Environmental Stewardship Continuous Improvement

REFERENCE MANUAL 2017

FOREWORD

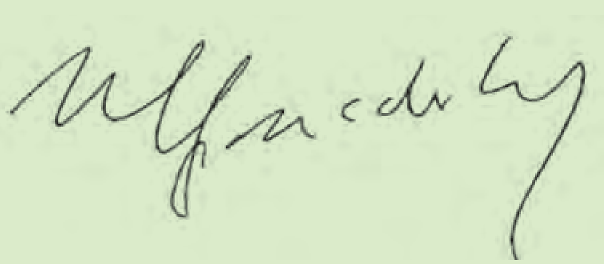
U.S. dairy farmers have always had a legacy of environmental stewardship and continuous improvement to help sustain their farms for future generations. Over time, our good business practices have made us among the world's most efficient and sustainable milk producers and in today's consumer-centric society we need to amplify that story. FARM Environmental Stewardship helps us tell it in a measurable, science-based way while providing business value that is both financially and environmentally beneficial.

The FARM Environmental Stewardship Continuous Improvement Reference Manual provides a resource that aggregates existing science and technology that can help us drive continuous improvement, all while tracking our progress in a way we can relay to dairy customers. As dairy farmers, we strategically monitor the efficiency of our operations to maintain their economic viability. The considerations we face on the business side of our dairy farms are often not mutually exclusive with environmental outcomes.

The FARM Environmental Stewardship assessment results can help us identify areas where our farms can improve their environmental footprint in relation to other dairy operations of the same size. This manual takes the next step by providing an array of ideas for us to consider that can improve our assessment results, while also improving the bottom line of our operations.

Dairy farmers in this country have a huge opportunity to meet the demands of consumers around the world in the coming decades. Through this program we can show why we are sustainability leaders in farming practices, while providing ourselves with the data to improve economic and environmental outcomes on our farms. I encourage all dairy farmers to sit down with their veterinarian, nutritionist and other on-farm specialists to review this manual because I think you will find the information useful in tailoring continuous improvement to your individual farms.

SINCERELY,



Michael J. McCloskey, DVM

Chairman of the Board for Fair Oaks Farms
CEO of Select Milk Producers
Chairman of NMPF Environmental Committee
Chairman of Innovation Center for U.S. Dairy Environmental Stewardship Committee

PREFACE

The National Dairy FARM (Farmers Assuring Responsible Management) Program, administered and managed by the National Milk Producers Federation (NMPF), is proud to introduce FARM Environmental Stewardship – a voluntary tool available to all FARM program participants for measuring and communicating their journey toward continuous improvement.

Retailers, processors and other purchasers of farm products are increasingly interested in the environmental footprint of agricultural production. Dairy buyers and stakeholders are asking farmers to share more information about the industry's environmental outcomes. The dairy industry has an impressive track record of efficiency gains that have produced positive environmental achievements.

Compared to 70 years ago, producing a gallon of milk uses 65 percent less water, requires 90 percent less land and has a 63 percent smaller carbon footprint.[1] Today's challenge is to continue to document and highlight our industry's progress.

FARM Environmental Stewardship (ES) is one tool available to milk marketing organizations and farmers to meet this growing demand. It currently focuses on greenhouse gas (GHG) emissions and energy utilization, building upon the groundwork established by the Innovation Center for U.S. Dairy Farm Smart tool. Farm Smart is a proven resource, having been field tested on farms by many major cooperatives and in several full supply chain pilot projects. FARM ES uses the methodology and science from Farm Smart to provide producers, dairy cooperatives and companies with a single streamlined source for voluntary on-farm assessment.

The FARM ES Continuous Improvement Reference Manual is presented as an informational resource to accompany the FARM Environmental Stewardship tool. In particular, the Reference Manual is intended for those who make on-farm decisions, including farmers, nutritionists, veterinarians, manure specialists, consultants and others. It offers practical, science-based ideas for reducing GHG emissions in the areas of Feed, Productivity, Manure and Energy. These ideas are presented as opportunities and options for consideration with links to resources for more information. We recognize that all on-farm practices must be considered in the context of a farm's daily management and that no one consideration will fit all dairy farms.

Managing the farm's GHG emissions over time can demonstrate to dairy buyers and stakeholders our industry's continued commitment to improving our environmental impact. Additionally, generating positive environmental outcomes often goes hand in hand with improving the economic bottom line – either directly or to manage risk.

Our hope is that this manual proves valuable for producers looking to improve the economic well-being of their farms, as well as their environmental footprint. For more information about FARM Environmental Stewardship, please visit **www.nationaldairyfarm.com/environment**.

ACKNOWLEDGEMENTS

The authors of the FARM ES Continuous Improvement Reference Manual are grateful to the Innovation Center for U.S. Dairy for directly providing material for Chapter 3: Feed and Chapter 4: Productivity. These two chapters capture the contents of the Considerations and Resources on Feed and Animal Management – a collaborative effort of more than 40 dairy professionals in industry and academia. The FARM ES Continuous Improvement Reference Manual builds on their impressive effort with additional guidance around energy and manure management.

FARM Environmental Stewardship acknowledges the following individuals and organizations for their time and effort in developing the manual:

FARM Environmental Stewardship Task Force

The FARM Environmental Stewardship Task Force includes cooperative staff who manage field staff interacting directly with farmers, corporate sustainability professionals and customers. The goal of this panel is to review, recommend and provide counsel on the governance of the FARM Program. Updates and official recommendations from the panel are sent to the NMPF Environmental Committee.

Sarah Beaubien *Tillamook*

Mike Billotte *United Dairymen of Arizona*

Jed Davis *Agrimark*

Dean Letter *Michigan Milk*

Joshua Luth *Foremost Farms*

Antone Mickelson *Darigold*

Kevin Olson *Prairie Farms*

Lindsay Reames *Maryland & Virginia Milk Producers*

Sarah Schmidt *Associated Milk Producers Inc.*

Tai Ullmann *Land O' Lakes, Inc.*

Jamie Zimmerman *Dairy Farmers of America*

Technical Review Panel

The Technical Review Panel provides an independent review of best management practices included in the FARM ES Continuous Improvement Reference Manual. Led by World Wildlife Fund, the panel's goal is to ensure FARM Environmental Stewardship provides a best-in-class guide to support farmers in understanding FARM ES results and to identify opportunities for improvement. The panel includes farmers, academics, processors and conservationists.

Kyle Clark *EnSave*

J.P. Cativiela *Dairy Cares*

Robert Foster *Farmer*

Curt A. Gooch *Cornell University*

Robert Hagevoort, PhD *New Mexico State University*

Jennifer Harrison *The Ohio State University*

John Jacobs *Farmer, Green Valley Dairy*

Roberta Osborne *Chobani*

Michelle Perez *American Farmland Trust*

Greg Thoma *University of Arkansas*

Sandra Vijn *World Wildlife Fund*

Andy Whitman *Manomet*

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Steve Rowe *Newtrient, LLC*

Karen Scanlon *Innovation Center for U.S. Dairy*

Juan Tricarico *Innovation Center for U.S. Dairy*

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Development and Design

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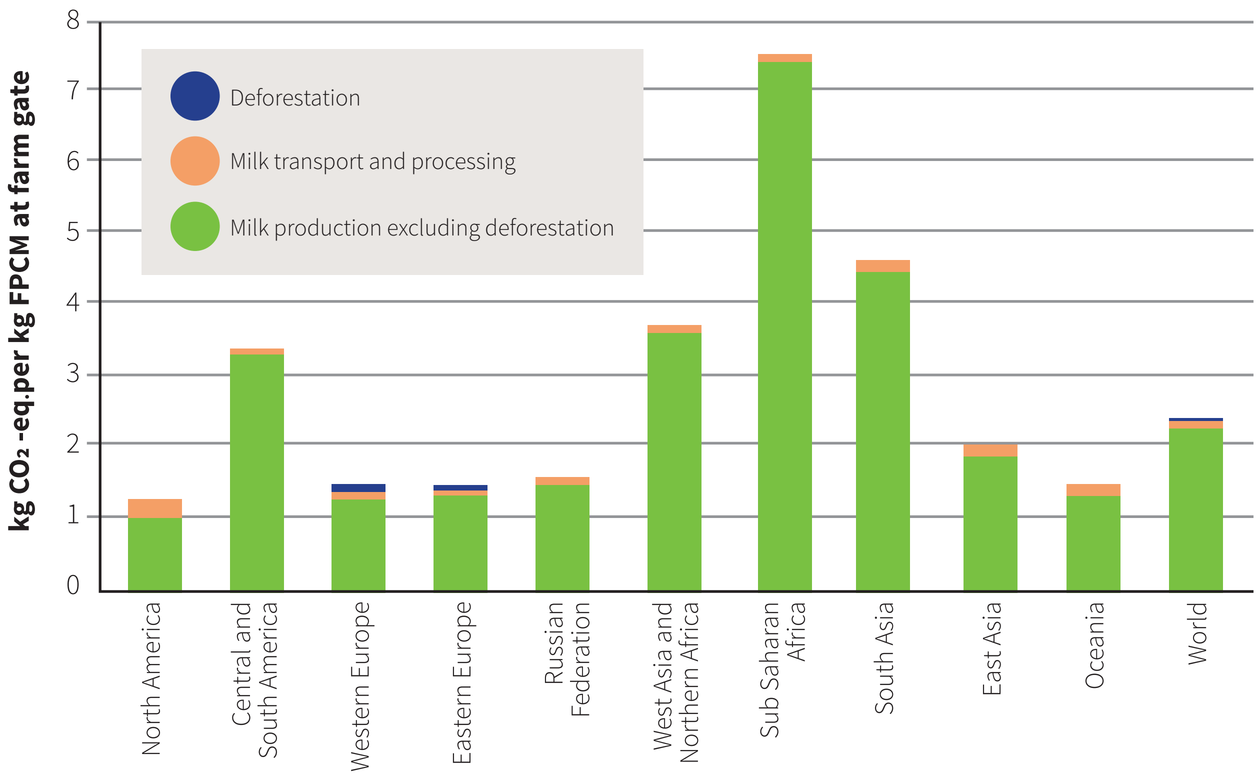
Introduction

