally sustainable dairy forage system is to make the best use of nutrients from start to finish -- to get those nutrients all the way from the forage plant to the milk produced without losing too many along the way. Lost nutrients cost money and can have a negative impact on the environment.

Reducing nutrient losses

Research at the U.S. Dairy Forage Research Center is finding ways to reduce nutrient losses at several locations on the dairy forage road map.



What are nutrients?

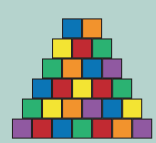
Elements, or building blocks, that all living things need to consume and assimilate in order to live. Examples include:

Humans, cows, other animals

carbohydrates	fats
proteins	vitamins
potassium	calcium
phosphorus	micronutrients

Plants

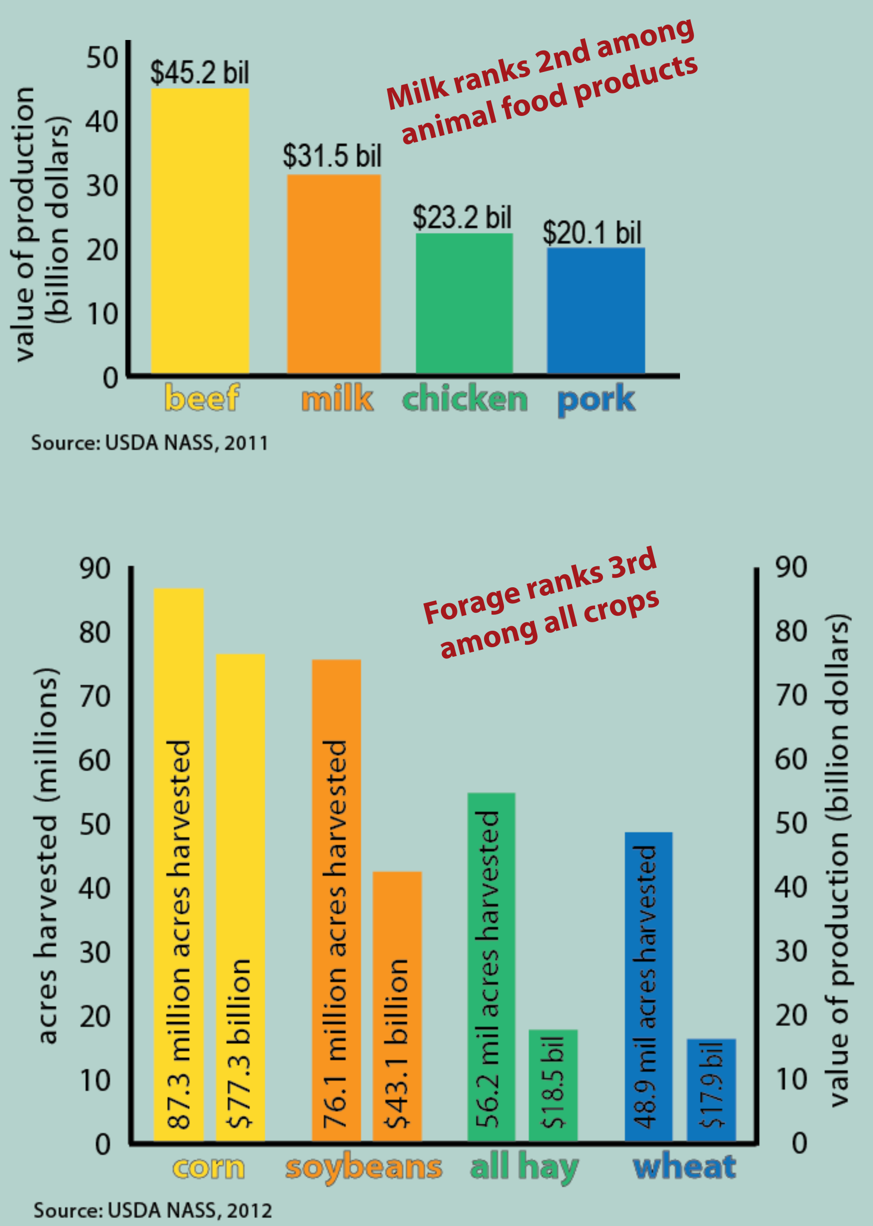
nitrogen	phosphorus
potassium	sulfur



sale as a bioenergy feedstock. The key to making the farm system both economically and environmentally sustainable is to keep nutrients from being lost along the way -- to capture nutrients to grow crops and feed animals that produce milk and meat.

Most of the research at the USDFRC is directly or indirectly aimed at making more efficient use of nutrients. The USDFRC is unique in that it takes a multidisciplinary, whole-systems approach to conducting research; the goal of capturing more nutrients must be a priority at every step in the farm system and with the knowledge of how a change in one part of that system affects the other parts.

Dairy and forage are economically significant among agricultural products produced in the U.S.



Striving for research that keeps pace with the changing times

Since the USDFRC was created in 1980, dairy and forage farmers have faced many new realities and challenges, and USDFRC research goals have adjusted accordingly. Also since 1980, new scientific methods and tools have been developed. This Road Map outlines some of the changes needed to help the USDFRC better leverage new tools and better answer new dairy and forage questions as they continue to emerge.

	1980	2012	Percent change	Implications for farmers and USDFRC research goals
Price of corn/bu*	$3.11	$7.20	+132%	In the past, cheap corn fueled large increases in milk production. Now dairy farmers must replace corn with more competitive feedstuffs, especially forages.
Price of nitrogen fertilizer (anhydrous ammonia)/ton*	$227	$783	+245%	Must find ways to capture more manure nutrients to fertilize crops. Must capitalize on the benefits of nitrogen fixation by alfalfa and other legumes.
Price paid for milk/cwt.*	$13.05	$18.50	+42%	Constant pressure for farmers to be more economically sustainable. With feed being the highest cost on dairy farms, research toward feed efficiency/nutrient utilization is crucial.
Avg. milk production (lbs./cow/year)*	11,891	21,697	+82%	Today's higher producing cows have different dietary requirements and challenges. The digestion data used to formulate diets need updating.
Use of byproduct feeds such as dried distillers grains, citrus pulp, almond hulls	Small volume, limited choices	Large volume, more choices		Dairy cows perform a great environmental service by consuming byproducts from the processing of food, fiber, alcohol, and ethanol. Farmers need more data to help formulate diets that best utilize these byproduct feeds.
Awareness of the need for environmental sustainability on farms	Low	High		There are many unanswered questions for research to address in order to advise farmers on best management practices for environmental sustainabilty.

* Source: USDA National Agricultural Statistics Service

The paradigm shifts

Here are some of the changes that have prompted the USDFRC to create a Road Map that will help plan for the future:

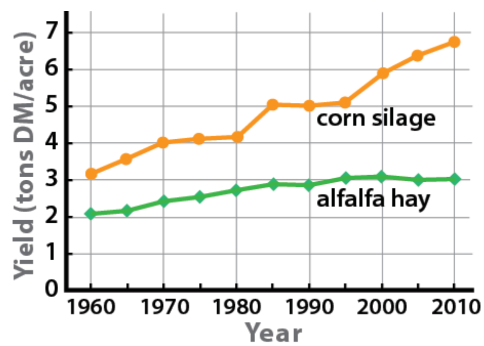
1. Increased competition for corn that has driven up grain prices for dairy producers who will have to rely more heavily on forages.
2. Increased milk production in dairy cattle that has changed the way diets are formulated.
3. New scientific methods that allow for new research.
4. Increased interest in the environmental impact and carbon footprint of dairy farming.
5. Recent and pending retirements of some USDFRC scientists.
6. An aging research farm at Prairie du Sac, WI.

Modify plants to improve nutrient availability

Why have we chosen this highway?

Perennial forages play key roles in the diet and health of dairy cattle, as well as the environmental sustainability of dairy farms. Forages are major sources of fiber, protein and energy in dairy cattle rations, often comprising at least 40% of the diet for lactating cows and nearly 100% of the diet of non-lactating cows and growing heifers. Forage fiber stimulates rumination and saliva production which helps maintain a healthy, effective digestive system and reduces disorders such as laminitis (hoof disease that causes lameness) that are affected by diet. Perennial forages minimize soil erosion. Their deep roots reduce the loss of nutrients to ground water, allow greater productivity in drought than grain crops, and sequester carbon deeper in the soil profile than other crops. Leguminous forages provide substantial supplies of nitrogen to succeeding crops in rotation, minimizing the need for commercial fertilizer. Many of these characteristics allow perennial forages to be grown on marginal lands that are not well suited for grain production. This maintains higher overall agricultural production levels without competing for land capable of direct human food production.

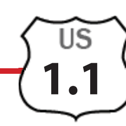
Figure 1: Increase in yield for corn silage compared to alfalfa hay, on a dry matter basis.



Source: USDA-NASS

In spite of these benefits to both livestock and the land, perennial forage production in the U.S. is declining. Dairy producers have gradually shifted acreage away from perennial forages to corn and corn silage. One reason for this shift is that yields of perennial forages have not increased at the pace observed in corn (Figure 1). Another reason is, as milk production has increased, lactating dairy cattle need more energy-dense diets; the easy solution has been to feed more grain, but that has led to more digestive and health issues in dairy cattle, and it diverts grain away from other food or industrial uses. A better solution would be to improve the digestibility of forage fiber, thereby making more plant energy available to the cow. Finally, protein in many of our forages (particularly alfalfa and ryegrass) is so digestible that it is not used efficiently by the cow, resulting in more dietary nitrogen being excreted in urine, contributing to ammonia emissions. Here are three ways that the USDFRC is working, in collaboration with others, to modify plants.

Increase yield and persistence



Since 1940, the average yield of corn has more than tripled in the U.S., whereas yields of alfalfa and other perennial forages have increased on the order of 50%. Improvements in perennial forage yields have been hampered by the complexity of the legume and grass genomes and the inability to develop in-bred lines as has been employed to develop varieties in corn and other crops. However, new genetic and genomic tools are being developed that hold promise toward making substantial improvements in forage yield and persistence. Primary efforts in ARS toward improving alfalfa yield and persistence are at St. Paul, MN. The USDFRC is charged with improving other legumes and grasses for dairy production.

With both legumes and grasses, genetic marker-assisted selection is being used in conjunction with traditional breeding techniques to make advances. On the legume side, a new marker-assisted paternal half-sib selection process developed at the USDFRC appears to be a promising avenue toward improving yields and other traits in alfalfa, red clover and birdsfoot trefoil. Efforts are directed at improving grasses and legumes for pasture use as well as conventional harvesting. Specific efforts in grasses are directed toward decreasing the cross-linking due to ferulates in cell walls. There have been, and will continue to be, efforts to improve forages for biomass uses as detailed later.

Drivers for Research

USDFRC	Sullivan, Riday, Casler
Other ARS	Lamb, Samac (St. Paul, MN)
Consortia	Consortium for Alfalfa Improvement (CAI)
Collaborators	
Stakeholders	Forage Genetics, Pioneer

US 1.2

Increase cell wall digestibility

Improving the energy conversion efficiency of forage cell walls (by ruminants or for bioenergy) is vital to maximizing the utilization of biomass produced on farmlands. For example, a 10% improvement in cell wall digestibility of forages by dairy cows in the U.S. would produce $350 million annually in increased milk and meat production; reduce grain supplements by 2.8 million tons, thereby saving dairy farmers $450 million in grain costs; and reduce manure solids by 2 million tons. Past efforts to improve digestibility via breeding efforts have had limited success. Consequently, basic research to understand cell wall structure and what components of the cell wall limit digestibility has been needed. Cell wall research at the USDFRC has already identified several enzymes for making lignin that appear to affect digestibility. Through collaboration with partners in the Consortium for Alfalfa Improvement, a cultivar of alfalfa that cannot produce the COMT enzyme, and has substantially better fiber digestibility, is nearing commercial release.

For the plant, cell walls are crucial for structure and rigidity. But when cows eat forage plants, cell walls are slowly digested and they limit utilization of the remaining nutrients in the plant.

While this is an encouraging step forward in alfalfa, there are multiple approaches (targets) to increasing cell wall digestion in legumes and grasses that need to be investigated because it is not as yet clear which approach may be most successful with a given forage species. These approaches include decreased cell wall cross-linking, increased readily digestible cell wall components (e.g., pectins), and altered lignification (amount/composition/location). As we understand which

Economic Sustainability

A 10% improvement in forage cell wall digestibility by dairy cows in the U.S. would produce $350 million annually in increased milk and meat production and save dairy farmers $450 million in grain costs.

Environmental Sustainability

The improved feed efficiency from a 10% improvement in forage cell wall digestibility by dairy cows would reduce manure solids by 2 million tons per year and thereby reduce nutrients being lost to the environment.

approaches have the most promise, targeted selection for increased specific cell wall traits or genetic modifications are more likely to be successful in developing forage cultivars with improved digestibility.

Drivers for Research

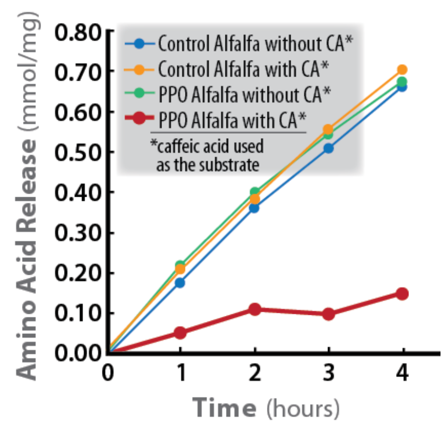
USDFRC	Hatfield, Zeller, Grabber
Other ARS	Lamb, Samac (St. Paul, MN), Sarath (Lincoln, NE)
Consortia	Consortium for Alfalfa Improvement (CAI)
Collaborators	Qu (NC State)
Stakeholders	Forage Genetics, Pioneer

Improve protein utilization

US 1.3

Excessive protein degradation during forage storage results in significant economic losses in agricultural production – as high as $102 million annually for alfalfa alone. These are direct losses to the producer and do not take into account other potential economic costs or environmental impacts due to increased nitrogen in animal wastes (e.g., increased nitrogen contamination of groundwater, nitrate in runoff, ammonia volatilization). Two naturally occurring systems in some forages, if successfully transferred to alfalfa, could be useful in protecting forage proteins during storage (Figure 2) and improving nitrogen utilization by the cow: the polyphenol oxidase (PPO)/*o*-diphenol system in red clover, and tannins in legumes such as birdsfoot trefoil. The USDFRC has been at the center of discovering how the PPO system works in red clover and at isolating key genes. More research is needed to allow potential duplication of that system in alfalfa and other forage species.