The dairy industry has a long history of progress when it comes to reducing greenhouse gas (GHG) emissions. Much of this progress is thanks to efficiency gains over the past several decades. Compared to 70 years ago, producing a gallon of milk uses 65 percent less water, requires 90 percent less land and has a 63 percent smaller carbon footprint.[1] In fact, the U.S. dairy industry may be the world's most efficient. According to a study by the United Nations Food and Agriculture Organization, dairy farming in North America has the lowest GHG emissions intensity of any region in the world (**Figure 1**).[2]

FIGURE 1: ESTIMATED GREENHOUSE GAS EMISSIONS



Estimated GHG emissions per kg of FPCM at farm gate, averaged by main regions and the world. Derived from FAO.[2]

Our industry's challenge today is to track and communicate dairy's continued efficiency and environmental gains. Dairy farmers, along with their cooperatives, can use the FARM ES tool to assure dairy buyers, retailers and consumers of our commitment to continuous improvement. To that end, the FARM ES tool estimates farm-level GHG emissions and energy intensity to show changes over time. Looking at the tool's results can also help identify areas to target for improvement.

This Reference Manual lays out management practices, technologies and other considerations that can help reduce on-farm GHG emissions and energy use in a way that makes business sense. Farmers and on-farm decision makers should consult the Reference Manual after completing the FARM ES assessment. **The Reference Manual is not meant to be read cover to cover. Instead, farmers should focus on chapters most relevant to their individual operations. Chapters 1 and 2** are useful for all farmers because they cover how best to use the Reference Manual, as well as provide advice on selecting specialists and detail options for financing certain practices and technologies.

The FARM ES Tool

The FARM Environmental Stewardship (ES) tool estimates GHG emissions and energy intensity by using the results from a life cycle assessment (LCA) conducted by the Applied Sustainability Center at the University of Arkansas.[3] The LCA incorporated data from more than 500 dairy farms across the United States.

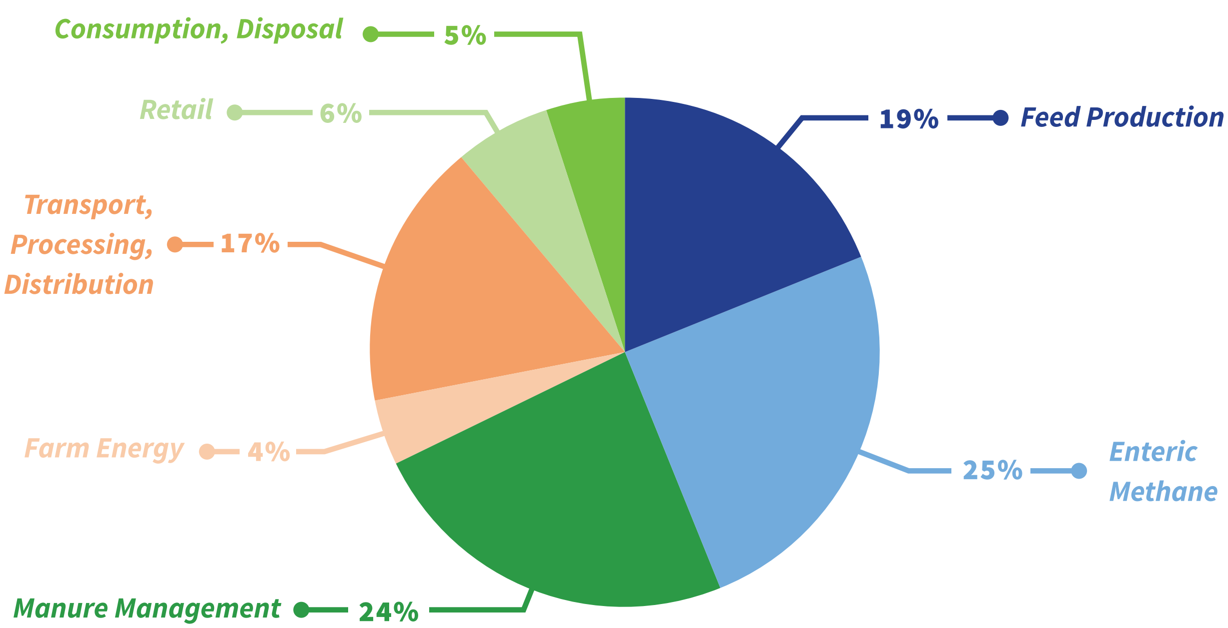
An LCA seeks to calculate the total environmental impacts from an entire chain of production. The dairy industry study, supported by the Innovation Center for U.S. Dairy, was a cradle-to-grave analysis – meaning an assessment of all the energy and GHG emissions associated with every step of dairy production, from fertilizer manufacturing to disposal of milk packaging. The dairy industry learned that about 72 percent of GHG emissions from dairy production occur before leaving the dairy farm gate. Emissions from enteric fermentation (a digestive process that releases methane), manure management and feed production were found to be the largest contributors (**Figure 2**). **Appendix A** provides more details on the sources of on-farm emissions.

Researchers translated the dairy LCA research into a tool dairy farmers can use to estimate their own emissions. These efforts resulted in the creation of Farm Smart by the Innovation Center for U.S. Dairy, which is now fully integrated into FARM ES.

Farm Smart is a proven resource, having been field tested on farms by many major cooperatives and in several full supply chain pilots. FARM ES uses the methodology and science from Farm Smart to provide producers, dairy cooperatives and companies with a single, streamlined source for voluntary on-farm assessment. As environmental science continues to evolve, the models behind FARM ES will be updated in partnership with the Innovation Center for U.S. Dairy.

FARM ES uses a model to calculate farm-level emissions from feed production, enteric fermentation, energy use and manure. It greatly simplifies the amount of data farmers need to enter compared to the original LCA survey. By asking only a limited set of questions, the FARM ES tool reduces the burden on farmers while still providing reliable, statistically robust estimates.

FIGURE 2: SUPPLY CHAIN CONTRIBUTIONS TO THE CARBON FOOTPRINT OF MILK



Derived from Thoma et al.[2]

FARM ES is a best-in-class tool for measuring the carbon and energy footprints of dairy farms. The inputs into the tool were carefully selected and explain 98 percent of the variability in carbon footprints across farms surveyed in the LCA. The tool does not currently address several key areas:

- FARM ES uses the dairy LCA research to make assumptions about feed production practices. It does not ask users about their specific feed production practices, such as tillage or fertilizer application.
- The tool does not take into account a user's manure application practices in generating emissions results. It is limited to manure storage and treatment.
- The tool does not cover issues like manure nutrient management or water quality. Pay particular attention to disclaimers noted in **Chapter 3: Manure** to understand the Reference Manual's limitations.
- FARM ES simplifies the data required from farmers about manure management by giving the option of only 18 manure management systems and treatment options, as well as specifying the use of an anaerobic digester. Except for the case of anaerobic digesters, it does not account for the effects of an integrative manure management system, in which the output of one management component may feed into another component.
- Farms using anaerobic digesters receive a reduction in manure-related GHGs in their FARM ES results. Other renewable energy sources, such as on-farm solar panels, do not directly impact GHG emissions results in FARM ES at this time. However, FARM ES does capture reductions in electricity or fuel use that may result from using renewable energy technologies.
- Cow longevity was not included as a factor in the dairy LCA research; keeping cows healthy and productive reduces the number of replacements that need to be raised, which measurably contributes to GHG emission reductions.
- The FARM ES model may not reflect changes in environmental footprint for all of the good management practices that are presented and discussed in this document. However, it is expected that adoption of these practices will generally support continual improvements in dairy farm sustainability, which could show up in the results over time.

Understanding Your Results

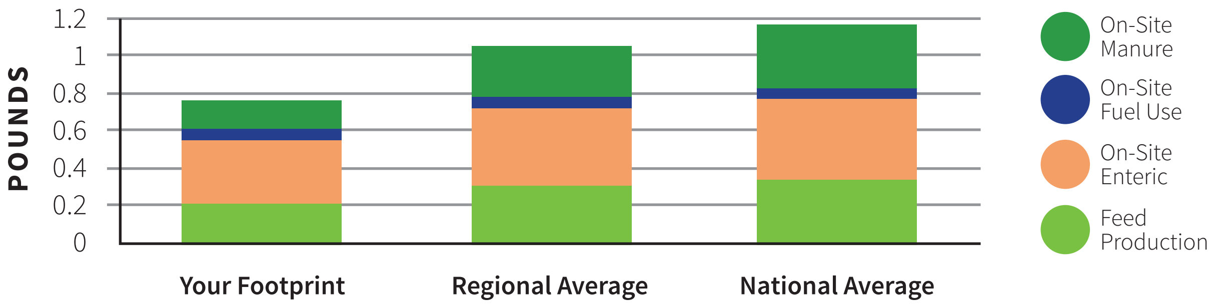
FARM ES estimates on-farm GHG emissions and energy use. Total emissions are normalized – or divided by – pounds of milk produced in order to compare performance year to year and across farms that differ in milk output. Specifically, milk output is converted to fat- and protein-corrected milk (FPCM). Because much of the energy in dairy feed is converted to milk solids (fat, protein, etc.), and not all farms produce milk with the same fat and protein composition, FPCM normalizes on-farm production to an average content (4 percent fat and 3.3 percent protein).[i]

FARM ES results are divided into four areas of GHG emissions: feed production, on-site enteric fermentation, on-site manure and on-site fuel/electricity use (**Figures 3 and 4**). "On-site" refers to dairy activities on the farm. If the operation purchases feed and/or doesn't raise its own feed, the tool will still estimate the environmental impacts of producing the purchased feed.