Figure 2: Protein degradation, as measured on the vertical axis, is greatly reduced (red line) when a PPO-containing alfalfa plant is ensiled with a caffeic acid substrate.



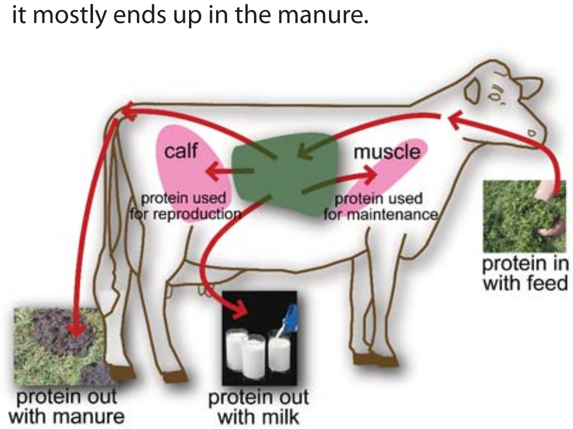
Source: Hatfield & Sullivan, USDFRC

The tannin system is complicated, and it is already known that some tannin-containing forages improve nitrogen utilization in the cow, whereas other forages have tannins that overprotect proteins so that the protein is not digested, but excreted, from the cow. Determining what types and concentrations of tannins are optimum for protecting forage proteins in the silo, while retaining the possibility of digestion in the rumen or lower gut, is critical for selecting the best tannin-containing forages for harvest.This effort also should lead to forage cultivars for pastures with better nitrogen utilization by cows.

Drivers for Research

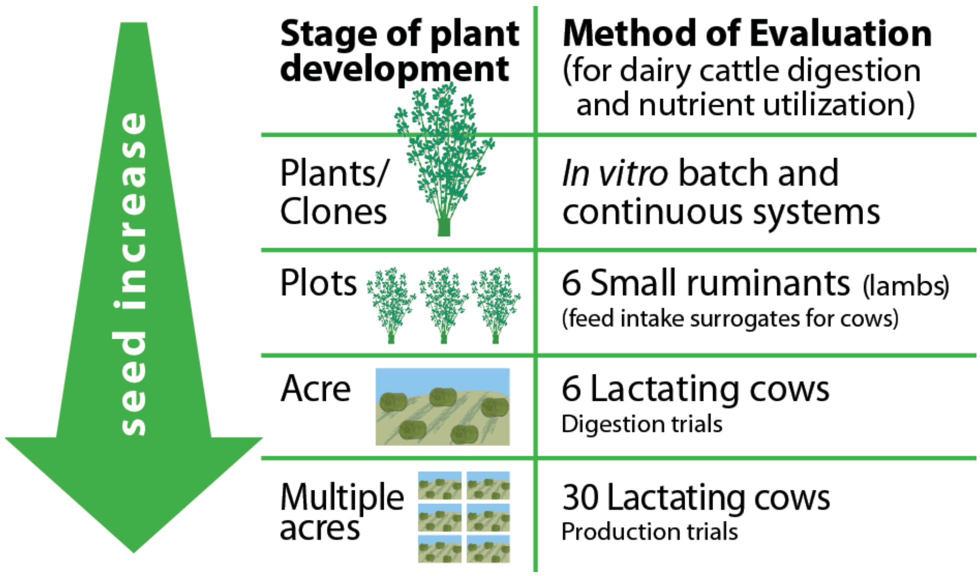
USDFRC	Sullivan, Hatfield, Zeller, Grabber, Coblentz
Other ARS	
Consortia	Consortium for Alfalfa Improvement (CAI)
Collaborators	Institute of Biological, Environmental and Rural Sciences, Aberystwyth University (UK); University of Reading (UK)
Stakeholders	Forage Genetics, Pioneer

If protein consumed by the cow is not efficiently captured for milk production or body maintenance, it mostly ends up in the manure.



Template for Plant Modification Research

This diagram illustrates a "template for research" at the USDFRC. Because the Center works with both plants and animals, it can conduct animal nutrition studies at the various steps in the plant cultivar development/seed increase process so that cultivar development isn't taken too far without knowing how the animal will respond to the improved plant.



Develop new cropping and pasture systems

INTERSTATE 2 cropping & pasture systems

Why have we chosen this highway?

With the development of improved forage species comes a need for improved management practices. Full benefits of these forages are typically realized when forages are part of a crop rotation and a component of an integrated dairy farm. So crop management must be integrated within the needs of the whole-farm system, minimizing both feed costs and impact on the environment. Dairy farms often utilize many different crops to meet the forage needs of both cows and replacement heifers. Historically, management strategies have sought to maximize forage yield while maintaining acceptable quality characteristics in order to support profitable milk production; this approach usually has been associated with harvest (mechanical or grazing) of various perennial and annual crop species at specific stages of plant growth and/or development.

However, comprehensive nutrient management planning has created a new criterion for crops, which is uptake and removal of nutrients deposited via application of manure. Dairy enterprises are now looking for improved cropping strategies that remove manure nutrients from soil, as well as limit nutrient losses through surface runoff. In addition, dairy enterprises need cropping programs that open opportunities for manure application during the summer and/or provide other options besides those traditionally occurring either before or after corn production. In the future, it also is likely that increased emphasis will be placed on sequestering carbon, thereby establishing another management hurdle in addition to removing nitrogen, phosphorus or potassium supplied from application of manure.

Improve methods for interseeding and living mulches US 2.1

Establishing alfalfa by interseeding into corn rather than by conventional spring-seeding after corn could double first-year yields of alfalfa, but interseeding is currently unworkable because competition between the co-planted crops leads to frequent stand failure of alfalfa and reduced yield of corn. Our goal is to identify plant growth regulator treatments and management practices that will boost successful establishment of interseeded alfalfa and limit yield depression of corn. An economic analysis suggests such a system could improve the profitability of first year alfalfa by about $80 to $160 per acre compared to conventional spring-seeded alfalfa. Preliminary studies suggest foliar applications of prohexadione-calcium (a gibberellin inhibitor) on interseeded alfalfa can substantially enhance its establishment and subsequent yield during forage production while lessening yield depression in corn. Additional work with prohexadione and related growth regulators is needed to develop workable production systems for farmers.

The alfalfa on the left was interseeded into corn with application of growth inhibitors the previous growing season. The alfalfa on the right was planted the following spring.

Living mulches incorporated into row crops can provide additional value to crop production systems, not only in terms of soil stabilization, but also as nutrient amendments. Much work is needed to identify appropriate forages that can grow quickly in the spring to provide a much needed crop cover. These same forages must be able to survive under dense canopies as the row crop develops during the height of the growing season. Unique forages such as rhizomatous alfalfa may provide opportunities to fit into this type of cropping strategy. Genetic selection may prove useful in selection of improved germplasm that best fits this growing niche.

Drivers for Research

Red clover as a cover crop for corn.

USDFRC	Grabber, Brink, Hatfield
Other ARS	Lamb, Baker (St. Paul, MN); Karlen (Ames, IA)
Consortia	
Collaborators	Lauer, Renz (UW)
Stakeholders	

US 2.2 *Develop management schemes that reduce the number of cuttings per season*

Corn silage is attractive to farmers because of the high yield of digestible forage harvested with only one cutting per year. This is encouraging a shift away from planting perennial forages. One component of being able to cut perennial forage less times per year is having a plant that does not lodge. ARS researchers at St. Paul, MN have developed alfalfa lines for biomass production with less lodging characteristics, but they perform best, in terms of both yield and lodging resistance, when planted at a lower density than current practice. Research is needed to precisely define optimal plant spacing for maximizing dry matter yields of alfalfa harvested under a reduced cutting schedule.

Economic Sustainability

Improved alfalfa establishment practices could provide farmers with $80 to $160 per acre more alfalfa in the first year of the stand.

Environmental Sustainability

Diversifying the crops on dairy farms, e.g., adding small grains, grasses, and/or cover crops, provides more opportunities to spread manure and reduce nutrient losses from farmsteads.

A second component is that, as forages mature and accumulate more biomass, there is an increase in lignification that decreases digestibility. ARS researchers at St. Paul have developed a more digestible stem alfalfa that could be harvested fewer times during the year. However, research is needed to determine what are the best ways to grow and utilize this material for optimum animal performance.

Third, as new forage materials become available (see Plant Modification section), research will be needed to determine best management strategies for optimizing the unique traits they contain. Fourth, the USDFRC is developing a system to separate alfalfa leaves and stems at harvest, in part to reduce the number of cuttings (see Harvest & Storage section).

Drivers for Research

USDFRC	Grabber
Other ARS	Lamb (St. Paul, MN)
Consortia	
Collaborators	
Stakeholders	

Develop alternative forage cropping strategies that will meet special needs

US 2.3

Alfalfa and corn silage are the dominant forages fed to dairy cows. But there is still a pressing need to develop alternative sources of forages. For example, in drought conditions, alternative forages planted in early fall are needed to make up for forage lost in the summer. Utilizing alternative forages may also open additional windows for manure management. In addition, while most forage management focuses on producing high-quality forages for lactating dairy cows, dry cows and heifers are healthier when fed lower-quality forages; alternative forages could fill this niche.

Our recent research indicates that spring cereals such as oats can be planted in late summer or early fall to provide dairy cows forage for either grazing in the fall or ensiling. This results in plants high in soluble carbohydrates and low in lignin with high degrees of digestibility. However, more research is required to determine growth, management and utilization parameters to provide the best opportunities in dairy production systems.

Fall-grown oats can extend the grazing season in northern climates and serve as emergency forage in drought years.

Warm season grasses such as eastern gamagrass have been overlooked on northern dairy farms as potential forages because of their low quality. But they might have a place in the diet of heifers and dry cows. Typical corn silage and alfalfa are of such high quality that, when fed to dry cows and heifers, straw often has to be added to the diet so as not to exceed the nutrient requirements of these animals. Unfortunately, cattle will sort out straw and avoid eating it. Initial research on eastern gamagrass has looked promising as a non-sortable, lower-energy feed. More agronomic and heifer utilization studies are needed to determine how to best use such grasses on dairy farms. Research is also needed to determine if other perennial forages can fill a similar niche in feeding strategies while providing additional environmental services.

Drivers for Research

USDFRC	Coblentz, Brink, Hall, Weimer
Other ARS	
Consortia	
Collaborators	Bertram, Esser, Hoffman, Undersander (UW)
Stakeholders	

Develop strategies to more fully utilize perennial grasses and legumes for grazing and harvested forage

US 2.4

Grazing-based dairy production systems make up an important segment of total dairy production in the U.S. Perennial grasses and appropriate legumes are generally utilized in these systems to meet the nutritional requirements of the lactating dairy cow, dry cow, or heifer. The USDFRC conducts grazing-related research from several directions.

One is to develop improved varieties of grasses for grazing-based dairy systems. This is a unique research niche because private industry does very little with grass development due to small market potential. Another is to develop improved legumes for pastures -- another research niche because of small market potential. The USDFRC is also developing methods for incorporating legumes such as red or white clover into pastures because they fix nitrogen, thereby reducing the fertilizer needed for productive pastures while also providing a higher protein content forage for better animal performance.

With its multidisciplinary style of research, the USDFRC also looks at the interaction between pasture plants and grazing livestock in management intensive rotational grazing systems. Grazing-based dairy producers try to optimize the quantity, quality and persistence of pasture plants while also meeting the nutritional needs of the cattle. USDFRC research is helping them make decisions such as how early in the season to start grazing without hurting future plant growth and yield; how late in the season to stop grazing so that the next year's pasture is not compromised; and how much residual height to leave after each grazing with the goal of capturing as much feed as possible without harming pasture regeneration. This pasture management research would be greatly enhanced if the USDFRC had the capacity to conduct it with lactating cows; current research farm facilities limit this research to heifers.

Research is needed to determine the best grass-legume mixtures and manure management practices for pastures.

Since pastures are also needed to spread manure collected when livestock are in confinement, the USDFRC conducts research to identify the appropriate time to apply manure. That timing is complicated by a desire to provide optimum yield distribution during the grazing season, to maximize utilization of applied nutrients, and to reduce nutrient loss to the environment in both grass pastures and pastures with varying amounts of legumes. The added challenge with grass-legume pastures is that fertilizer/manure management not only affects nutrient use by the pasture, but also affects the persistency of legumes in the pasture. There is the additional goal of developing management strategies that maintain a stable mix of grasses and legumes in productive pastures.

Drivers for Research

USDFRC	Brink, Coblentz, Riday, Casler
Other ARS	Soder (University Park, PA)
Consortia	
Collaborators	
Stakeholders	

Pasture management research has answered questions on the effect of residue height and timing of grazing on pasture quality, productivity and persistence. This research would be greatly enhanced if the USDFRC had the capacity to conduct it with lactating cows, not just heifers.

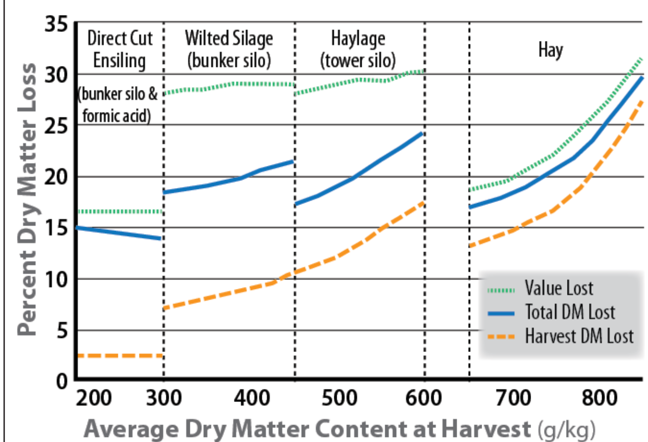
Growing grass for mechanical harvest helps meet certain nutrient requirements for dairy cows and provides more opportunities for applying manure nutrients to the land.