[i] *Lactose has little impact on the overall calculation. When lactose is kept as a constant, FPCM is the same measurement as energy-corrected milk.*

FIGURE 3. YOUR FARM GREENHOUSE GAS EMISSIONS

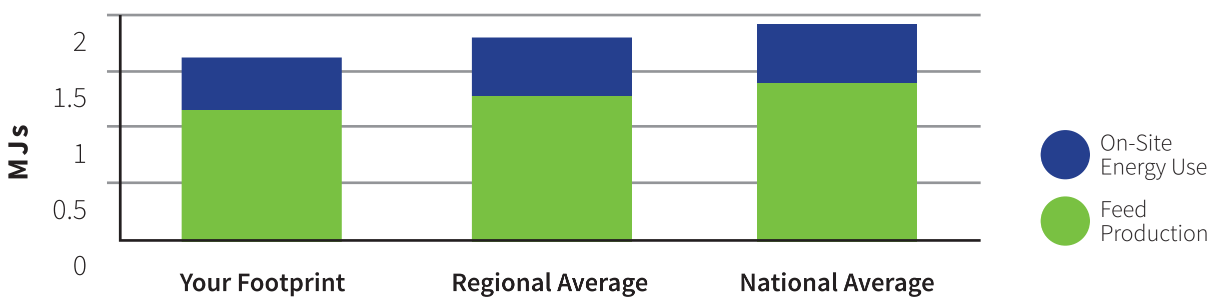
lb CO_2e / lb FPCM produced



	Your Footprint	Regional Average	Regional Difference	National Average	National Difference
Feed Production	0.20	0.29	*(0.09)*	0.32	*(0.12)*
On-Site Enteric	0.34	0.42	*(0.08)*	0.43	*(0.09)*
On-Site Fuel Use	0.06	0.07	*(0.01)*	0.07	*(0.01)*
On-Site Manure	0.17	0.30	*(0.13)*	0.36	*(0.19)*
TOTAL	**0.77**	**1.08**	***(0.31)***	**1.18**	***(0.41)***

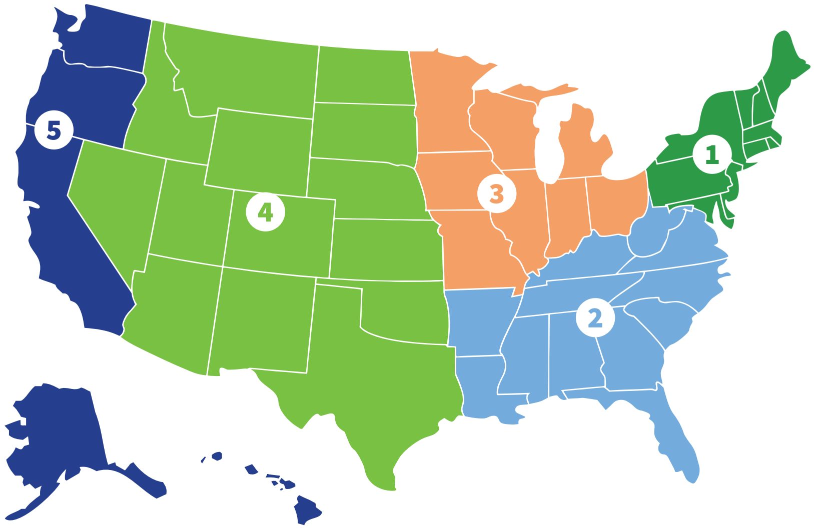
FIGURE 4. YOUR FARM ENERGY USE

MJs / lb FPCM produced



	Your Footprint	Regional Average	Regional Difference	National Average	National Difference
Feed Production	1.12	1.29	*(0.17)*	1.47	*(0.35)*
On-Site Energy Use	0.42	0.44	*(0.02)*	0.41	0.01
TOTAL	**1.54**	**1.73**	***(0.19)***	**1.88**	***(0.34)***

FIGURE 5. REGIONS



The tables in **Figures 3 and 4** provide greater insight into how the operation's results compare to similarly-sized farms, by showing regional and national averages. Regions are shown in **Figure 5**. The regional and national averages come from the results of the dairy LCA research.

How to Use this Manual to Improve FARM ES Results

Readers of the Reference Manual should focus on the chapters most relevant to their farm and most useful for improving their carbon and energy footprint results. After completing the FARM ES assessment, for example, you may identify areas where your emissions are higher than the regional or national average. Or, if your results are below average in all areas, you may consider which of your emissions is closest to average because there may still be opportunities for improvement. We recommend that you consult the relevant chapter(s) of the Reference Manual to find practice and management considerations to reduce emissions in those areas. Additionally, everyone can benefit from reading **Chapter 2: Moving Forward**, which offers advice on selecting consultants/vendors and options for financing.

The following table shows how Reference Manual chapters relate to the sources of emissions found in the ES tool results.

Emissions Type	Relevant Reference Manual Chapter(s)	Chapter Page	Example Topic Areas Covered
All	Chapter 2: Moving Forward	Page 8	• Selecting a specialist/vendor • Financing options
Feed Production	Not covered in the Reference Manual		
On-Site Enteric	Chapter 3: Feed Chapter 4: Productivity	Page 16 Page 38	• Ration formulation • Feeding • Herd health
On-Site Fuel Use	Chapter 6: Energy	Page 72	• Energy efficiency options for milking, ventilation and lighting
On-Site Manure	Chapter 3: Feed Chapter 5: Manure	Page 16 Page 58	• Manure storage and treatment options • Ration formulation

The Reference Manual is divided into four chapters that align with the sections of the ES tool: Feed, Productivity, Manure and Energy.

Each chapter offers practical, science-backed ideas for farmers and on-farm decision makers to reduce GHG emissions. These ideas are presented as considerations, with links to resources within each chapter and in **Appendix B** beginning on Page 90. **The considerations are not prescriptive; they should be evaluated in the context of a farm's unique circumstances.**

When reading through the considerations in each chapter, you may realize that you are already using some or most of the practices on your farm. The lists of considerations intentionally include a range of practices, from those that are very common to those that are less common. Some farms may find that they can benefit from many of the considerations; others will only find a handful that they are not yet implementing. The lists of considerations can be thought of as a checklist to help determine if there are practices not yet being employed that could be beneficial to pursue.

The Reference Manual focuses on strategies that relate directly to the FARM ES results, so it does not currently include all of the possible ways farms can reduce their carbon footprint. The following summarizes the contents of the Reference Manual:

Feed and Productivity – Chapters 3 and 4

Improving herd productivity and feed efficiency are two of the most promising and cost-effective avenues toward reducing GHG emissions per unit of FPCM. Special attention to ration formulation, forage quality and concentrate management as well as animal health, nutrition and cow comfort all contribute to achieving gains in productivity and feed efficiency.

Manure – Chapter 5

Shifting manure management systems or implementing technologies, such as solid-liquid separation, can reduce emissions. Capital costs, labor availability, water quality outcomes and other feasibility issues are chief concerns in making decisions about manure management. Consideration should be paid to these issues when evaluating the considerations presented in **Chapter 5: Manure** to reduce GHG emissions. Additional opportunities also exist in adjusting ration formulations to affect the nutrient content of manure (see **Chapter 3: Feed**).

Energy Use – Chapter 6

Exploring equipment and technologies with higher energy efficiency can reduce energy use. Additionally, certain behavioral practices like performing regular maintenance can help farms use less fuel. Reductions in energy use lead to lower GHG emissions. See **Chapter 6: Energy** for ideas on how to reduce the farm's energy use.

Feed Production

Crop production activities like tillage, planting, harvest, grain drying and nutrient application all influence GHG emissions. But FARM ES users are not asked about their feed production practices because the model uses the dairy LCA research to make well-informed assumptions about typical practices. For this reason, the Reference Manual does not have a chapter on feed production.

Instead, FARM ES participants seeking to learn more about issues related to feed production are encouraged to consult Field to Market. Field to Market is a diverse collaboration working to create opportunities across the agricultural supply chain for continuous improvements in productivity, environmental quality and human well-being. The dairy industry is currently collaborating with Field to Market to understand environmental impacts of dairy feed production (**http://fieldtomarket.org/**).

02 Moving Forward

The Reference Manual describes a variety of strategies to reduce on-farm GHG emissions. Consulting a specialist or technology vendor and securing financing can help implement those strategies.

Selecting a Nutritionist, Veterinarian or Related Specialist

A nutritionist, veterinarian or other animal health specialist can be key to a productive herd. Below are tips for selecting a specialist.

Goals

It's important to know the goals and priorities for your farm prior to engaging in any sort of nutrition or veterinary service. For example, is your biggest priority productivity, profits, health, reducing shrink or all of the above? What are the current or past challenges facing your farm?

Referrals

Once at the stage of considering a service, it's helpful to check on referrals. Are there other dairies in the area using the nutritionist or veterinarian? Can you contact them? What results have they generated for other clients?

Credentials

Another step in determining the reliability of a specialist is checking their credentials. What education, certifications and experience do they have? Nutritionists, for example, should have an advanced degree in dairy science or nutrition. Applicable certifications, such as through the American Registry of Professional Animal Scientists, can show additional expertise.

Service Expectations

Discuss roles and responsibilities. What level of communication do they need from you to be successful? How frequently will they visit the dairy? What is their availability to handle unexpected/ emergency situations? What is the best way to reach them? How far away are they located?

Methods

How do they plan to measure success/herd performance over time? Do they set benchmarks? Do they use/recommend any particular software?

Observation

Walk the dairy with the prospective specialist. How do they interact with the cows? How do they interact with employees? Do they ask you or staff appropriate questions?

Evidence

When considering an innovative solution, such as a feed additive, it's reasonable and expected that farmers ask for evidence and data to back up any claims made by the consultant or vendor. Can they provide data that you can take to an extension agent or other trusted expert to evaluate?

RED FLAGS

Be wary of any consultant or vendor that exhibits the following traits.

- Does not possess appropriate education, certification or experience.
- Doesn't ask questions about your goals or challenges. This can signal a specialist who uses the same approach for every dairy rather than tailoring advice to the farm's unique circumstances.
- Is not able to explain how changing the system at one point will affect other parts of the dairy.
- Seems to have all of the answers, even in subjects outside of core area of expertise.

Selecting a Manure Consultant or Vendor

Developing and implementing strategies for manure management can benefit from the expert advice of trained and experienced specialists. Subject matter experts, such as certified agronomists and engineers, can be invaluable for a wide range of manure-related services such as developing a nutrient management plan, designing manure storage or treatment structures, considering innovative technologies, and more.

Below are some tips to help select a reputable and appropriate manure consultant or technology provider.

Goals

It's important to know what type of solutions your farm is looking for prior to purchasing any sort of technology or services. For example, if your farm has more manure than it can currently handle, an anaerobic digester won't solve your problem on its own. Talking with a cooperative extension agent, independent consulting engineer or other subject matter expert can help your farm define its challenges and goals.

Referrals

When considering a service or technology, it's helpful to check on referrals. Are there other dairies in the area using the service or technology? Can the company put you in touch with them? How long has the technology been around? What are the average costs for comparable technology in the area?

Credentials

Checking the level of credentials and the reliability of a specialist or technology is important. For a technology, this can mean third-party evaluations such as the Newtrient Technology Catalog (see the Resource Spotlight on Page 12). For a specialist, consider their training, experience and, if applicable, certifications.

Evidence

Operators want to know that the product or service they are purchasing is legitimate. It's reasonable and expected that farmers ask for evidence and data to back up any claims made by the consultant or vendor. Can they provide data that you can take to an extension agent or other trusted expert to evaluate? Can they explain, in detail, the processes behind the given technology?

RED FLAGS

Be wary of any consultant or vendor that exhibits the following traits.

- Apparent lack of knowledge. Does not provide evidence when answering important questions.
- Is not able to explain the process or provide data for a given technology. Even if the technology is proprietary, they should be able to describe the physical processes.
- Is not able to explain how changing the system at one point will affect other parts of the dairy.
- Does not have proper credentials, such as certifications, documented experience or evaluation by a third party.

Performance Guarantees

Longevity of parts and components is an important factor in determining overall costs. What sort of warranty does the company offer? What is the effective useful life of the components? Where are the components manufactured and assembled?

Whole-Farm Impacts

Related to evidence, farmers will also need vendors to explain how the manure management change or technology will impact other parts of the farm. What are the anticipated environmental outputs? Will it impact the quality of bedding or manure available for application? How will it change the nitrogen balance?

Labor Requirements/Technical Expertise

Any change in technology or practices will require some shift in labor. What are the labor requirements associated with installing, operating and maintaining the equipment? What kind of technical expertise is needed? Will training be required? What is the time commitment?

Regulatory Implications

Some new practices or technologies will trigger the need for additional permits. Find out if the vendor or specialist has worked in the farm's area before, and if so, what steps were required to ensure regulatory compliance. Can the vendor assist in the permitting process?

Costs

Seek to understand the full scope of costs associated with the project. What are the initial capital costs? Define roles, recurring costs, lifespan, payback period, etc.

Service Expectations

Define roles and responsibilities. What aspects of operation and maintenance are the farm's responsibility versus the vendor's? Does the company offer a service agreement to maintain the equipment on a regular basis? If so, where are the service personnel located?

RESOURCE SPOTLIGHT

NEWTRIENT

The Newtrient Technology Catalog is a tool for evaluating the many technologies and vendors available for managing and creating manure-based products.

Visit **http://www.newtrient.com/Catalog/Technology-Catalog**.

Newtrient improves sustainability by advancing technologies that transform manure into products like soil conditioners, fertilizer and energy, and by connecting stakeholders in this new and growing business arena. They serve as catalysts for new technologies, practices, products and markets.

Selecting an Energy Consultant or Vendor

Developing and implementing energy projects or technologies can benefit from the expert advice of trained and experienced specialists. Below are some tips to help select a reputable and appropriate energy consultant or vendor.

Goals

It's important to know what type of solutions your farm is looking for prior to purchasing any sort of technology or services. Talking with an independent third party, such as a cooperative extension agent, independent consulting engineer or other specialist can help your farm define its challenges and goals. Additionally, these third-party specialists can help evaluate proposals.

Referrals

When considering a service or technology, it's helpful to check on referrals. Are there other dairies in the area using the service or technology? Can the company put you in touch with them? How long has the technology been around? What are the average costs for comparable technology in the area?

Credentials

Checking the level of credentials and the reliability of a specialist or technology is important. For a technology, this can mean looking at respected industry standards. For example, ideally lights should be DesignLights Consortium (DLC) listed (**www.designlights.org**). Many ventilation fans are performance tested through Bioenvironmental and Structural Systems Laboratory (**http://bess.illinois.edu**). For a specialist, consider their training, experience and, if applicable, certifications.

Performance Guarantees

Longevity of parts and components is an important factor in determining overall costs. What sort of warranty does the company offer? What is the effective useful life of the components? Where are the components manufactured and assembled?

Ag Appropriate

For some equipment, such as lighting, operators should check with the vendor on whether the component has been tailored to operate in an ag environment.

Evidence

Operators want to know that the product or service they are purchasing is legitimate. It's reasonable and expected that farmers ask for evidence and data to back up any claims made by the consultant or vendor. Can they provide data that you can take to an extension agent or other trusted expert to evaluate? Can they explain, in detail, the processes behind the given technology?

Labor Requirements/Technical Expertise

What are the labor requirements associated with installing, operating and maintaining the equipment? What kind of technical expertise is needed? Will training be required? What is the time commitment?

Costs

Seek to understand the full scope of costs associated with the project. What are the initial capital costs, and operation and management costs? Define roles, recurring costs, lifespan, payback period, etc. Ask for an explanation of any assumptions the vendor makes in estimating full project costs. Consult with a trusted expert to evaluate the assumptions as needed.

Service Expectations

Define roles and responsibilities. What aspects of operation and maintenance are the farm's responsibility versus the vendor's? Does the company offer a service agreement to maintain the equipment on a regular basis? If so, where are the service personnel located? Does the company offer any free operations and maintenance services?

RED FLAGS

Be wary of any consultant or vendor that exhibits the following traits.

- Apparent lack of knowledge. Does not provide evidence when answering important questions.
- Is not able to explain the process or provide data for a given technology. Even if the technology is proprietary, they should be able to describe the physical processes.
- Does not provide sufficient information on the quality and longevity of components.
- Is not able to explain how changing the system at one point will affect other parts of the dairy.
- Does not have proper credentials, such as certifications, documented experience or evaluation by a third party.

Financing Options

Financing options are available to support the implementation of certain practices or on-farm technologies that help reduce GHG emissions. Eligibility and timelines vary by program.

EQIP: Environmental Quality Incentives Program

EQIP is a voluntary program through the Natural Resources Conservation Service (NRCS) that provides financial and technical assistance to implement conservation practices and to develop conservation plans. EQIP covers a variety of issues, from feed management to waste storage. Payments are made after practices are completed. Cost-share rates range from about 50 to 75 percent. There are program priorities at both the national and state levels that are used, among other factors, in making award decisions.

The local NRCS office can provide greater detail on eligibility, ranking information and application guidelines. NRCS practice codes at the national level provide overall guidance and set the minimum acceptable standards for each practice. However, each state determines which practices are applicable in their state and can tailor the practices to best suit implementation at the state level. Application timelines vary by state.

For more information, consult the following links:

https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/eqip/

https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/technical/cp/ncps/?cid=nrcs143_026849

USDA Rural Development Programs

Rural Energy for America Program (REAP)

REAP is a loan guarantee and grant program that provides financing for the purchase of renewable energy systems, energy efficiency improvements, energy audits and feasibility studies. There are two types of REAP.

- Energy Audits & Renewable Energy Development Grants can be used for energy audits, renewable energy technical assistance or renewable energy site assessments. Eligible project costs may include salaries directly related to the project, travel expenses directly related to conducting energy audits or renewable energy development assistance, office supplies and administrative expenses up to a maximum of five percent of the grant (**www.rd.usda.gov/programs-services/rural-energy-america-program-energy-audit-renewable-energy-development-assistance**).
- Renewable Energy & Energy Efficiency Loans & Grants can be used to improve energy efficiency or to install new renewable energy systems. Energy efficiency improvements can include the purchase, installation and construction of insulation, lighting, doors/windows and more. There are limits on how much of the project costs can come from this funding source. Grants from this program can fund up to 25 percent of the total eligible project costs. Combined grant and loan guarantees can fund up to 75 percent of total eligible project costs. And loan guarantees can apply to loans of up to 75 percent of total eligible project costs (**www.rd.usda.gov/programs-services/rural-energy-america-program-renewable-energy-systems-energy-efficiency**).