Improve harvest & storage systems

Why have we chosen this highway?

Forage harvest and storage systems are major contributors to the loss of dry matter and value between the field and cow as shown in Figure 3. Harvest losses increase in drier forage because of greater mechanical losses and increased opportunities for rainfall damage during wilting. Storage losses decline with increasing dry matter content. Effluent loss and poor fermentation are issues in direct-cut silages. Respiration or spoilage losses are greater in silages than hay. Protein breakdown to non-protein nitrogen in alfalfa silage does not affect dry matter losses, but substantially reduces the value of the crop.

Figure 3: Typical harvest and storage losses of dry matter and value for various alfalfa production systems in Michigan.



Source: Rotz et.al. (1991)

Beyond these losses, legume and grass forage production has suffered relative to corn silage because corn silage is high in energy and cut only once per harvest season. In contrast, the number of cuttings per year of legumes and grasses has increased as farmers strive to harvest higher-quality forages for lactating cows. The increased number of cuttings has reduced stand life, reduced yields and increased soil compaction while increasing harvest costs per ton. Ideally, we want forage harvesting and storage systems that will deliver more high-quality forage to cows with fewer cuttings. This goal suggests that we need to continue to research ways to minimize losses, but we also need to investigate innovative harvesting strategies that will maximize yield and reduce cuttings.

Develop additives to improve preservation of forage and utilization by livestock

US 3.1

Some lactic acid bacterial inoculants have shown an impressive ability to improve milk production while reducing the amount of dietary nitrogen lost in urine. This has led to a nice return on investment to the producer while reducing environmental effects from ammonia loss from urine. Understanding why this happens may boost the search for additives that allow the cow to be even more efficient in producing milk from her diet and reduce her environmental footprint.

Drivers for Research

USDFRC	Muck, Zeller, Weimer
Other ARS	
Consortia	
Collaborators	
Stakeholders	Ecosyl

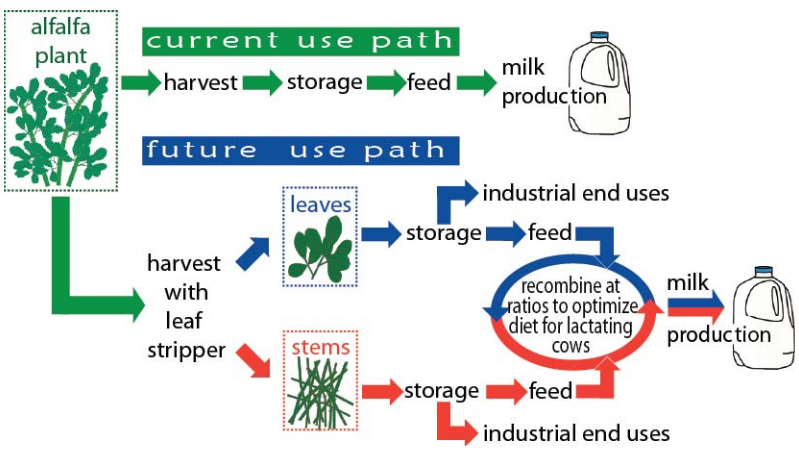
US 3.2

Develop harvest and storage equipment to create alfalfa leaf and stem forage fractions for feeding and other uses

A new method of harvesting alfalfa leaves and stems in the field shows great promise for providing dairy and other ruminant livestock operators new feeds (leaves, a protein resource; stems, a fiber resource). The leaves are harvested directly and ensiled, whereas the stems are dried and harvested for silage or hay. Because leaves change little in quality with maturity, the harvesting window can be lengthened. When compared to the whole plant, stems are closer in forage quality to that needed by heifers and dry cows. So leaf/stem separation should increase forage use across the herd. It will also increase the potential for using alfalfa off the farm for industrial uses or producing feeds for monogastrics (poultry, swine, etc.). However, considerable research is needed to develop the equipment for harvesting and the techniques to perfect the ensiling of the leaves. Research is also needed to investigate alternative uses for the leaf and stem fractions.

Proposed alfalfa harvesting and storage system

This system would separate leaves (high protein) from stems (high fiber), leading to fewer cuttings per season, better diet formulation for stage of lactation, and potential industrial uses.



Pile of alfalfa leaves stripped from the stems during harvest.

Alfalfa stems cut and drying in the field after leaves are harvested.

Drivers for Research

USDFRC	Digman, Hatfield, Muck, Coblentz
Other ARS	Karlen (Ames, IA)
Consortia	
Collaborators	Shinners, Hoffman, Esser, Runge (UW)
Stakeholders	Case New Holland, John Deere

Develop techniques to increase silage density and reduce losses

US 3.3

Considerable research in the past 15 years has focused on improving density in bunker silos, silage piles and bag silos. Current efforts are aimed at determining if specialized packing equipment can improve densities in bunkers and piles. In addition to bulk density, losses in these silo types are influenced by the quality of the plastic film, how tightly the film is held against the crop, and the depth of silage removed per day. Future research will be needed to test new films or sealing technologies as they are developed.

Because silage is a major source of conserved forages on dairy farms, research that reduces the amount of silage dry matter lost is crucial to improving both the economic and environmental sustainability of dairy farms.

Drivers for Research

USDFRC	Muck
Other ARS	
Consortia	
Collaborators	Holmes (UW)
Stakeholders	

Develop strategies to limit spontaneous heating in hay packages

US 3.4

In the humid regions of the U.S., it is often difficult to get hay dry enough before baling to prevent heating. The producer is frequently faced with baling moist hay or suffering rain damage. Limited spontaneous heating can improve the efficiency of protein utilization from hay, but more extensive heating results in substantial dry matter losses, as well as reduced energy density and poorer nitrogen availability within the cow. The most common hay additive, propionic acid, minimizes heating in small rectangular bales but does not reduce dry matter losses. Propionic acid appears to be ineffective in large-round bales, but recent research has shown effectiveness when this preservative is applied to large-square bales. Reasons for these inconsistent responses across bale types remain unclear, and further work is needed.

Drivers for Research

USDFRC	Coblentz
Other ARS	
Consortia	
Collaborators	Hoffman (UW), Coffey (U of Ark.)
Stakeholders	

Economic Sustainability

In the U.S. livestock industry, reducing feed losses from bunker and pile silage by just 5 percentage points translates to an annual savings of about $150 million.

Environmental Sustainability

When less feed is lost to spoilage, less land is needed to feed the same number of cows. And when silage quality improves, more of its protein is utilized by the cow and less nitrogen is excreted and lost to the environment.

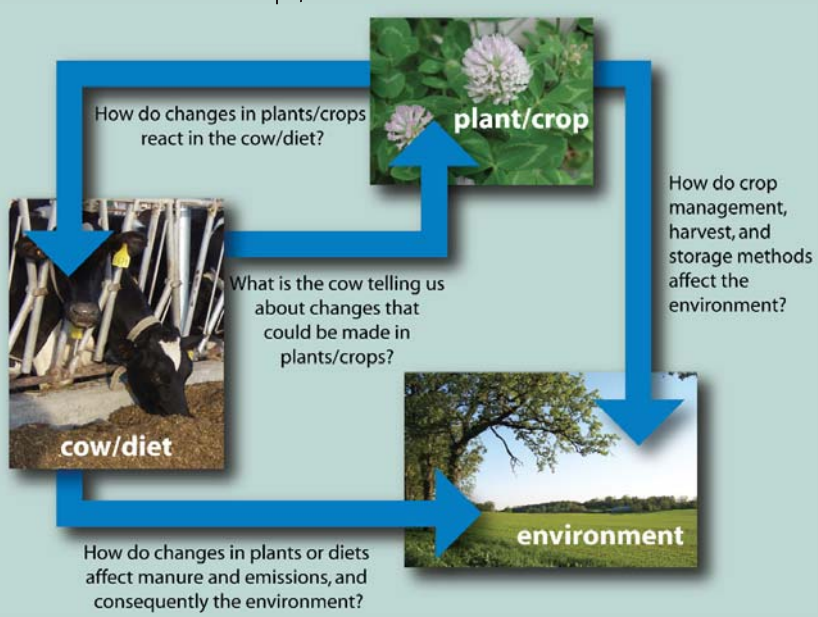
Multi-faceted forages create multiple research challenges and needs

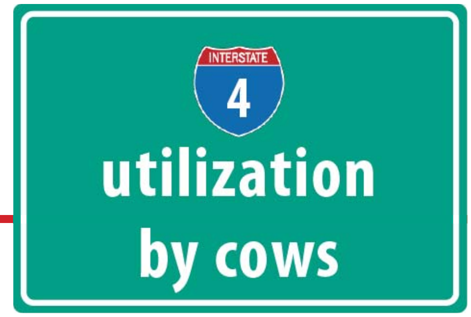
Research with forages isn't as straightforward as it is with other major crops such as corn, soybeans and wheat. The many types of forage, the perennial nature of most forages, the degree of climatic variation where forages are grown, and the multiple harvest and storage options with forage all create a wide range of research questions to be answered.

Forage is not one single plant species like corn, soybeans or wheat.	alfalfa	clover	warm season grass	cool season grass	small grain silage	corn silage
Most forages are perennial, not annual like corn, soybeans or wheat. Unique management challenges of perennials include:	stand establishm't	stand persistence	insect build-up	disease build-up		
Forage type and management vary across the country with differences in climate.	southeast	northeast	north central	central plains	west	
Forage harvest and storage vary more compared to corn, soybeans or wheat.	grazing dry range mgmt intensive	green chop	hay large bales small bales wrapped unwrapped	silage bunkers piles bags tower silos		

Mulidisciplinary Research

With its multidisplinary, whole-farm approach, the USDFRC studies the interactions between crops, animals and the environment.





Improve nutrient utilization by cows

Why have we chosen this highway?

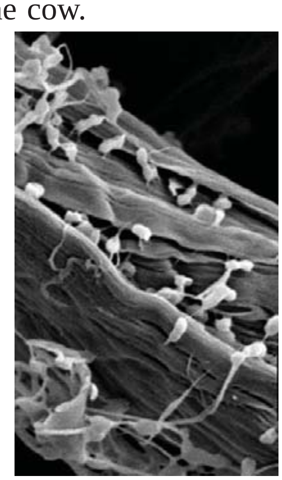
The major component of diets for lactating dairy cows is forage that provides energy, protein, effective fiber, vitamins and minerals. Before corn prices escalated to well over $6 per bushel, many dairy operations, especially large operations in the West, developed diets with minimal forage supplemented with corn grain and by-product feeds. However, as corn and soybean prices have increased, dairy producers have had an incentive to increase the proportion of forage within dairy cow diets. A recent survey of top herds in Wisconsin demonstrated that these successful dairy producers feed a high proportion of forage within production diets (50 to 68%). No matter which direction circumstances shift the composition of cow diets, forages will remain central because forage fiber is important for healthy cows, stimulating rumination and saliva production that aids in digestion.

In spite of their benefits to the cow, forages are not always efficiently utilized. Typically, the least digestible fractions of the ration are the forages. Cow performance may be limited by excessive rumen degradable protein from alfalfa and/or the availability of degradable starch from corn silage. All of these issues affect how efficiently the cow converts her diet into milk. Today there is an additional issue. The U.S. dairy industry funded a life cycle analysis of the carbon footprint of delivering fluid milk to the consumer. The two biggest sources of carbon dioxide equivalents per unit of milk were enteric methane and manure management, each contributing approximately one quarter of the total carbon footprint. So half of the carbon footprint for delivering milk to the consumer is linked to how the cow utilizes her ration.

Improve understanding of the role of rumen microbes

US 4.1

A key to understanding how the cow utilizes forages is knowing how the rumen microbial population digests the cellulose and hemicellulose in forage fiber (something that the cow cannot do on her own). Rumen microbes are also the main source of protein to the cow. On the negative side, rumen microbes are the source of the methane emitted by the cow. New PCR-based research techniques, some developed at USDFRC, are available that can identify specific rumen microbes, thereby enabling us to identify contributions from specific microflora toward increasing fiber digestion as well as improving starch digestion and microbial protein production. It is vital to know how and why microbial species vary from cow to cow and on different diets (e.g., grazing vs. confinement; hay vs. silage). We need to know if additives can manipulate the rumen microflora to achieve better utilization of forages by the cow. All of this information is critical to better diet formulation and to breeding cows whose digestive tracts support the most beneficial microbial species, leading to less methane and more milk per unit of feed.



Microscopic view of rumen microbes digesting fiber.

Drivers for Research

USDFRC	Weimer, Hall
Other ARS	Connor (Beltsville, MD)
Consortia	
Collaborators	
Stakeholders	

US 4.2

Improve forage protein utilization in dairy rations

The forages that produce the most milk per acre (alfalfa in the legumes; ryegrass in the grasses) are also the forages with a protein content that rapidly breaks down to non-protein nitrogen in the silo and to ammonia in the rumen. High ammonia levels in the rumen result in excessive excretion of urea through the urine, rather than benefitting the cow. Today only 20 to 25% of the nitrogen consumed by the cow ends up in her milk on a typical farm. Research suggests that 35% is a reasonable target for the future. Earlier we discussed approaches to modify forages so that the cow would utilize protein in the diet more efficiently. Key components needing study from the cattle side of the problem are: 1) rapid and accurate methods to estimate rumen degradable protein; 2) assessment of improved forages to determine if they do in fact improve nitrogen utilization by the cow; 3) the interaction of forages and other diet components on nitrogen utilization; and 4) the effects of supplementary essential amino acids, tannins and other additives on nitrogen utilization. The overall aim is a methodology to help producers and nutritional consultants develop and deliver rations that allow the cow to more efficiently convert dietary protein to milk protein.