Producers should contact their state USDA Rural Development office to learn more about eligibility, terms and the application process (**www.rd.usda.gov/contact-us/state-offices**).

Value-Added Producer Grants (VAPGs)

VAPGs offers financial assistance for producers to engage in value-added activities related to the processing and/or marketing of value-added products. Funds can be used for planning activities, for example, feasibility studies or developing business plans, or for working capital expenses like processing costs, marketing/advertising expenses and some inventory/salary expenses. VAPGs relate to strategies in the Reference Manual that entail development of bio-based products, such as through anaerobic digesters.

Producers should contact their state USDA Rural Development office to learn more about eligibility, terms and the application process (**www.rd.usda.gov/contact-us/state-offices**).

Clean Water State Revolving Funds (CWSRF)

CWSRF programs provide financing for a wide range of water quality and infrastructure projects. States each administer their own CWSRF programs, which may differ on specific loan terms (interest rates, repayment periods, etc.), as well as community or environmental priorities. CWSRF financial assistance can include loans, debt purchasing and loan guarantees. Some states have programs specific to livestock operations that finance projects like the development of manure management plans or the construction of manure management structures. States may also finance the implementation of best management practices (BMPs) connected to a state's Nonpoint Source Management Program (319 plan) through their respective CWSRF programs.

Producers should contact their state CWSRF program to find out more information about eligibility, terms and the application process (**www.epa.gov/cwsrf/forms/contact-us-about-clean-water-state-revolving-fund-cwsrf#state**).

Other Resources

Database of State Incentives for Renewables & Efficiency® (DSIRE)

Operated by North Carolina State University and funded by the U.S. Department of Energy, the DSIRE database is an up-to-date resource on incentives and policies by state to support renewable energy and energy efficiency (**www.dsireusa.org**).

Utility Providers

The farm's utility provider may have incentive or technical assistant programs to promote energy efficiency. Check with your utility to learn more.

03

Feed

Opportunities to Reduce GHG Emissions through Ration Formulation, Feeding and Feed Management

Introduction

Farmers know that producing more milk with the same amount of feed saves money and improves efficiency. It also cuts enteric methane emissions per unit of FPCM. Increasing feed efficiency means less dietary energy is wasted as enteric methane and lower amounts of nutrients are excreted into the environment as manure. Additionally, formulating rations to optimize the herd's nutrition and health can improve milk quality and yield.

Increases in feed efficiency and productivity will lower the GHG footprint results in the FARM ES tool over time. However, increasing feed efficiency and productivity isn't simple.

This chapter covers a wide variety of topics to help producers reduce GHG emissions through feed management. It can serve as useful background to inform conversations with the farm's nutritionist, veterinarian or other specialist. A specialist can also help answer any questions that come up after reading this chapter. **Chapter 2: Moving Forward** contains helpful tips on selecting a specialist.

Some farms may prefer to focus only on specific sections to gain greater insight into a particular topic area. Veterinarians, nutritionists and other subject matter experts can consult **Appendix B** for detailed lists of supplemental resources by topic area.

Ration Formulation

Addresses basic concepts of rumen function, energy requirements and other factors that go into creating a balanced diet. The basics are important for managing GHG emissions because diet formulation directly impacts feed intake, energy availability, passage rate, feed efficiency and other factors that influence enteric methane formation.

Forage Management

Addresses the role of forage in the diet, grazing, establishment/growth, harvest/processing, storage and feedout. High-quality forage promotes feed intake, overall ration digestibility and high productivity, leading to more profits and reduced enteric methane emissions per unit of FPCM.

Concentrate Management

Addresses the basics of carbohydrates, proteins, lipids and by-products. It also includes a short discussion on feed additives. By directing rumen fermentation away from methane-producing pathways, concentrates (e.g. grains, oilseeds and by-product feeds) added to dairy cattle rations also reduce enteric methane emissions per unit of FPCM.

Key Considerations

- Work with a nutritionist, veterinarian or other specialist to formulate. rations and optimize feeding conditions.
- Maximize overall diet digestibility for highest feed efficiency.
- Focus on improving forage fiber digestibility to promote forage intake and rumen health and maximize productivity.
- Monitor protein and carbohydrate levels. Unbalanced diets lead to inefficient use of feed protein and elevated nitrogen waste, which impacts emissions from manure.
- Match protein in the feed to the protein requirements of the animal at each life stage to mitigate manure ammonia and nitrous oxide emissions.
- Consider the use of concentrates to direct fermentation away from methane production.
- Evaluate forage storage methods to preserve nutrient quality and minimize spoilage.

Ultimately, the best strategies will depend on the farm's unique management structure, its geography, the composition of its herd, and other factors. Producers looking for more information on nutrition and animal management are encouraged to consult the FARM Animal Care Reference Manual (**www.nationaldairyfarm.com/resource-library**).

General Feed Resources:

Nutrient Requirements of Dairy Cattle: Seventh Revised Edition. (2001). www.nap.edu/catalog/9825/nutrient-requirements-of-dairy-cattle-seventh-revised-edition-2001

Feeding the Dairy Herd. (2005). Linn, J.G. et al.: www.extension.umn.edu/agriculture/dairy/feed-and-nutrition/feeding-the-dairy-herd/

Practical Approaches to Feed Efficiency and Applications on the Farm. (2007). Hutjens, M.F.: http://articles.extension.org/pages/26134/practical-approaches-to-feed-efficiency-and-applications-on-the-farm

Nutrition and Feeding. Penn State Extension: http://extension.psu.edu/animals/dairy/nutrition/nutrition-and-feeding

Spartan Dairy Ration Evaluator/Balancer Version 3.0. (2011). Michigan State University: http://spartandairy.msu.edu/

Dairy Cattle Nutrition of Milking and Dry Dairy Cows. (2016). http://articles.extension.org/pages/15603/dairy-cattle-nutrition-of-milking-and-dry-dairy-cows

Ration Formulation

Good feeding practices and a balanced diet – one that that meets productivity, health and reproductive needs – will improve profits and reduce enteric methane emissions per unit of FPCM. Ration formulation requires careful balancing of ingredients to ensure that nutrients are not overfed or underfed to each animal class in the herd. Consistent with the FARM Animal Care program, rations must provide the required nutrients for maintenance, growth, health and lactation for the appropriate physiological life stage.

Ration formulation has a significant impact on profitability and enteric emissions. It directly affects feed intake, fermentable energy availability, passage rate, feed efficiency and other factors that influence digestion, enteric methane formation and nutrient supply in dairy cattle.

Rumen Function

Rumen function is vital to the survival and productivity of dairy cattle. The cow's rumen allows for microbial fermentation and digestion of fiber in feed.

Dairy nutritionists must ensure adequate nutrient supply for maximum FPCM production while maintaining rumen function in the dairy cow. A healthy rumen will support extensive feed digestion and microbial protein synthesis, stimulating milk production.

Cows efficiently convert microbial protein into milk protein due to its amino acid profile. So high levels of microbial protein production are desirable and are influenced by conditions in the rumen, such as pH, as well as carbohydrate/nitrogen availability to the rumen microbes.

The rumen mat – a floating layer containing the most recently consumed feed – is another important feature because it encourages cudding and helps facilitate fermentation by keeping particles in the rumen longer. When diets are too high in concentrates or contain only very fine fibrous material, the rumen mat may be very small or non-existent.

When rumen function is impaired, feed digestion, intake and productivity drop, and the health of the animal may be compromised. Feeding unbalanced rations may also lead to ruminal disorders such as bloat and subclinical acute acidosis (SARA). Feeding the appropriate amount of starch and long fibers will lead to a balanced diet that improves productivity and reduces enteric methane emissions for overall milk production.

Considerations:

- Have a conversation with your nutritionist or veterinarian about your herd's rumen health and if there are any issues to address.
- Monitor indicators of rumen health, such as rumination activity, manure appearance, milk fat percentage and hoof health.
- Evaluate ration formulations to ensure they are compatible with a healthy rumen. For example, supply combinations of energy and protein sources that maximize microbial protein synthesis. Additionally, supply

adequate energy without excessive amounts of rapidly fermentable carbohydrates that reduce rumen pH. Use ration formulation tools to help (see General Feed Resources on Page 19).

- Consider the inclusion of dietary feed additives that enhance rumen function. See Feed Additives in **Chapter 3: Feed** on Page 37 for more information on evaluating options.

Resources:

Feeding the Dairy Herd. (2005). Linn, J.G. et al.: www.extension.umn.edu/agriculture/dairy/feed-and-nutrition/feeding-the-dairy-herd/

6 ways to monitor the 'rumen factory'. (2011). Quaife, T. In Dairy Herd Management: www.dairyherd.com/dairy-herd/features/6-ways-to-monitor-the-rumen-factory-113940554.html.

Components of Ration Formulation

The following sections describe core concepts in ration formulation. They are intended for those readers that do not have an educational background in dairy nutrition science and wish to understand foundational concepts.

Energy Requirements

Cows vary in their ability to digest feedstuffs and thus will have different feed conversion efficiencies. Natural variability between cows means that higher-yielding cows have the ability to partition more energy into milk. These cows also produce less methane per unit of milk produced.

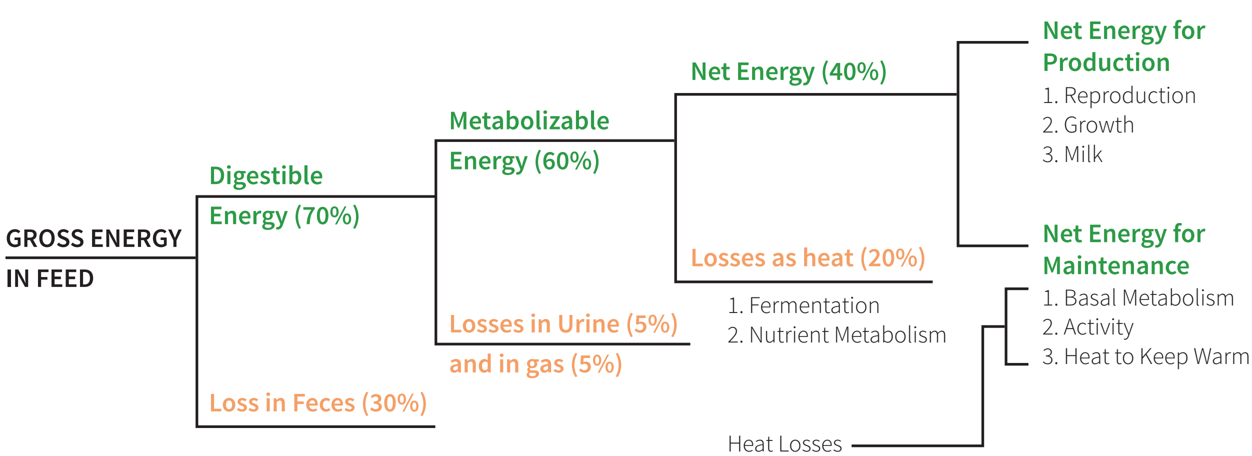
Energy in dairy feed is primarily supplied by carbohydrates, with fat and protein providing smaller amounts.

Nutritionists describe the flow of energy through the animal, or energy partitioning, using a basic model known as the net energy for lactation system (NEL). This system describes energy supply and energy losses associated with digestion and metabolism, and energy availability for productive purposes.

The NEL supplied by feeds is estimated based on their contents of non-fiber carbohydrate (NFC, which is mostly starch), crude protein (CP), fat, and neutral detergent fiber (NDF). Energy supply adjustments are made according to predicted digestibility and rate of passage of feeds.

The total amount of energy in feed delivered to a cow is called gross energy (GE), but the cow cannot

FIGURE 6. EXAMPLE OF THE DIVISION OF ENERGY IN FEED



Derived from the University of Minnesota.[5]

digest all of that energy and loses some in feces (**Figure 6**). The GE that is not lost, but is digested by the animal, is referred to as digestible energy (DE). Digestion and metabolism include a variety of biochemical processes during which:

1. Ruminal microbes digest feed and turn it into energy-rich substrates in the form of volatile fatty acids (VFA) that the cow absorbs from the rumen, and;
2. The cow itself digests a portion of undigested feed that escapes microbial fermentation in the rumen, providing energy-rich compounds that are absorbed at the intestinal level.

During digestion and metabolism, energy is lost in the forms of gas and urine. The gas is lost largely as carbon dioxide, methane and occasionally some hydrogen. The amount of energy remaining after subtracting gas and urinary losses from DE is called metabolizable energy (ME).

The energy loss due to heat production resulting from digestion and metabolism is subtracted from ME to provide the net energy (NE) available to the animal for productive purposes.

Every dairy operation should strive to decrease energy losses in feces, enteric methane, urine and heat production.

Protein and Amino Acids Requirements

The protein and amino acids requirements of the dairy cow are expressed in terms of metabolizable protein (MP). MP is true protein that flows from the rumen and is digested and absorbed as amino acids. These amino acids are the required nutrients that are metabolized by the cow to support maintenance, growth, reproduction and milk production.

Some protein in feed can be digested in the rumen while some cannot. Feed protein that is digested by ruminal microbes is referred to as rumen-degradable protein (RDP), while protein that escapes microbial digestion is referred to as rumen-undegradable protein (RUP). Metabolizable protein (MP) is synthesized in the rumen from RDP and from a small amount of endogenous or recycled protein.

Microbial growth in the rumen is optimized when RDP and fermentable carbohydrates are available at all times. Rations where RDP and fermentable carbohydrates are unbalanced lead to inefficient use of feed protein and elevated nitrogen waste. Milk urea nitrogen (MUN) concentrations may be used to indicate how much nitrogen a lactating dairy cow is wasting.

Excess ammonia in the rumen occurs when there is excess nitrogen for the ruminal microbes to use. Ammonia enters the cow's bloodstream and is converted to urea by the kidneys and the liver. When the concentrations of urea in the blood increase, MUN also increases, serving as an indicator of inefficient nitrogen utilization in the animal.

The overall goal in protein nutrition of dairy cows is to produce milk with a desirable protein content and to optimize amino acid utilization and efficiency, which minimizes feed costs and maximizes economic returns. Ideally, amino acids in lactating cow diets would be directly balanced, but given current scientific research and knowledge, the best available strategy is to balance diets for metabolizable protein.

Ingredient and Diet Nutritional Analysis

The nutritional value of feed ingredients defines their ability to support animal performance. Laboratory analyses of feed ingredients for nutrient composition and digestibility allow for their best use in a ration that is formulated to meet the specific needs of an animal group without under feeding or over feeding nutrients.

Dairy cattle are used to relatively high-fiber diets. Forage is usually a major contributor of fiber in dairy cow diets. Forages are home grown in many cases and extensive forage use can minimize the need to import nutrients onto the farm. However, forages are subject to the greatest variability in nutrient composition and digestibility.

Ration formulation for dairy cattle should seek to meet fiber requirements for rumen health, to appropriately maximize forage use and to include sufficient concentrates and supplements (i.e., minerals and vitamins) to meet specific nutrient requirements.

The two main classes of carbohydrates are:

1. Neutral detergent fiber (NDF)
2. Non-fiber carbohydrate (NFC)

Chemical analysis with a neutral detergent solution is used to measure NDF. The NDF fraction includes cellulose and hemicellulose, plus the indigestible compound lignin. High-producing cows with a well-functioning rumen are limited in forage intake by the bulkiness of the fiber that fills up the rumen and/or slows the rate of passage. This bulkiness is best estimated by the forage NDF content and NDF digestibility.

NFC is a very diverse fraction containing organic acids, sugars, starches, fructans and pectins. The NFC fraction is commonly calculated as 100 percent (CP% + NDF% + EE% + Ash%), where CP = crude protein, NDF = neutral detergent fiber and EE = ether extract. NFC provides energy to rumen microbes, which in turn produce volatile fatty acids as an energy source for the cow.

Starch provides between 20-to-30 percent of ration dry matter in lactating cow rations. Starch is commonly supplied by corn, sorghum, other small grains, silages and by-products, potatoes and bakery waste. Many factors, including sources, particle size and processing, cause starch digestibility to range from fast to slow.

Sugars typically make up three-to-eight percent of the ration dry matter and are typically supplied by molasses, citrus pulp, bakery waste, fresh forages or hay.

Neutral detergent soluble fibers include pectins, fructans and other soluble fibers that ferment quickly without the risk of acidosis. These soluble fibers are typically supplied from legume forages, citrus pulp and beet pulp.

Protein, made up of amino acids, is important for milk production, body maintenance and reproduction. CP (nitrogen x 6.25) is fractionated according to its rate of degradation in the rumen. Soluble protein (Fractions A + B1) is rapidly available. The soluble protein fraction includes non-protein nitrogen (NPN) such as urea. Protein fractions B2 and B3 are slowly available in the rumen. Acid detergent insoluble protein (Fraction C) is indigestible.

Fats make up two-to-six percent of the diet dry matter in dairy rations. Fats are added to the rations of high-producing cows to supplement the NEL when feed intake might limit milk production. Sources of fat added to diets of dairy cows include high-fat by-product feeds, oilseeds and granular inert fats.

Dry Matter Intake and Feed Efficiency

Higher productivity per unit of feed intake is desirable to increase profitability and reduce enteric methane emissions per unit of FPCM. Feed efficiency (FE) is often calculated for lactating cattle by dividing the amount of FPCM produced by the amount of dry matter intake (DMI).

This approach ignores factors that affect feed efficiency such as the NEL concentration of feed DM, changes in body weight, cold and heat stress, days in milk (DIM) and feed digestibility. It is, however, still useful for environmental and economic benchmarking, especially when used in combination with income over feed cost (IOFC) and income over purchased feed cost (IOPFC).

Increasing feed efficiency is both economically and environmentally beneficial because less dietary energy is wasted as enteric methane and lower amounts of nutrients are excreted into the environment as manure.

Improvements in feed efficiency can be achieved by increasing milk production while holding DMI constant or by holding milk production constant and decreasing DMI. Due to compromised rumen health or insufficient ration formulation or feed processing, situations exist where DMI is not depressed but digestion is not optimal – resulting in lower milk production and poor feed efficiency. Increasing feed efficiency is both economically and environmentally beneficial because less dietary energy is wasted as enteric methane and lower amounts of nutrients are excreted into the environment as manure.

Considerations:

If possible, work with a nutritionist, veterinarian or other specialist to formulate rations. The following considerations may help inform conversations with hired experts.