Today only 20 to 25% of the nitrogen consumed by the cow ends up in her milk protein (positive end use) with much of the rest being excreted in the urine (negative end use). Research suggests that 35% is a reasonable goal for the future, but more research is needed to find ways to meet this goal.

Drivers for Research

USDFRC	Vice-Broderick, Powell, Grabber, Muck, Zeller, Coblentz
Other ARS	
Consortia	
Collaborators	Wattiaux (UW)
Stakeholders	Consortium for Alfalfa Improvement (CAI)

Economic Sustainability

A 25% increase in alfalfa crude protein utilization by the cow will save U.S. dairy farmers $100 million per year in reduced protein supplement purchases.

Environmental Sustainability

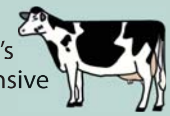
If we can feed cows so that 35% of their dietary nitrogen ends up in milk, nitrogen losses to air and water from the whole farm will be reduced by 40%.

Optimize diets to utilize more forage and increase the conversion of feed to milk

US 4.3

With high grain prices, dairy producers are seeking ways to increase the proportion of home-grown forages in rations without reducing milk production. The fiber fraction of forages is variable in digestibility, whereas proteins and non-fiber carbohydrates are almost completely digested by the cow. Consequently, increasing forage in the diet while maintaining or increasing milk production per unit of feed requires improved digestibility of forage fiber. Efforts to modify forage plants and understand the roles of rumen microbial species in digesting fiber carbohydrates have already been discussed. We also need a better understanding of how the cow interacts with her diet. Forage digestibility measured by in vitro or in situ methods is becoming more common to assist in ration balancing. However, the utilization of dry matter or fiber digestibilities is complicated. A meta-analysis of published research concluded that higher in vitro or in situ estimates of digestibility were related to increased intake and not to improved in vivo digestion. In vivo digestibilities are affected by retention time and associative effects among ingredients in mixed diets. Thus, in vivo cattle studies are needed to investigate the interaction of forage quality, forage processing and other components of the ration on intake and the conversion of feed to milk with commercial forage cultivars, as well as the enhanced digestibility forages that USDFRC is involved with developing.

In vitro -- Outside of the living organism, such as in a test tube. Cheapest and easiest, but least reliable.



In vivo -- Inside the living organism, such as inside a cow's rumen or intestine. Most expensive and difficult, but most reliable.

In situ -- Something intermediate between in vitro and in vivo. With dairy cattle nutrition studies, usually it means forage or feed samples are sealed inside an 'in situ bag' that is placed in the rumen of a cow through a surgical opening, or canula.

Some research questions can only be answered by the cow herself.

Drivers for Research

USDFRC	Hall, Vice-Mertens
Other ARS	
Consortia	
Collaborators	Casper (SD State), Weiss (Ohio State)
Stakeholders	Consortium for Alfalfa Improvement (CAI)

Understand the effects of various non-fiber carbohydrates on the digestibility/utilization of fiber and protein in the ration

US 4.4

Potential keys to increasing the conversion of forages to milk are non-fiber carbohydrates (primarily starches, sugars and fructans). These carbohydrates have been largely ignored in dairy cattle nutrition because, in theory, they are completely digestible. However, recent research indicates variability in the rate and extent of digestion of these carbohydrates from different crops due to structure, level of processing, and type of carbohydrate. These differences affect the efficiency with which rumen microorganisms grow and produce microbial protein. Individual carbohydrates appear to have differing effects on cell wall digestion by rumen microorganisms. Consequently, it appears that the makeup of non-fiber carbohydrates may play a significant role in how efficiently a cow utilizes her diet, but considerable research is needed to elucidate these interactions in both in vitro and in vivo trials.

Although starches are completely digestible, recent research has shown great differences in the rate and extent of digestion which affect efficiency of rumen microbes.

Drivers for Research

USDFRC	Hall, Coblentz, Powell
Other ARS	
Consortia	
Collaborators	
Stakeholders	Consortium for Alfalfa Improvement (CAI)

US 4.5 *Reduce the cost and carbon footprint of raising dairy replacement heifers*

There's a significant cost for raising dairy replacement heifers for the two years before they start producing milk. Raising heifers also contributes significantly to the carbon footprint of milk production. Alternate means of raising heifers should be investigated as a way of reducing feed costs while maintaining the animal's milk production potential. Management that allows heifers to reach their genetic potential for milk production will invariably increase the efficiency of milk production and minimize greenhouse gas production per unit of milk.

Grazing is one means of reducing the cost of raising heifers. Unfortunately, relatively little is known regarding the biological, economic, and environmental effects of rearing heifers partially or wholly on pasture. Lower feed intake on pasture can reduce post-pubertal growth rate below optimum levels, reducing first lactation milk production and resulting in greater enteric methane production. Pasture rearing can also interact with genetics, resulting in lower body weight at puberty in cattle strains having greater body weight and height at maturity. Thus, rearing heifers on pasture to reduce costs may have diverse impacts on growth, health, and performance – impacts that are not fully understood at this time and need further research.

To improve the economic and environmental sustainability of milk production, some focus must be given to raising dairy replacement heifers.

Drivers for Research

USDFRC	Coblentz, Brink, Powell , Weimer, Hall
Other ARS	
Consortia	
Collaborators	Hoffman, Esser
Stakeholders	

What if we knew the genetic potential of each heifer born and only raised those with the most potential, thus eliminating the financial and environmental costs of raising unproductive animals? Genomics research at the ARS Bovine Functional Genomics Laboratory in Beltsville, MD and at the University of Wisconsin-Madison is focused on finding the genetic components linked to feed efficiency. Current research suggests that there is a genetic component to feed efficiency. However, that just begins to explain why some cows are more efficient milk producers. Our collaboration with these genomics groups will be important to understanding why some cows are more efficient than others. Ultimately, we want to produce genetically superior heifers, managed so that they reach their full potential.

Drivers for Research

USDFRC	Coblentz, Weimer, Hall
Other ARS	Connor, Baldwin, Van Tassell (Beltsville, MD)
Consortia	
Collaborators	Weigel, Armentano, Suen, Hoffman, Esser (UW)
Stakeholders	

While harvesting alfalfa leaves and stems separately, as described earlier, has many advantages from a harvesting perspective, the viability of this new strategy really depends on how cattle will utilize the two products. Alfalfa stems are lower in energy and higher in protein than corn silage, which should allow heifers to grow at an ideal rate on stems with few other supplements. Alfalfa leaves have the potential to reduce protein supplementation of lactating cow diets. In vivo trials of both leaves and stems are needed to determine how to best include them in rations for growing heifers, as well as lactating and dry cows.

Drivers for Research

USDFRC	Digman, Hatfield, Muck, Coblentz
Other ARS	
Consortia	
Collaborators	Shinners, Hoffman, Esser (UW)
Stakeholders	

Develop rapid techniques of forage/grain/by-product analyses on-farm to reduce diet variability and improve diet utilization

US 4.6

The ration consumed by the cow is not necessarily what the nutritionist or farmer planned to feed the cow. Between the time a forage, silage or commodity is sampled and analyzed at a commercial lab, quality may change as the farmer continues to feed from the silo or pile that was analyzed. Rainfall at the face may change the moisture content of a feed. These factors affect the balance of nutrients in the ration and how livestock respond to the ration – intake, digestion and utilization. In trials at the USDFRC that simulated the effects of rainfall on silages, a temporary (1 to 3 days) 8-point change in silage moisture content reduced both dry matter intake and milk production by as much as 5 pounds per cow per day if the ration was not adjusted to account for differences in moisture content. Methodologies such as near infrared reflectance spectroscopy (NIRS) offer the potential to adjust rations on-the-fly as quality and moisture content vary. However, inexpensive NIRS technologies and robust calibration equations are needed to accomplish this.

From the time a forage is analyzed at a commercial lab to the time it's fed to cows, quality factors can change to the extent that the ration is no longer properly balanced, and milk production suffers. On-farm analysis methods are needed to reduce diet variability so that the ration formulated 'on paper' is closer to what cows actually consume.

Drivers for Research

USDFRC	Karlen, Vice-Mertens
Other ARS	
Consortia	NIRS Forage & Feed Testing Consortium
Collaborators	
Stakeholders	

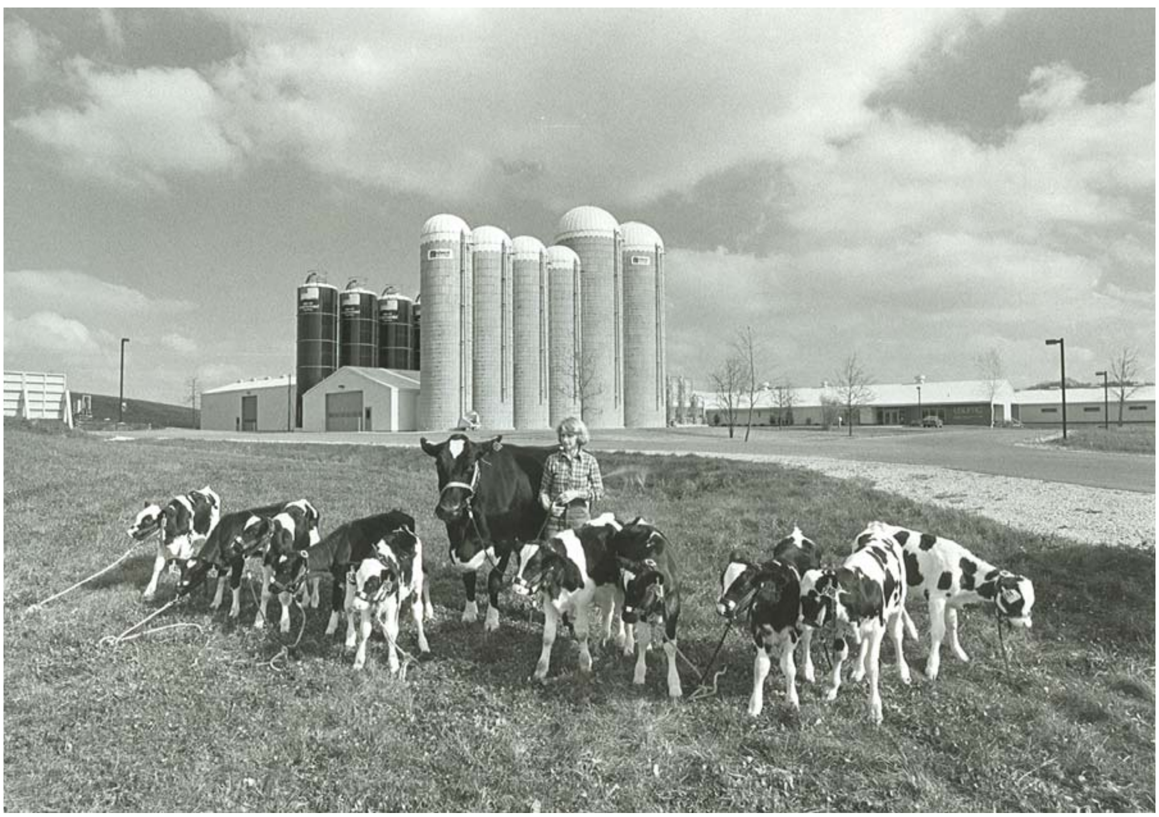
US 4.7

Develop a more accurate system to functionally characterize the value of forage fiber to the cow

The ability of forage fiber to stimulate rumination and saliva production is currently being estimated by forage particle size through use of sieves or shaker boxes. However, forages/silages/straws of the same average particle length do not produce an equivalent forage mat in the rumen, stimulate the same amount of chewing and rumination time, or have the same effect on solid and liquid passage rates from the rumen. Thus, digestion and utilization of diets are affected in ways that cannot be explained by particle size. A more accurate means of characterizing the physical nature of forage fiber on intake, rumination, passage rate, digestion and utilization is needed.

Drivers for Research

USDFRC	Hall, Vice-Mertens
Other ARS	
Consortia	
Collaborators	
Stakeholders	



When the U.S. Dairy Forage Research Center Farm was built in 1980, embryo transfer was a new technology being used to get more offspring from superior cows; the calves in the picture are all from the same cow. Today, advances in genomics research may soon make it possible for dairy producers to know the genetic potential of each heifer born and sell those that do not meet the anticipated herd potential, thus eliminating the financial and environmental costs of raising less productive animals. USDFRC scientists are collaborating with others to take part in this research effort.

Reduce nutrient escape to the environment

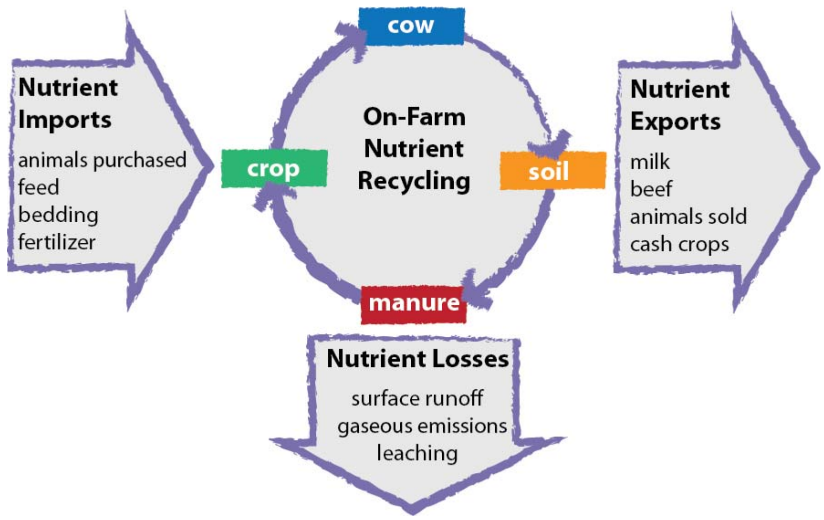
INTERSTATE 5 nutrient management

Why have we chosen this highway?