- Routinely analyze diet ingredients at a laboratory for nutrient content and digestibility.
- Calculate dry matter intake (DMI), feed efficiency (FE), income over feed cost (IOFC) and income over purchased feed cost (IOPFC), and compare your farm's results over time. Check with a hired specialist or an extension agent for current recommended targets.
- Determine the availability of multiple protein and carbohydrate sources to allow for precise ration balancing.
- Consider cow energy needs:
    - o Meet net energy requirements of each dairy cattle group on the farm.
    - o Dilute maintenance energy requirements by maximizing milk production.
    - o Reduce fecal energy losses by maintaining rumen health, processing feed and maintaining an effective rumen mat to slow rate of passage of grains.
- Consider the importance of diet digestibility:
    - o Maximize overall diet digestibility for highest feed efficiency. Focus on improving forage fiber digestibility to promote forage intake and rumen health and maximize productivity. Improvements in fiber digestion can reduce reliance on other carbohydrate sources.
    - o Pay particular attention to starch concentration and digestibility for control of acidosis and reduction of energy losses from the cow.
    - o Use ration models that utilize multiple protein and carbohydrate fractions and estimate their extent of digestion to predict cow response.
    - o Promote dry matter intake (DMI), especially in early lactation, by feeding forages containing highly digestible fiber.
- Evaluate the diet's protein sources and content:
    - o Use the metabolizable protein system to formulate rations that supply adequate rumen degradable protein (RDP) and rumen undegradable protein (RUP) for each dairy cattle group on the farm.
    - o Consider using non-protein nitrogen (NPN) to partially supply RDP requirements.
    - o Consider using sources of RUP and/or rumen-protected amino acids to more accurately supply limiting amino acids to improve productivity, reduce waste and potentially reduce diet cost.
    - o Monitor milk urea nitrogen (MUN) concentration in groups of cows consuming the same diet to assess nitrogen waste and success of nitrogen capture and utilization by the cow. MUN should appear on the farm's DHIA or other milk report.

Resources:

Energetics for the Practicing Nutritionist. (2010). Weiss, W.P: http://articles.extension.org/pages/22405/energetics-for-the-practicing-nutritionist

Why Use Metabolizable Protein for Ration Balancing? (2010). Varga, G.A.: http://articles.extension.org/pages/26135/why-use-metabolizable-protein-for-ration-balancing

Dry Matter Determination. (2007). Nennich, T. et al.: http://articles.extension.org/pages/11315/dry-matter-determination

Forage Sampling Frequency as Influenced by Dairy Herd Size. (2010). Hoffman, P. et al.: http://fyi.uwex.edu/forage/files/2014/01/ForageSamplingFrequency-FOF.pdf

Nutrient Variability in Feeds within Farms. (2012). Weiss, W. et al.: https://ecommons.cornell.edu/bitstream/handle/1813/36470/cnc2012_Weiss.txt.pdf?sequence=1

Interpretation of Milk Urea Nitrogen (MUN) Values. (2008). Ishler, V.: http://extension.psu.edu/animals/dairy/nutrient-management/certified-dairy/tools/interpretation-of-mun-values

Practical Approaches to Feed Efficiency and Applications on the Farm. (2007). Hutjens, M.F.: http://articles.extension.org/pages/26134/practical-approaches-to-feed-efficiency-and-applications-on-the-farm

Feeding Management

Feeding management is the last necessary step of a feed program that successfully promotes optimal productivity, profits and mitigation of enteric methane emissions. Non-dietary factors associated with feed mixing, delivery and consumption can explain a large portion of variability in DMI, milk production, feed efficiency, IOFC, profits and enteric methane emissions per unit of FPCM.

Feeding management involves delivering a balanced ration in the appropriate amounts, forms and times. A key goal is to accurately and repeatedly provide feed in an environment that promotes healthy feeding behaviors. This is achieved by daily evaluation of dairy feed mixing and delivery, feed refusal and animal productivity/status. Daily pen training and employee incentives that align with measured and desired outcomes are effective tools for successful feeding management. In best practice, body condition scoring is used to monitor the energy balance and nutritional condition of the herd.

Considerations:

- Use feed management software and equipment to monitor and evaluate feed shrink, procedures and the influence of personnel and facilities on feed management.
- Provide sufficient feed bunk space that allows all animals to feed at the same time or sufficient quantities of feed for all animals during a 24-hour period. The recommended space at the feed bunk is 18 inches/head for heifers 6-12 months of age, 20 inches for heifers 12-28 months and 24 inches for heifers over 18 months in age. See the FARM Animal Care Reference Manual for more details (**www.nationaldairyfarm.com/resource-library**).
- Deliver fresh feed after milking to promote standing and reduce the risk of mastitis.
- Deliver fresh feed more frequently (two times a day or more). This stimulates eating behavior, reduces sorting and avoids slug feeding (rapid consumption of large amounts of concentrate in one meal).
- Measure feed ingredient weights accurately and follow mixing equipment directions (for example, mixing time and staying within mixer load capacity limits).
- Establish a routine or procedure for consistently mixing and delivering feed every day.
- Examine feed refusals for evidence of extensive feed sorting and selective consumption of concentrate.
- Consider frequent feed push-up (pushing feed closer to animals between feedings to provide continuous access) because it stimulates eating, though to a lower extent than fresh feed delivery.
- Monitor and record feed delivery and refusals by pen daily, preferable with feed management equipment and software.
- Provide sufficient bunk space, preferable with a physical partition (for example, headlocks) to allow animals to eat simultaneously.
- Train employees and evaluate their performance according to the established feed mixing and delivering procedures.

Resources:

Impact of Feeding Management on Cow Behavior, Health, and Productivity. (2013). DeVries, T.J.: http://www.wcds.ca/proc/2013/Manuscripts/p%20193%20-%20204%20DeVries.pdf

Using Feedstuff Inventory Management and Feeding Management Software on the Dairy: Concepts and Tasks. (2009). Jamison, C.A.: ftp://173.183.201.52/Inetpub/wwwroot/DairyWeb/Resources/3SDNC2009/Jamison.pdf

Drinking Water Quality and Access

Water is the most important nutrient required by dairy cattle and is especially important for lactating cows. Consequently, drinking water quality and accessibility are very important components of successful feeding programs.

Free and easy access to plentiful sources of high-quality and clean drinking water is absolutely essential for optimum production and profits. Water intake also lowers enteric methane emissions by dairy cattle. **Table 1** shows estimates of daily water consumption for a 1,500-lb. lactating cow.

Considerations:

- Always provide multiple sources of plentiful drinking water located in accessible alleys with sufficient space for cows to move around them easily.
- Collect drinking water samples and submit for laboratory analysis (including mineral analysis) on a routine basis or when a new water source is used or quality issues are suspect.
- Compare measured water intake to predicted requirements for the level of productivity.
- Locate drinking water troughs near feed troughs and within 50 feet of all stalls.
- Monitor drinking water intake with in-line water meters installed in each water source and include water intake from feed in the total water consumption estimates.
- Monitor water cleanliness on all troughs daily and clean as required.
- Provide one-to-two feet of linear trough space in return alleys from the milking parlor to promote water consumption immediately after milking.
- Consider relatively shallow watering troughs that are easy to clean and refill quickly with water.

Resources:

Evaluation of Water Quality and Nutrition for Dairy Cattle. (2006). Beede, D.K.: http://www.highplainsdairy.org/2006/Beede.pdf

Scientific Data for Developing Water Budgets on a Dairy. (2013). Harner, J. et al.: http://www.wdmc.org/2013/Scientific%20Data%20for%20Developing%20Water%20Budgets%20on%20a%20Dairy.pdf

Table 1. Estimated Daily Water Consumption for a 1,500-Pound Lactating Cow Producing 40-to-100 Pounds of Milk Daily

Milk Production (lbs/day)	Estimated DM Intake (lbs/day)	Mean Minimum Temperature[b] GALLONS PER DAY[c]				
		40°F	50°F	60°F	70°F	80°F
40	42	18.4	20.2	22.0	23.7	25.5
60	48	21.8	23.5	25.3	27.1	28.9
80	54	25.1	26.9	28.7	30.4	32.2
100	60	28.5	30.3	32.1	33.8	35.6

[a]Sodium intake = 0.18% of DM intake • [b]Mean minimum temperature typically is 10 to 15°F lower than the mean daytime temperature • [c]1 gallon of water weighs 8.32 pounds.

Forage Management

High-quality forage promotes feed intake, overall ration digestibility and high productivity, leading to increased profits and reduced enteric methane emissions per unit of FPCM. Forage management also adds financial value by influencing animal health and performance, feed utilization and costs, and land and nutrient management on dairy farms.

Forage quality is dependent on field conditions, plant species and variety, fertilization, maturity at harvest or during grazing, length of cut, processing and preservation. Reducing dry matter losses at harvest, during storage and feedout are key strategies to improving both animal performance and reduce enteric methane emissions.

Forage Importance and Contributions to the Diet

Forages are an essential part of dairy diets. In many rations, they contribute more than half of the total dietary dry matter intake (DMI), as well as several nutrients including energy, protein, starch and minerals. High intakes of highly digestible forages offer the greatest benefit in terms of improving productivity while reducing enteric emissions per unit of milk.

Composition and digestibility are two of the primary factors when evaluating forages. Together, they determine forage quality and ultimately influence animal performance. Additionally, composition and digestibility are highly variable in forages, more so than any other feed ingredient in the dairy diet. As a result, regular analyses are critical.

In many rations, forages contribute more than half of the total dietary dry matter intake (DMI).

Forages are often major contributors of dietary neutral detergent fiber (NDF) and affect overall diet digestibility. As noted previously in Ration Formulation, total dietary NDF content and digestibility are directly related to methane formation in the rumen, rumen function maintenance and feed intake regulation – all significant factors that determine productivity and enteric methane emissions. So forages need to be considered within the context of the whole diet when seeking to improve performance and reduce GHG emissions.

Lactating dairy cows have the greatest nutrient demand of any class of animal on the dairy farm and benefit the most from including high-quality forage in their diets. Feeding higher-quality forage to lactating cows usually increases milk production while reducing the need for supplemental concentrate in their diet.

The production, storage and feeding of high-quality forage can also be economically beneficial for the farm operation, reducing the need for off-farm feed purchases – thus mitigating rising feed costs and improving overall farm profitability. In addition to the economic benefits of self-producing high-quality forage, on-farm forage production influences land-use decisions and whole-farm nutrient balance, offering potential solutions to environmental management challenges faced by intensively managed dairy farms.