Nutrient management was a term synonymous with manure management and largely focused on nitrogen and phosphorus in that manure. That is no longer true. Concerns today are much broader, i.e., the full environmental footprint of the dairy farm. This includes not just nitrogen and phosphorus, but greenhouse gas emissions and the fate of pathogens on the farm. Perennial forages on farms can have a positive effect environmentally by sequestering carbon in addition to using nutrients. Considered at a broad scale, modern dairy production represents a complex system of nutrient flows and cycles, both within and among farms. The figure at right depicts how nutrients cycle continuously from feeds, through animals, into feces and urine, onto pastures and cropland that receive manure, and back into feeds upon harvest. Nutrients also are lost from the system to the surrounding environment, primarily with water in surface runoff and subsurface leaching, and to the atmosphere as gaseous emissions. The nutrient cycle may extend to neighboring farms as manure and harvested feeds are exchanged between operations.

Imports, exports, recyling and losses of nutrients

Nutrients are imported to the farm via purchased inputs; recycled on the farm via manure management and crops; and exported from the farm via sales of milk, meat, animals, cash crops and, in some cases, manure or the energy produced from it.



Improved management of dairy farms requires successfully managing its nutrient flows, both to maximize nutrient use by animals and crops in order to optimize profit, and to minimize nutrient loss to the environment in order to optimize sustainability. While many years of scientific research have provided a basic understanding of nutrient flows on the dairy farm, there remain critical knowledge gaps. These knowledge gaps relate not only to fundamental biological, chemical, and physical processes, but also are generated by the ever-changing nature of dairy production to which science must adapt, such as genetic engineering, economic pressures, or regulatory policies.

Develop strategies to minimize emissions of ammonia and greenhouse gases

US 5.1

Emissions of ammonia from livestock facilities have been a concern of EPA for a number of years because of the downwind effects on acid rain, as well as adding excess nitrogen to certain ecosystems. More recently, dairy production has come under scrutiny relative to global climate change. Half of the carbon footprint to deliver milk to the consumer comes from two on-farm factors: methane emitted by cows and manure management. The

Air emission research is needed to measure and reduce the carbon footprint of milk production. Shown here is an air emission chamber at the USDFRC research farm.

Center is well positioned to address these issues. Chambers at our research farm are being used to measure ammonia and greenhouse gases from cows in tie stalls in order to investigate dietary means of reducing methane emissions and urea in urine, the principal source of ammonia. Additionally, we are measuring the transformations that occur once manure is applied to soil. Current efforts are emphasizing the potential role of tannins to minimize these emissions: tannin-containing forages such as birdsfoot trefoil, tannin additives to diets or barn floors, etc. While we expect to have a substantial effort in this area, there is the need for chambers in a free-stall setting. Also, given the national importance of this work, additional scientists are needed to provide more timely answers.

Drivers for Research

USDFRC	Powell, Vice-Broderick
Other ARS	
Consortia	
Collaborators	Wattiaux (UW)
Stakeholders	Innovation Center for U.S. Dairy

US 5.2

Evaluate new manure application technologies that potentially increase crop utilization and minimize nutrient losses

The goal in manure management is to have more of the manure nutrients utilized for crop production and not subject to runoff or volatilization as ammonia or nitrous oxide products. There is a need for better manure application technologies that reduce ammonia emissions, minimize nitrate leaching to groundwater, and minimize nitrogen, phosphorus and soil in surface runoff. This is particularly challenging when applying manure to perennial forages where some technologies of application may be too disruptive to the stand. Research is seeking to find the best management practices to prevent nutrient losses.

Testing new methods for applying manure to alfalfa, without damaging the crop, at the USDFRC's Environmentally Integrated Dairy Management Research Unit in Marshfield, WI.

Drivers for Research

USDFRC	Jokela, Powell, Vadas
Other ARS	Russelle (St. Paul, MN)
Consortia	
Collaborators	Peters (UW)
Stakeholders	USDA-NRCS (Natural Resources Conservation Service)

US 5.3

Develop alternative cropping systems that open opportunities for manure application throughout the growing season

Cropping systems are keys to managing nutrient movement and soil losses. For example, forages/small grains planted immediately after corn silage is harvested may scavenge mobile nitrogen and phosphorus left in the soil and reduce soil erosion over winter. Alternate crops may provide opportunities for manure spreading other than the traditional windows in spring and late fall. Other windows of opportunity for manure application include after the harvest of perennial forages and as sidedress for corn. Overall we seek to create opportunities for additional forage production on dairy farms while at the same time reducing the potential for nutrient loss from the farm.

Drivers for Research

USDFRC	Coblentz, Jokela
Other ARS	
Consortia	
Collaborators	Laboski (UW)
Stakeholders	USDA-NRCS

Identify the fate of pathogens in manure systems and develop methods to mitigate transfer of these pathogens into the environment

US 5.4

Manure contains pathogens and has been implicated in various food and waterborne outbreaks. Yet we know relatively little about how manure management processes affect the survival of pathogens and how long remaining pathogens survive in the soil. With the application of PCR-based technologies, we are at the forefront of being able to measure a wide range of pathogens quickly, accurately and safely. Research efforts focus on two areas: reduction of pathogens during anaerobic digestion, and movement of pathogens in runoff. Other systems will be investigated in the future.

Drivers for Research

USDFRC	Borchardt, Jokela
Other ARS	
Consortia	
Collaborators	U.S. Geological Survey
Stakeholders	USDA-NRCS

Research fields are designed so that runoff flows toward one of four flumes. The amount of flow is measured, and samples are collected.

Samples are later analyzed for the extent and type of manure nutrients and pathogens.

Economic Sustainability

Techniques that allow more manure nutrients to be utilized by crops will reduce purchases of commercial fertilizer, a major production cost for most crops.

Environmental Sustainability

Techniques that permit more efficient uptake of manure nutrients by crops reduce the potential for losses to the environment via surface water runoff, groundwater leaching, and air emissions.

US 5.5

Assess grazing systems for their effectiveness at limiting nutrient/soil losses in runoff

The number of dairy farmers using managed intensive grazing systems has grown in recent years. While such systems appear idyllic to the public, it is not clear what the environmental consequences of grazing are. Urine spots and "cow pies" mean concentrated local applications of nutrients. Research efforts are focused on determining the impact of these concentrated "applications" of animal waste upon pasture health and the environment. We have an increasing effort in this area to determine if there are problems and, if so, to develop management techniques to minimize environmental issues.

Cow pies create concentrated local applications of nutrients. Is this an environmental problem?

Drivers for Research

USDFRC	Brink, Vadas
Other ARS	Bjorneberg (Kimberly, ID)
Consortia	
Collaborators	
Stakeholders	USDA-NRCS

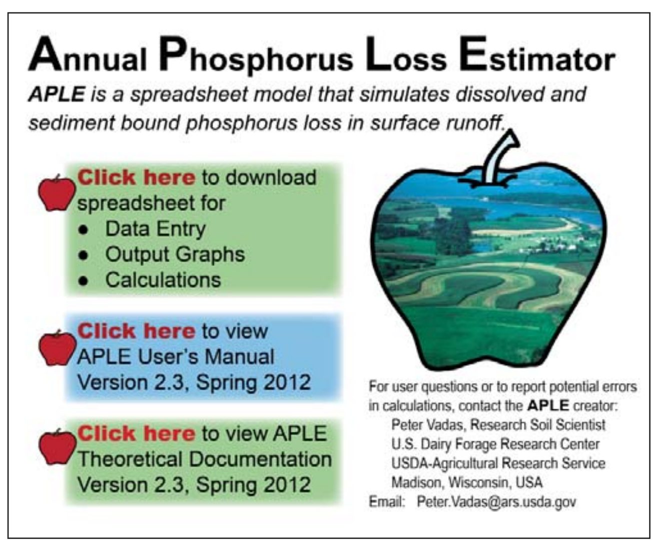
US 5.6

Improve prediction of phosphorus losses from the environment using models

Reduction of nutrient losses from farms is site-specific, affected by soil, topography and climate in addition to farm management. Specialists for the USDA-NRCS and nutrient management consultants need good software tools to predict phosphorus losses so that they can make recommendations that will best fit the circumstances on each farm. The USDFRC has developed an Annual Phosphorus Loss Estimator (APLE) model that already has received widespread industry use. We will continue to refine it for more accurate predictions.

Drivers for Research

USDFRC	Vadas
Other ARS	Bjorneberg (Kimberly, ID)
Consortia	
Collaborators	
Stakeholders	USDA-NRCS



The Anuual Phosphorus Loss Estimator is available for free download on the USDFRC web site.

Develop new bioenergy and bioproduct uses

Why have we chosen this highway?

Economically viable production of biofuels from agricultural crop residues and dedicated perennial bioenergy crops requires high yields of plant material that can be efficiently converted to biofuels. Currently, analysis by the U.S. Department of Energy (DOE) has determined that switchgrass is the leading perennial grass candidate for biofuel production, and DOE is sponsoring research, including at the Center, to develop switchgrass's potential. Today in the U.S., the dominant biofuel is ethanol produced from corn grain which utilizes prime farmland that is typically geared toward food, feed and fiber for human needs. As populations grow and world demand for food increases, there will be additional pressure on our prime farmland to meet human needs. Switchgrass grown on marginal lands would provide a source of biofuel feedstock that does not compete with land best suited for human food production.

Another potential solution to sustainable bioenergy production could be legumes that capture nitrogen from the air. Forage legumes such as alfalfa, when included in crop rotations with corn, can almost completely offset the nitrogen needs of corn in the first year after alfalfa and have continuing effects in succeeding years of corn. Because nitrogen fertilizer is a major energy input to corn and grass production, inclusion of alfalfa in rotations would enhance the energy efficiency of biofuel production. There are added advantages of disrupting pathogen/disease cycles and improving soil health. However, a current shortcoming of alfalfa is its single-product stream use as an animal feed. Grains have multiple uses; they branch into several consumer products for human use, as well as animal feed. Similar approaches must be taken with alfalfa to develop multiple product streams.

The USDFRC has one of the few switchgrass breeding programs in the nation.

Develop improved forages for bioenergy/bioproduct uses (feedstock development)

US 6.1

Economic models and life-cycle analyses consistently demonstrate that development and deployment of dedicated cellulosic bioenergy feedstock is limited largely by biomass yields. Because switchgrass is not a highly domesticated plant, with most breeding populations originating directly from wild populations, there is great potential for genetic improvement in biomass yield. Vast reserves of genetic variability exist for biomass yield; these reserves have largely been untapped due to lack of effort to conduct genetic selection for increased biomass yields and to develop varieties better adapted to specific geographic regions. At the USDFRC, both traditional and genetic marker-based technologies are being used to develop improved switchgrass cultivars in collaboration with ARS scientists at Lincoln, NE.

Drivers for Research

USDFRC	Casler, Weimer
Other ARS	Vogel (Lincoln, NE)
Consortia	Consortium for Alfalfa Improvement, NIRS Consortium
Collaborators	
Stakeholders	

US 6.2

Use anaerobic fermentation to create VFAs for bioproducts or biofuels

Improving the economics of cellulosic ethanol requires the development of marketable co-products. Both of the leading platforms for cellulosic ethanol (simultaneous saccharification and fermentation, and consolidated bioprocessing) will produce large amounts of fermentation residues containing microbial cells, lignin and other recalcitrant materials. To date, there has been little research on co-product quality and utility. The small profit margins likely for cellulosic ethanol (or other biofuel) production warrant the identification and development of new uses for co-products. Recently, a volatile fatty acid (VFA) platform has been proposed as a novel strategy for producing fuels from a wide variety of waste materials. This platform combines well-established anaerobic fermentations of biomass by stable mixed cultures to produce VFA, which can be converted by various chemical and electrochemical pathways to hydrocarbons, alcohols and ketones which can be formulated into "drop-in" fuels compatible with existing fuel storage and delivery infrastructures. Residues from the fermentations (microorganisms and plant components, lignin, carbohydrates, protein) may be sources of valuable co-products such as replacements for phenol compounds in wood adhesives.

The USDFRC has discovered a residue product that could be used to produce a bio-based adhesive to replace phenol compounds in wood adhesives.

Drivers for Research

USDFRC	Weimer, Zeller
Other ARS	
Consortia	
Collaborators	
Stakeholders	

Economic Sustainability

Using ruminal bacteria to produce fuel precursors leaves a complex residue that can be used as a substituent for adhesives in plywood. This provides a less toxic adhesive that could have an economic value of $550 million per year.

Environmental Sustainability

Cellulosic ethanol from switchgrass is expected to produce more than 5 times the net energy of ethanol from corn grain while net greenhouse gas production will be 85% lower than that produced by gasoline or corn ethanol.

Develop management/treatment/processing to create new products from alfalfa leaves (poultry feed, protein source for aquaculture)

Alfalfa is a valuable crop, not only for use in crop rotations (decreasing biotic stress while adding nitrogen to soils and improving soil health), but also as a potential protein source for animal and human nutrition. On an annual basis, alfalfa can produce 1,000 to 1,200 pounds of protein per acre (assuming a total production of approximately 4 tons to the acre total biomass and only the leaf fraction used for protein extraction/product development) compared to 800-1,000 pounds per acre for corn grain or 900-1,000 pounds for soybeans. What is lacking is: 1) the technology to effectively harvest leaves from crops such as alfalfa that allow multiple product streams, and 2) biological and mechanical systems/processes to convert this raw material into high-value products (see harvest and storage section). Once leaves are separated from the stems, the protein-rich fraction must be converted into usable high-value products. Research is needed to optimize protein extraction from leaf material for conversion to new products.

Alfalfa leaves can be pressed with and without maceration to release much of the water and cytoplasmic contents of individual cells. This juice can be easily fermented with *Lactobacillus* to produce a low, stable pH. At low pH, protein within the juice will precipitate from solution, aiding in its removal. Research is needed to determine if additional microbes could be added and allowed to ferment in concert with *Lactobacillus* or singly to generate specialty fermentation products that could have industrial uses or provide pro-biotic function along with the protein. Such treatments could modify the fermentation products such that the combined materials would have an added value as animal feed for poultry or in aquaculture.

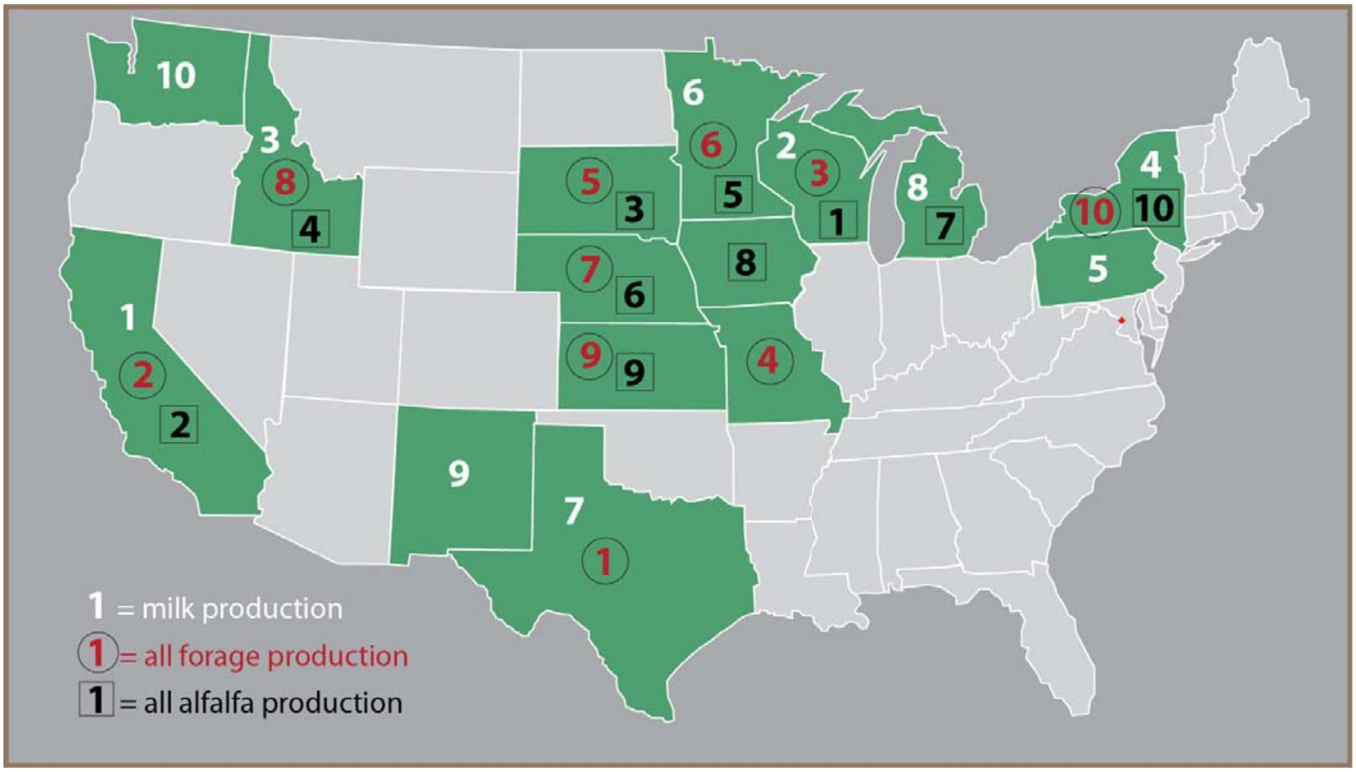
Drivers for Research

USDFRC	Digman, Hatfield, Zeller, Weimer
Other ARS	Selling (Peoria, IL), Barrows (Aberdeen, ID)
Consortia	
Collaborators	Case New Holland , John Deere, Runge (UW), Lamsal (ISU)
Stakeholders	

Press cake being made from leaf portion of alfalfa.

Juice from alfalfa leaves in the process of being fermented.

Dairy and forage production are important across the U.S. and often go hand-in-hand



This map shows the Top 10 states for milk, all forage, and all alfalfa production. Forage growing conditions and dairy management practices vary greatly in the top milk and forage-producing states. Research must address these differences in order to be national in scope.

Source: USDA National Agricultural Statistics Service

Maintaining our progress on the road map

Staffing plans

As our scientists reach retirement, we will be faced with decisions concerning staffing patterns to best meet the needs of customers, stakeholders, and consumers at large. Since 2009, we have lost five major positions within the Center: Russell (Microbiologist, Ithaca, deceased, Sept. 2009), Mertens (Dairy Scientist, retired Feb. 2010), Jung (Dairy Scientist, St. Paul, retired Dec. 2011), Broderick (Dairy Scientist, retired Jan. 2013), and Martin (Center Director, retired Jan. 2013). The Russell and Jung positions have been lost, and the dollars associated with their positions absorbed by other programs at those locations.

We currently have only two Dairy Scientists (Hall, Coblentz) so that filling the vice-Mertens and vice-Broderick positions in a timely fashion is as critical as filling the Center Director position. These three positions are currently at various stages of moving through the system. Hopefully the Center Director and vice-Mertens positions will be filled in 2013.

In addition to these open positions, other scientists have indicated plans to retire within the next five years. As these positions move closer to a definite timetable for replacement, they will be reviewed (by the staff) to determine the most appropriate type of scientific expertise needed for the 21st century. Listed here are the open positions (plus positions for which we have a definite indication of retirement) and the expertise/area of research viewed to be critical for our mission and to complete the journeys laid out by our road map.

> Vice-Martin: Center Director, overseeing the research program for the USDFRC and interactions with stakeholders, customers, government.
>
> Vice-Mertens: Dairy Scientist, improving feed efficiency, especially related to the structural carbohydrates/fiber in forages and other feedstuffs.
>
> Vice-Broderick: Dairy Scientist, improving the utilization of forage protein (especially alfalfa) and other dietary protein sources.
>
> Muck: Agricultural Engineer, retiring 2013 or 2014, replace with a Microbiologist, maintaining focus on silage work, but shifting to address microbial interactions during ensiling and carryover effects in the rumen when fed to dairy cows.
>
> Russelle: Soil Scientist, retiring 2013, understanding and improving the utilization of nutrients by forages within different cropping/management systems.

Expanding beyond current expectations to meet future research priorities

The road map laid out is a vision based on our current resources, both physical and human. We have attempted to be realistic as to what could be accomplished by scientists at the Center while also considering collaborations with other scientists in both the public and private sectors.

If additional funding were available, it would allow us to expand the scope of our research. Substantial effort has already been devoted toward defining the research areas we cannot

	Current scientist positions and facilities	Future scientist positions and facilities needed to meet emerging priorities
Madison	facilities staff	facilities — maintain as is staff — fill current vacancies and future vacancies as scientists retire
Prairie du Sac	facilities staff	facilities — build (1)new animal facilities and (2)Intensive Animal Nutrition Research Facility/Center of Excellence staff — add 4 scientist positions for research at new IANRF and training at Center of Excellence
Marshfield	facilities staff	facilities — maintain as is; occupy all labs staff — add 3 scientists (as originally planned) to expand capacity in manure/nutrient and environmental research
Stratford	facilities staff	facilities — maintain as is staff

= scientist = scientist vacancy = other critical staff = other critical staff vacancy = new position
= facilities in excellent condition = facilities currently adequate = facilities need replacing

address adequately now and developing plans if funds were available. The two major areas of research expansion are envisioned: fully staffing the Environmentally Integrated Dairy Management laboratory in Marshfield, and building expanded barn and laboratory facilities at our current research farm in Prairie du Sac.

Fully staffing Marshfield

Greenhouse gas emissions from dairy farms and the effects of climate change on dairy farms are extremely important to the sustainability of dairy farming in the future. While the Center has done some work in this area, it is inadequate to meet the demands for information. The laboratory in Marshfield is capable of addressing some climate change research and has space for three more scientists. With additional funding, the following positions are recommended:

Collecting samples to measure greenhouse gas emissions after various manure application methods at the Environmentally Integrated Dairy Management Research Unit in Marshfield and Stratford, WI.

Soil Scientist/Engineer: Research emphasis would be on investigating the effects of soils, plants, and animals on the aerial components of nutrient cycling (i.e., ammonia, nitrous oxide, carbon dioxide, and methane, along with other natural and anthropogenic trace gases).

Animal Nutritionist: Research emphasis on the impact of diet feed efficiency and susceptibility of gaseous emissions from manure during collection, storage and application to soils.

Agronomist/Soil Scientist/Micrometeorologist: Research emphasis on the uptake/utilization of animal waste nutrients and conversion to usable nutrients for dairy production with special consideration of environmental factors.

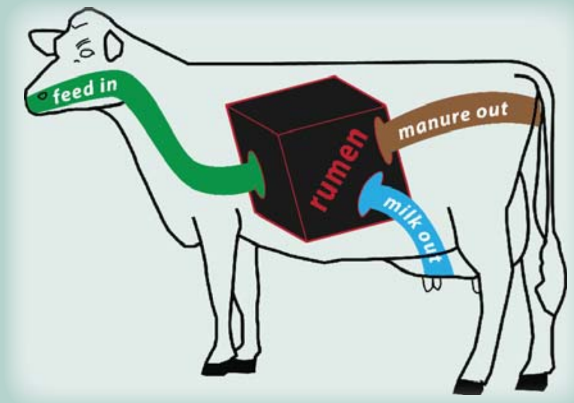
New dairy facility and staff at Prairie du Sac

The current dairy barns at the USDFRC research farm are more than 30 years old and were designed for smaller cows than the typical cow today. Similarly the research capacity was designed for the types of experiments being performed in the 1980's. We have gone through the formal planning process of developing a program of requirements and an environmental assessment to build new barns and laboratories at Prairie du Sac, including an Intensive Animal Nutrition Research Facility (see page 34) and a set of free-stall chambers. The new facilities would permit hiring four more scientists to expand dairy cattle digestion research, focusing on forage digestibility and feed efficiency, both in confined feeding and grazing operations. The following scientist positions are recommended:

> Rumen Physiology/Microbiology: Research to address forage digestibility/feed efficiency, microbial-feed component interactions, and dairy cow-microbial interactions.
>
> Post-Rumen Physiology: Research to address digestion of feedstuffs in the hind gut, nutrient uptake by the animal, and animal benefits from efficient forage utilization and nutrient uptake.
>
> Dairy Nutritionist: Research to address forage nutrition under grazing systems, forage digestibility in lactating cows, optimizing grazing management, forage-dairy cow supplement interactions.
>
> Forage Physiology/Biochemist/Agronomist: Research to address perennial forage development, carbon assimilation/storage, carbohydrate partitioning between structural and soluble carbohydrates, and effects of forage-growing environment on digestibility of carbohydrates.

The tie-stall barns at Prairie du Sac are extremely labor intensive for research. For example, research diets must be delivered by hand, and refusals (what the cow doesn't eat) are shoveled and weighed by hand. Also, stall size is not big enough for today's larger Holstein cows.

Unlocking rumen secrets with an Intensive Animal Nutrition Research Facility



In many ways, a cow's rumen is like a big black box. We can see what goes in and what comes out, but there are many questions about what happens inside.

One of the goals of USDFRC scientists is to build an Intensive Animal Nutrition Research Facility in order to achieve more precise knowledge on how cows and other ruminants digest forages and other feedstuffs.

Why should we learn more about the rumen?

- Ruminants produce nearly all of the milk and about 32% of the meat (including poultry and fish) consumed in the U.S.
- Ruminants take crops and byproduct feeds that humans can't use and turn them into protein and other nutrients needed by humans.
- Today's dairy cattle diets are balanced with digestion data that were created 30 to 50 years ago when feed ingredients were different, cows weren't producing as much milk, and the nutrient content of manure wasn't an issue. But there is no industry-wide effort underway to systematically update digestion data.

What do we want to learn from more intensive digestion research?

- How fiber is digested.
- What affects the rate and extent of digestion.
- Which rumen microbes are important.
- What improves the microbes' ability to digest fiber.
- How digestion can be improved at high levels of feed intake. As cows eat more, digestibility decreases; many high-producing cows are eating so much that they don't adequately digest their feed.

What are the basic objectives of this research?

1. Provide basic knowledge about the factors that limit the intake and digestion of forages.
2. Develop strategies to optimize forage utilization in dairy cow diets and minimize the negative effects of ingredients in the diet that limit forage utilization.
3. Increase the accuracy of forage evaluation and improve the formulation of dairy rations.
4. Develop feeding strategies to minimize the environmental impact of dairy cattle, such as reducing methane and ammonia emissions or producing manure with nutrient availability that more closely matches the patterns of nutrient use by crops.
5. Create an integrated system for evaluating novel forage germplasm that increases the rate of development of high intake and digestibility forages that improve the productivity, health, and longevity of dairy cattle.

Proposed working groups to leverage resources

Improving the utilization of alfalfa: more value on more acres

Alfalfa is considered to be the Queen of forages due to its high nutritional value as feed and ability to fix large quantities of nitrogen. However, challenges related to managing alfalfa to maintain low fiber (i.e., harvest earlier and more often) have inadvertently resulted in the expansion of corn silage into feeding rations (harvest only once). Early-cut alfalfa also results in exceptionally high levels of protein, making it difficult to balance rations and not create protein waste. Development of novel alfalfa management and field harvesting equipment that separates high-protein leaves from high-fiber stems allows optimizing both fractions in animal diets, thus providing a higher quality and consistent nutrient supply. It also reduces the impact of adverse weather on crop harvest, and it increases yields by capturing some of the approximately 30% loss typically occurring during harvest.

There are two major working group initiatives in which the USDFRC is taking a lead role: 1) Improving the capture of nutrients in alfalfa from the field to the cow; and 2) expanding the utilization of alfalfa as animal feed, along with other uses, to increase production acres to more widely leverage the environmental services of alfalfa. Although these are two unique initiatives, there is overlap which allows us to take advantage of knowledge gained from one working group to use in the other.

Alfalfa Working Group

Major players: ARS Plant Research Unit, St. Paul, MN; ARS USDFRC, Madison, WI; and Forage Genetics International, Nampa, ID.

The major thrust is on genetic improvement of alfalfa to improve cell wall digestibility and increase the efficient utilization for protein. Genetic approaches range from typical germplasm selection for improved traits to molecular approaches to insert genes that enhance functionality. Progress has already been made in the selection of traits that increase stem digestibility (St. Paul), increase total biomass production (St. Paul), to add the polyphenol oxidase (PPO)/o-diphenol system to decrease protein degradation (Madison), and decrease leaf loss (Madison). Working relationships already focus on providing mutual support in areas where one or the other members lack a particular type or level of expertise (e.g., USDFRC providing animal trials to test the level of genetic improvement). It is envisioned that as this group moves forward, there will be joint planning and project development to move key projects forward at a faster pace.

Alfalfa Fractionation Working Group

Major players: ARS Plant Research Unit, St. Paul, MN; ARS USDFRC, Madison, WI; ARS National Laboratory for Agriculture and the Environment, Ames, IA; ARS Plant Polymer Research Unit, Peoria, IL; UW Marshfield Ag Research Station; John Deere forage group; Case-New Holland forage group; other business/industry partners.

This initiative is much broader in nature and covers work from the field (new genetics with value-added traits), harvest technology changes, storage, feeding and new product development. There are efforts underway focused on development of new harvest and storage strategies to capture more of the accumulated nutrient value to optimize dairy cow rations. Current plans are to build a larger leaf stripper to efficiently harvest sufficient leaf and stem fractions to conduct a feeding trial with dairy cows (USDFRC, John Deere, Case-New Holland). It is envisioned that multiple sub-projects will be developed with input from different players within the working group as expertise is needed to carry out a specific sub-project.

Understanding forage digestion in relation to feed efficiency

Efficient utilization of forages by dairy cattle is critical economically and environmentally. Today, the increased cost of grain and protein supplements have producers looking for means of getting more energy and protein from the forage portion of the diet. From an environmental standpoint, having more forage on the landscape provides great benefits contributing to the long-term sustainability of dairy farming systems. However, for forages to increase as a portion of dairy diets, we must increase forage utilization efficiency – more milk and less methane and manure from a given amount of forage. We know from past efforts that just breeding a more digestible plant is not the full answer. Other components of the diet, the rumen microbial community, and the physiology and genetics of the cow affect digestion and utilization of forage. Unfortunately, the precise contribution of each of these factors to the utilization of a specific diet by a specific cow or group of cows is not known.

The USDFRC is committed to understanding the factors affecting the digestion and utilization of forages by dairy cattle and developing the knowledge base to increase forages in the diet and feed efficiency on high-forage diets. This will require a diverse team of animal nutritionists, physiologists, geneticists, microbiologists and animal modelers, as well as substantial resources. When the vice-Mertens and vice-Broderick dairy scientist positions are filled, the Center will develop an Animal Digestion Working Group, inviting scientists from other ARS units, universities, private industry, and public institutions to leverage the combined expertise and resources of the group. Already the Center is forging closer ties to the ARS group at Beltsville, MD, to researchers at the University of Wisconsin who are studying the genetic components of feed efficiency, and with various public and private stakeholders who may be part of the future working group. It is envisioned that this group will interact on a regular basis to identify the most critical problems and define a work plan to answer these problems.

U.S. Dairy Forage Research Center Facilities

Main offices, laboratories, greenhouses and engineering wing, designed for 12 scientists and built in 1981 on the west side of the University of Wisconsin-Madison campus.

Research farm near Prairie du Sac, Wisconsin, built in 1980. Home to about 350 lactating cows and an equal number of replacement heifers. Located inside the former Badger Army Ammunition Plant. Total of 2,006 acres in cropland, pastures, woodlands, buildings and roads. The farm is operated jointly with the University of Wisconsin Agricultural Research Stations.

The Environmentally Integrated Dairy Management Research Unit is based at a laboratory designed for 6 scientists and built in 2008 on the southeast side of Marshfield, Wisconsin (left). It also includes a research farm (below), about 10 miles north of the Marshfield lab, that was completed in 2011, is designed for 128 lactating cows and 550 heifers, and is operated jointly with the University of Wisconsin Agricultural Research Stations.

One Center	**U.S. Dairy Forage Research Center**
Three Management Units	Dairy Forage & Aquaculture Research Unit Cell Wall Biology & Utilization Research Unit Environmentally Integrated Dairy Management
Five Locations	Madison • Prairie du Sac • Milwaukee Marshfield • Stratford

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Vacancy

Research Dairy Scientist (Vice-Dave Metens)

Vacancy

Research Dairy Scientist (Vice-Glen Broderick)

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Vacancy

Center Director (Vice-Neal Martin)

Current and Potential . . .

Collaborating Scientists and Organizations

Other ARS

Plant Science Research Unit
St. Paul, MN
JoAnn Lamb, Research Geneticist (plants)
Michael Russelle, Soil Scientist
Debby Samac, Research Plant Pathologist

Bovine Functional Genomics
Beltsville, MD
Ransom Baldwin, Research Animal Scientist
Erin Connor, Research Molecular Biologist
Curt Van Tassell, Research Geneticist (animals)

Northwest Irrigation and Soils Research Unit
Kimberly, ID
David Bjorneberg, Supervisory Agricultural Engineer

Small Grains and Potato Germplasm Research Unit
Aberdeen, ID
Rick Barrows, Research Physiologist (fish)

Grain, Forage & Bioenergy Research Unit
Lincoln, NE
Gautam Sarath, Molecular Biologist
Ken Vogel, Research Geneticist

Soil and Water Management Research Unit
St. Paul, MN
John Baker, Research Leader

Pasture Systems & Watershed Management Research Unit
University Park, PA
Kathy Soder, Animal Scientist

Plant Polymer Research Unit of NCAUR
Peoria, IL
Gordon Selling, Research Chemist

National Laboratory for Agriculture and the Environment
Ames, IA
Douglas Karlen, Research Soil Scientist

Other Government Agencies

USDA Naturational Resource and Conservation Service
U.S. Geological Survey, Water Science Center (Wisconsin)
Wisconsin Dept. of Agriculture, Trade & Consumer Protection

Land Grant Universities

University of Arkansas
Fayetteville, AR — Ken Coffey

Iowa State University
Ames, IA — Buddhi Lamsal, Stuart Birrell

Michigan State University
East Lansing, MI — Mike Allen

North Carolina State University
Raleigh, NC — Ron Qu

Ohio Agricultural Research & Development Center
Wooster, OH — William Weiss

South Dakota State University
Brookings, SD — David Casper

University of Wisconsin
Madison, WI
Lou Armentano, Mike Bertram, Nancy Esser, Pat Hoffman, Brian Holmes, Carrie Laboski, Joe Lauer, John Peters, Mark Renz, Troy Runge, Kevin Shinners, Garret Suen, Dan Undersander, Michel Wattiaux, Kent Weigel

Private Non-Profit

Canola Council of Canada

Innovation Center for U.S. Dairy, Dairy Management, Inc.
Rosemont, IL

Midwest Forage Association
St. Paul, MN

NIRS Forage & Feeding Testing Consortium

The W.H. Miner Agricultural Research Institute
Chazy, NY

*The Samuel Roberts Noble Foundation**
Ardmore, OK

Industry

Archer Daniels Midland
Balchem Corp.
Cal-West Seeds, Inc.
Case New Holland
*DuPont Pioneer**
Elanco Animal Health
Evonik Degussa Corp.
*Forage Genetics International**
John Deere
Kuraray America, Inc.
Pioneer Hi-Bred International, Inc.

International Organizations

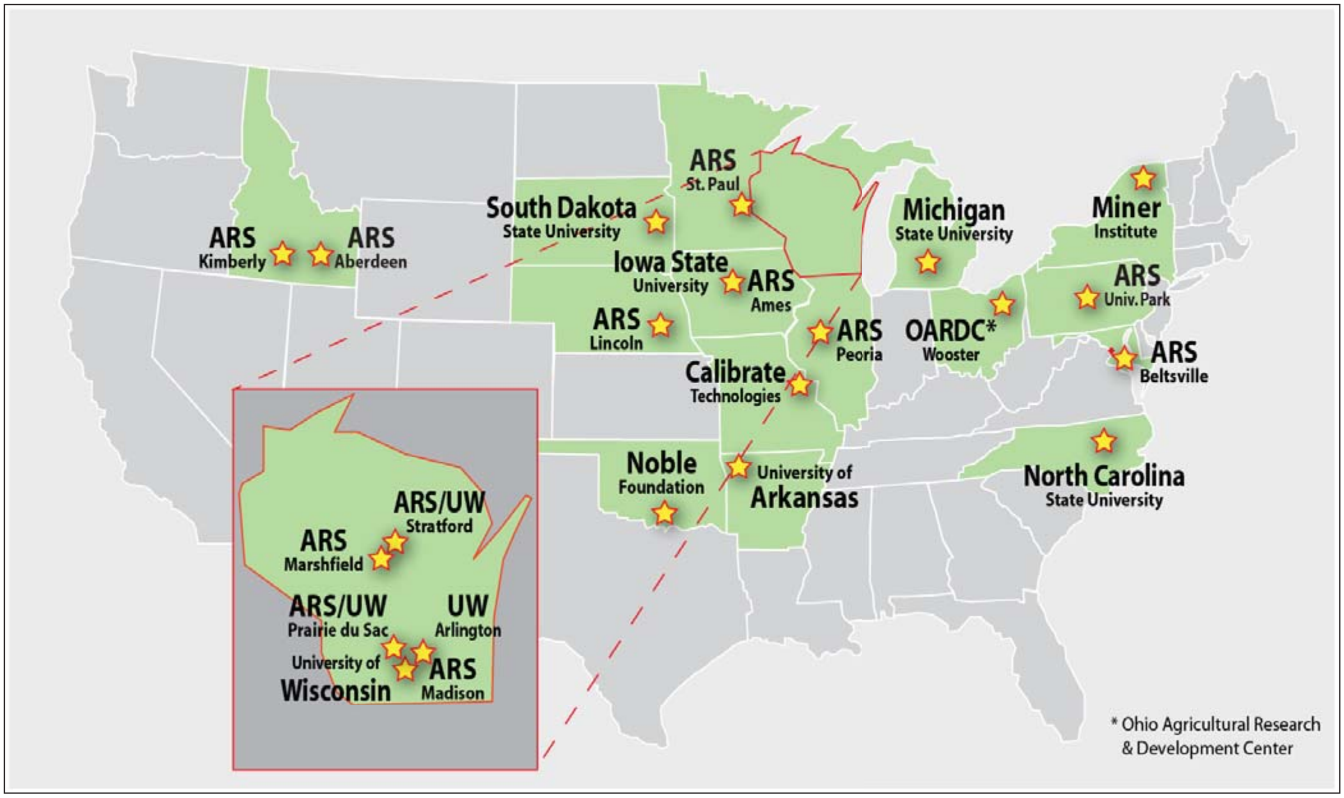
Institute of Biological, Environmental and Rural Sciences
Aberystwyth University, United Kingdom

University of Reading, Reading, United Kingdom

United Nations Food and Agriculture Organization
Rome, Italy

**Member of the Consortium for Alfalfa Improvement*

Current and Potential . . .
Collaborating Organizations Across the U.S.



On the following pages . . .

A blueprint for research at the U.S. Dairy Forage Research Center

CRIS (Current Research Information System) is the U.S. Department of Agriculture's (USDA) documentation and reporting system for ongoing and recently completed research projects in agriculture, food and nutrition, and forestry.

Research at the U.S. Dairy Forage Research Center falls under these six major CRIS projects.

Current CRIS projects at the USDFRC

Forage Characteristics that Alter Feed Utilization, Manure Characteristics and Environmental Impacts of Dairy Production

This Feed Efficiency project is one of six main areas of research emphasis at the U.S. Dairy Forage Research Center

Project Number: 3655-31000-023-00
Project Type: Appropriated
Start Date: November 1, 2012
End Date: October 31, 2017

Scientists: Richard Muck
J. Mark Powell
John Grabber
Vacancy (vice Mertens)

Objectives:

1. Determine the effects of dietary crude protein and forage type on feed utilization by dairy cows and heifers, in-barn methane and ammonia emissions, the production and chemistry of manure, and the impacts of these outcomes on manure nutrient availability in soils.
2. Characterize polyphenol-containing plant extracts and determine how they can be used to alter dairy cattle nitrogen efficiency, reduce in-barn emissions of ammonia and greenhouse gases and modify manure nitrogen availability in the soil.
3. Determine how silage feed additives alter rumen fermentation and feed utilization in dairy cattle.
4. Develop a functional characterization of forage fiber, accounting for physical form, fragility and digestion characteristics.

Approach:

1. Alfalfa silage, corn silage, corn grain and roasted soybeans will be 15N (nitrogen) enriched in the field and fed separately as part of a standard ration. Urine and feces will be collected from lactating cows on these rations and used in laboratory studies to estimate ammonia emissions from barn floors and soil nitrogen transformations after manure application as influenced by each feed. Feeding options for dairy replacement heifers in confinement and grazing settings will also be evaluated.
2. The ruminal-gastrointestinal digestibility of alfalfa proteins treated with tannin fractions will be determined by in vitro incubation followed by enzymatic hydrolysis. Tannin extracts will be fed to lactating dairy cows at 0 to 3% of dietary dry matter, and effects on in-barn emissions of ammonia and methane will be measured. Feces collected from this experiment will be applied to soil to measure effects on soil carbon and nitrogen cycles. Adding tannin extracts to free-stall barn floors will be studied as a means of reducing in-barn ammonia and methane emissions.
3. In vitro analyses of untreated, inoculated and formic acid-treated silages will be performed to understand how a *Lactobacillus plantarum* silage inoculant can affect rumen microbial growth. Inoculated silage extracts that appear to contain the factors affecting ruminal microbial growth will be compared to extracts from untreated silages.
4. A series of lactating cow trials will be performed to examine the effects of forage quality on energy intake, partitioning and feed conversion efficiency. Functional relationships between physical form, fragility and digestion characteristics of forage fiber will be developed and tested in ruminally fistulated cows. Differences in the mix of energy sources in lactating cow rations on intake and partitioning at different stages of lactation will also be measured.

UNDERSTANDING RUMEN INTERACTIONS

Determining Influence of Microbial, Feed, and Animal Factors on Efficiency of Nutrient Utilization and Performance in Lactating Dairy Cows

This Rumen project is one of six main areas of research emphasis at the U.S. Dairy Forage Research Center

Project Number: 3655-31000-024-00
Project Type: Appropriated
Start Date: October 10, 2012
End Date: October 9, 2017

Scientists: Mary Beth Hall
Paul Weimer
Vacancy (vice Broderick)

Objectives:

1. Maximize nitrogen use efficiency and animal performance by determining the optimal levels and qualities of dietary protein appropriate for differing base forages in dairy cattle diets, and determining the influence of polyphenol (o-quinones, tannins) or other feed additives on feed nitrogen use efficiency.
2. Assess the relationships of ruminal microbial community profile or animal genotype with animal factors including feed efficiency and lactation performance in dairy cattle.
3. Determine how the interactions among dietary components influence product formation by ruminal microbes and implications for effects on digesta passage from the rumen in order to optimize meeting animal nutrient requirements and enhancing animal performance.

Approach:

1. Feeding studies with lactating dairy cows will be performed to test the effects of different combinations of dietary forage and supplemental protein sources and the interaction of dietary tannins and crude protein level of the diet as they influence milk production and efficiency of nitrogen use for milk production. Omasal sampling will be performed in order to quantify differences among dietary treatments in flow of amino acids from the rumen. Effects of tannin and protein levels on nitrogen volatilization will also be evaluated using manure samples from this study.
2. Studies will explore the relationship of ruminal microflora profile and milk fat depression in lactating dairy cows. The impact of interactions of cow genome, lactation performance, and accrual of disease events over multiple lactations will be investigated using records of 4,000 genotyped cows. Phenotypic data will be used to establish heritability of phenotypes, and it will be adjusted for effects of age on increased risk of decreased performance/increased treated disease events.
3. In vitro fermentations will be used to investigate relationships among nonfiber carbohydrate sources and level and type of protein supply as they alter the profile, amount, and rate of fermentation product formation by ruminal microbes. The impact of the protein x carbohydrate interactions, combined with influence of changing rates of liquid passage and forage sources, will be investigated in studies with lactating cows. A series of in vivo studies with lactating cows will be conducted to explore the effects of dietary components (salts, soluble protein) on ruminal digesta liquid and dry matter proportions, total digesta weight, liquid passage rate, and water intake.

Current CRIS projects at the USDFRC

BASIC FORAGE RESEARCH

Removing Limitations to the Efficient Utilization of Alfalfa and Other Forages in Dairy Production, New Bio-Products, and Bioenergy

This Basic CRIS project is one of six main areas of research emphasis at the U.S. Dairy Forage Research Center

Project Number: 3655-21000-055-00
Project Type: Appropriated
Start Date: January 25, 2013
End Date: January 24, 2018

Scientists: Ronald Hatfield
Michael Sullivan
Wayne Zeller

Objectives:

1. Increase profitability, improve animal welfare and reduce manure production by improving the digestibility and energy conversion efficiency of forages in dairy rations by manipulating forage cell-wall biosynthetic pathways to lower indigestible residue formation, lower waste production, and develop more efficient tools for evaluating forage quality.
2. Increase profitability and reduce the amount of nitrogen-containing wastes that enter the environment by reducing protein loss during the post-harvest storage and livestock consumption of alfalfa and other forages through manipulation of forage phenolic metabolic pathways.
3. Improve forage biomass production (quantity and quality) for increased nutrient availability and novel bio-products that integrate bioenergy production with alfalfa and other forage crops to reduce input costs while improving environmental conditions.

Approach:

1. We will utilize a multidisciplinary approach combining plant physiology/biochemistry, chemistry, agronomy, molecular biology and genetics. To enhance positive characteristics of forages, work will focus on: improving cell wall digestibility under high biomass production, capturing more plant protein in products, e.g., milk and plant bio-products, while generating less nitrogen waste. Improved utilization of cell walls can be achieved through manipulation of genes involved in biosynthesis of structural carbohydrates and lignin. Small changes in cell wall composition may lead to decreased cross-linking and increased digestibility.
2. Cell wall screening methods will be used to identify chemical characteristics related to improved energy conversion efficiency. Molecular approaches will be used to modify plant biosynthetic pathways (lignification, cell wall cross-linking, structural polysaccharides) to identify avenues for altering cell wall digestibility. Efficient capture of protein nitrogen in the rumen is related to slowing protein degradation and availability of adequate digestible carbohydrate. Molecular, chemical, and biochemical approaches will be used to determine the roles of polyphenol oxidase/o-diphenols and tannins in decreasing protein degradation during ensiling and in the rumen.
3. Molecular approaches will be used to alter plants for reduced protein loss during post-harvest storage and during livestock consumption of forages. A polyphenol oxidase/o-diphenol system will be inserted into alfalfa to protect proteins during ensiling. Chemical characterization of polyphenol (e.g., o-quinones and tannins) interactions with proteins will reveal mechanisms to protect proteins from degradation and provide selection criteria for forage improvement. Multiple approaches will be used to improve forage biomass production for improved animal performance and new bio-products.

Redesigning Forage Genetics, Management and Harvesting for Efficiency, Profit and Sustainability in Dairy and Bioenergy Production Systems

This Forage project is one of six main areas of research emphasis at the U.S. Dairy Forage Research Center

Project Number: 3655-21000-056-00
Project Type: Appropriated
Start Date: January 25, 2013
End Date: January 24, 2018

Scientists: Michael Casler
Heathcliffe Riday
Geoffrey Brink
John Grabber

Objectives:

1. Develop appropriate defoliation (grazing and harvested) and nitrogen application management guidelines for temperate grass-legume pastures of the North Central and Northeastern USA to improve seasonal yield distribution, extend the grazing season, and improve the efficiency and utilization of energy inputs.
2. Improve establishment, harvest management, and storage methods to reduce nitrogen inputs, increase the profitability of crop rotations, increase the recovery of dry matter and nonstructural carbohydrates, improve the energy density of baled hays, and mitigate the negative effects of rainfall on ensiling, storage, and feeding characteristics of rain-damaged silages.
3. Improve pasture grass and legume production systems through increases in establishment capacity, persistence, productivity, resilience to climate extremes, and quality.
4. Improve profitability, conversion efficiency, and adaptability to climatic variation in forage and bioenergy crops.

Approach:

1. Solid and liquid manure applications will be evaluated in a series of grazing experiments designed to improve seasonal availability of nutrients and seasonal distribution of pasture productivity. Defoliation and manure application treatments will be applied to grass-clover mixtures to identify combinations that increase the competitiveness of red clover in mixed grazed swards.
2. High- vs. low-density plant spacing will be evaluated to determine the effect on biomass yield for high-biomass alfalfa cultivars. Gibberellin-based growth regulator treatments will be evaluated for their effect on establishment and seeding-year biomass yield for alfalfa interseeded into corn. Propionic acid preservatives will be evaluated to determine their effect on reducing spontaneous heating and nutrient loss of large-rectangular bales of alfalfa hay.
3. The comparative effectiveness of mass selection, half-sib selection, and marker-assisted half-sib selection will be determined in an empirical study designed to improve persistence and forage yield of red clover. The optimal age for selection of red clover plants will be identified.
4. The effect of lignin and etherified ferulates on persistence and forage yield will be evaluated in a series of field experiments designed to evaluate progeny with high or low levels of each cell-wall component in three grass species. Heterosis between upland and lowland switchgrass ecotypes will be evaluated in a series of experiments to quantify hybrid vigor and to identify sources of variation that contribute to variation in hybrid vigor.

Current CRIS projects at the USDFRC

Adding Value to Biofuels Production Systems Based on Perennial Forages

This Biofuels project is one of six main areas of research emphasis at the U.S. Dairy Forage Research Center

CRIS Project Number: 3655-41000-006-00
Project Type: Appropriated
Start Date: December 14, 2009
End Date: December 13, 2014

Scientists: Paul Weimer
Matthew Digman
Ronald Hatfield

Objectives:

1. Develop new germplasm of perennial forage species that display increased yield and bioconversion potential.
2. Develop new commercially viable technologies for harvest, storage and/or on-farm pretreatment and biorefining of perennial bioenergy crops, and use modeling to assess the economic and environmental impacts of integrating these new technologies into sustainable farming systems.
3. Develop technologies based on mixed culture ruminal fermentation that enable commercially viable processes for producing hydrocarbon and alcohol fuels from lignocellulosic biomass via volatile fatty acid intermediates.

Approach:

1. Use conventional breeding methods and molecular analytical tools to develop and characterize new varieties of switchgrass adapted to growth in the northern United States.
2. Develop equipment and technology for harvesting perennial grasses and alfalfas at reduced cost or producing fractions having higher value and different end uses (e.g., stem fraction as biofuels feedstock and leaf fraction as animal feed). Evaluate practicality and economics of on-farm biomass pretreatment with acid, lime, ozone, and/or other reagents. Evaluate economics and environmental impact of biofuels production systems and assess opportunities for integration into dairy farming systems.
3. Modify cultivation methods and use selective pressure to improve mixed culture fermentations for converting cellulosic biomass to volatile fatty acid (VFA) mixtures. Economically prepare fermentation broths for further processing. Demonstrate and improve electrolytic conversion of VFA to hydrocarbons in aqueous systems using Kolbe and Hofer-Moest reactions.
4. Identify secondary plant cell wall structural factors that limit plant cell wall biodegradation. Improve fermentation of plant cell wall materials to ethanol and adhesive-containing fermentation residue. Improve bacterial strains and culture media to increase yield of adhesive material, and improve adhesive properties through further chemical modification.

Improving Dairy Forage and Manure Management to Reduce Environmental Risk

This Nutrients project is one of six main areas of research emphasis at the U.S. Dairy Forage Research Center

Project Number: 3655-12630-003-00
Project Type: Appropriated
Start Date: October 1, 2010
End Date: September 30, 2015

Scientists: Bill Jokela
Mark Borchardt
Wayne Coblentz
Peter Vadas

Objectives:

The overarching objective of our research project is to address current knowledge gaps in understanding and managing the nutrient cycles and pathogen transmission on modern dairy farms. Our specific research objectives are as follows:

1. Determine the effects of dairy cattle diet and dairy herd management (e.g., pasture, confinement, hybrid systems) on manure nutrient excretion, capture, recycling, and loss via gaseous emissions, leaching, and runoff.
2. Determine the effects of dairy manure management practices and cropping systems on crop production, soil properties, and loss of nutrients, sediment, and pathogens (e.g., *Cryptosporidium parvum*, *Salmonella spp*., and bovine diarrhea virus) in surface runoff or atmospheric emissions.
3. Determine the effects of timing and rate of dairy manure application on nutrient uptake and nutritional characteristics of fresh and harvested annual and perennial forages.
4. Develop crop management strategies to optimize the exchange of nitrogen, phosphorus, and potassium as manure and feed between neighboring dairy and cash grain farms.
5. Develop improved methods for detection and quantification of pathogens in manure, forages, and surface runoff and evaluate effects of management practices on pathogen transport and survival.

Approach:

Improved management of dairy farms requires successfully managing its nutrient flows, both to maximize nutrient use by animals and crops to optimize profit, and to minimize nutrient loss to the environment. We will investigate key aspects of nutrient cycling throughout the dairy-farm system with a variety of methods and at different scales (replicated field plots, field-scale paired watersheds, feeding trials with replicated pens of heifers, etc.). We will also examine pathogen transport and viability at different points in the dairy farm system. Our research team also has a longer-term goal, which is to integrate information across experiments to more completely describe, quantify, model, and manage the entire dairy-farm nutrient cycle. Achieving this goal will help ensure the existence of sustainable, profitable, environmentally benign dairy farming for coming decades.

United States Department of Agriculture

One Center

U.S. Dairy Forage Research Center

Three Research Units

Environmentally Integrated Dairy Management
Cell Wall Biology and Utilization
Dairy Forage and Aquaculture

Five Locations

Madison
Prairie du Sac
Marshfield
Stratford
Milwaukee

Madison
Laboratories, greenhouses, engineering lab, and the administrative offices on the University of Wisconsin-Madison campus.

1925 Linden Dr. West — Phone: (608)890-0050
Madison, WI 53706 — Fax: (608)890-0076

Prairie du Sac
The research farm consists of 2,000 acres, about 350 cows in milk, and an equal number of young stock.

S8822 Sunset Dr. (off of Hwy. 78)
Prairie du Sac, WI 53578 — Phone: (608)643-2438

Marshfield
The Environmentally Integrated Dairy Management Research Unit is researching manure and nutrient management options.

2615 Yellowstone Dr. — Phone: (715)387-4609
Marshfield, WI 54449

Stratford
Research farm for the EIDMRU. Same contact info as above.

Milwaukee
Aquaculture research at the Great Lakes WATER Institute.

600 East Greenfield Ave. — Phone: (414)382-1767
Milwaukee, WI 53204

Visit our web site at:
www.ars.usda.gov/mwa/madison/dfrc

Dairy Data

Dairy products provide:
- 72% of our dietary calcium
- 19% of our dietary protein
- 33% of our dietary phosphorus
- and more!

Forage Facts

Forage is good for the environment!
- improves soil structure, health
- protects soil from erosion
- protects the water supply

Forage keeps cows healthy and productive; provides needed fiber.

Economic Impact

Dairy's ripple effect:
- Every $1 of milk sold off the farm generates $3 in economic activity
- $1 million of U.S. milk sales generates 17 jobs
- Economic output of U.S. dairy industry is estimated at $140 billion