Considerations:

- Analyze forages for nutrient composition and neutral detergent fiber (NDF) digestibility regularly.
- Establish a forage management system that takes into consideration available land base, agronomic conditions, harvest methods, storage systems, feeding strategies and whole-farm nutrient balance.
- Maximize use of forage resources by feeding to various animal classes according to their nutrient demands and forage analyses results.
- Strive to produce the largest quantity of high-quality forage for the available land base in a cost-effective manner.

Resources:

Focus on Forage. University of Wisconsin Extension: http://fyi.uwex.edu/forage/fof/

Forages – Dairy Cattle Nutrition. Penn State Extension: http://extension.psu.edu/animals/dairy/nutrition/forages

Forage Quality Affects Profitability. (2007). Paulson, J.: www.extension.umn.edu/agriculture/dairy/forages/forage-quality-affects-profitability/

High Forage Rations for Dairy Cattle: How Far Can We Go? (2011). Chase, L.: http://livestocktrail.illinois.edu/uploads/dairynet/papers/4%20Chase.pdf

Understanding Forage Quality. (2001). Ball, D.M.: www.agfoundation.org/files/UnderstandingForageQuality.pdf

Grazing

Although grazing systems require different management approaches to confined-feeding systems, the considerations relative to forage management are similar for both. Grazing systems should target high animal productivity to increase profitability and reduce enteric methane output per unit of FPCM.

Because some areas have snow cover for several months, year-round grazing systems may not be feasible and must be considered when planning the overall planting and grazing schedule. Grazing forages at maturity, which provides the best combination of nutrient content and digestibility for cows, is highly desirable and requires careful pasture management.

Considerations:

- Consider that a key feature of high-quality pasture is the high rate of fiber degradation, which is associated with intense rumen fermentation and high milk yields.
- Apply manure and commercial fertilizer according to soil analyses and the nutrient needs of each pasture, and avoid grazing on very wet soils.
- Consider mechanical treatments such as pitting, contour furrowing, chiseling, ripping or subsoiling to modify soil and address natural resource concerns prior to planting.
- Consider selective breeding of dairy cows better suited to diets of grazed pasture to maximize efficiency of grazing program.
- Consider strategic supplementation with concentrates.
- Consider using legumes in warm climates to replace warm-season grasses.
- Consider pasture sampling to perform a nutritional analysis.
- Estimate pre-grazing herbage mass and post-grazing sward height to target pre-grazing herbage mass allowance that optimizes intake and performance.
- Increase the efficiency of utilization of grazed forage crops via controlled rotational grazing or management-intensive grazing.
- Time grazing to optimize plant maturity and provide the best combination of nutrient content and digestibility from each pasture.

Resources:

Grazier's Notebook. University of Wisconsin Extension: http://fyi.uwex.edu/forage/g-n/

NEPC Grazing Guide. Northeast Pasture Consortium: http://grazingguide.net/

Pasture-Based Systems for Dairy Cows in the United States. (2004). Muller, L.: http://extension.psu.edu/animals/dairy/nutrition/forages/pasture/articles-on-pasture-and-grazing/pasture-based-systems-for-dairy-cows-in-the-united-states

Pasture Quality and Quantity. (2003). Soder, K. et al.: http://extension.psu.edu/animals/dairy/nutrition/forages/pasture/articles-on-pasture-and-grazing/pasture-quality-and-quantity

Forage Establishment and Growth

Alfalfa and Other Legumes: Three key management details for the establishment of alfalfa and other legumes are:

1. Proper Soil pH
2. Properly firmed soil
3. Accurate planting depth

Fields can be direct-seeded, but seeding forage grasses with legumes can help limit soil erosion. This keeps nutrients in place, reducing the amount of fertilizer needed and improving the farm manure management plan.

Grasses: Well-managed grasses can improve overall ration fiber digestibility and nutrient management, and reduce soil erosion. Established grasses also provide a convenient place for in-season applications of manure and reduce the need for commercial fertilizer application.

Grasses are much less sensitive to wheel traffic than alfalfa and will greatly benefit from the nitrogen in manure. Grass management, however, can be more difficult than alfalfa management because grasses lose quality quickly after heading. When seeded with alfalfa, it's important to select a grass variety that matures at a similar time as the alfalfa matures. The ideal is to have the grass in the late boot (preheading) stage at the same time the alfalfa is in the late boot (pre-flowering) stage.

Corn Silage: Most corn hybrids planted for silage harvest are conventional hybrids, which vary in yield, grain content and fiber digestibility. Corn hybrids should be selected based on hybrid maturity, traits and their performance in replicated trials. University or other third-party trials are useful sources of information for selecting a hybrid.

Seed companies are the most reliable source of maturity information on their hybrids. Fiber (NDF) digestibility is important, but corn silage contains substantial amounts of energy-dense starch (30 percent on average), so starch yield is a very important factor in hybrid selection. Maturity, seed treatments, technology traits, planting population and chop height must all be the same for meaningful corn hybrid comparisons. Seeking out as much information as possible from the seed company will help ensure proper planting dates, target plant populations and fertility programs best suited to the particular hybrid of choice.

Fertilizer applications should always be based on a recent soil analysis. Manure can provide a large proportion of the plant's nutrient needs. Supplemental commercial fertilizer can be used for the remainder.

Forage crop yields and quality can be significantly reduced by weed growth, pest infestation and disease. Effective weed, disease and pest control begins with proper soil and growing conditions. Selection of resistant plant varieties or hybrids is also an important factor for successful weed and pest control.

Vigorous forage crop growth is the most important factor to control weed infestation. Monitoring forage crop growth and insect and weed pressure is essential for all forage crops. Having an action plan to act quickly and accordingly for the specific type of crop, disease or infestation is important to the risk management plan of the farm. Always follow manufacturers' recommendations when applying herbicides and pesticides to ensure appropriate application rates and timing.

Considerations:

- Conduct regular soil analyses and target manure and commercial fertilizer applications accordingly. Follow the farm's nutrient management plan or comprehensive nutrient management plan, as applicable.
- Determine the optimum combination of legume, grass and corn silage acres to best fit growing conditions, ration needs and nutrient waste management requirements.
- Evaluate corn silage hybrid research results prior to purchasing seed.
- Follow herbicide and pesticide manufacturers recommendations to ensure proper application rates and timing.

- Follow seed company recommendations for optimum growth conditions.
- Monitor growth and pressure from weeds and insects to spot problems early and take corrective action.
- Select plant varieties based on yield, days to maturity, geographic location, planned use, winter hardiness and disease resistance.

Resources:

Alfalfa Management Guide. (2011). Undersander, D. et al.: www.agronomy.org/files/publications/alfalfa-management-guide.pdf

Forage Crops – Crops and Soils. Penn State Extension: http://extension.psu.edu/plants/crops/forages

Successful Forage Establishment. Penn State Extension: http://extension.psu.edu/plants/crops/forages/successful-forage-establishment

Team Forage. University of Wisconsin Extension: http://fyi.uwex.edu/forage/

Forage Harvest and Processing

Highly digestible forages, which help reduce grain levels in the ration, improve rumen health and reduce ration costs.

Several factors influence the level of neutral detergent fiber (NDF) digestibility. As plants mature, their NDF content and lignification increases and their NDF digestibility decreases. This maturation process can occur quite rapidly in grasses, making harvest timing and speed critical to maximizing digestibility.

Legumes have less total NDF than grasses, but due to greater lignification, their NDF digestibility is lower than in grasses. Grasses, including corn silage, have less lignin but a large range in NDF digestibility.

Cows need fiber to maintain optimum rumen function. Forages must provide adequate amounts of long, chewable (effective) fiber, which induces saliva production to buffer the organic acids produced from the digestion of carbohydrates in the rumen. Fiber also stimulates the movement of rumen contents to increase the absorption of organic acids from the rumen.

Michigan State University research showed that increasing in vitro or in situ NDF digestibility of ration forage by one percentage point increases DMI by .37 pounds and four percent FPCM production by .55 pounds per day.

Corn silage provides both fiber and starch to the diet. Proper processing of corn silage at harvest is essential to increase starch digestibility and reduce the need for additional grain in the ration. It's generally recommended that corn silage be cut at a 0.75-inch theoretical length of cut and that a 1/8-inch roller clearance be maintained so that all corn kernels are crushed. Recommendations for particle size (calculated using the Penn State Particle Size Separator) are listed in **Table 2** (see Page 30).

Considerations:

- Maintain and adequately size harvesting equipment to avoid harvest delays.
- Analyze forages for nutrient composition and neutral detergent fiber (NDF) digestibility and target feeding to various animal classes according to their nutrient demands.
- Check forages at time of harvest for length of cut and extent of kernel processing and adjust harvesting equipment as necessary.
- Harvest all forages at the proper moisture for the chosen method of preservation – hay, wrapped baleage, bunker silo, tower silo and oxygen-limiting silo.
- Harvest all forage types at the recommended maturity to optimize digestibility without greatly compromising yield.
- Harvest forages at an appropriate length to stimulate cud chewing in the cow yet still optimize silage packing density.

- Provide other sources of long fiber in the ration such as coarsely chopped hay or straw if silage length is not adequate.
- Utilize a corn silage processor to increase kernel starch digestibility.

Resources:

Forage and TMR Particle Size and Effects on Rumen Fermentation of Dairy Cattle. (2012). Kononoff, P. et al.: http://articles.extension.org/pages/11319/forage-and-tmr-particle-size-and-effects-on-rumen-fermentation-of-dairy-cattle

The Penn State Particle Separator (DSE 2013-186). (2013). Heinrichs, J.: http://extension.psu.edu/animals/dairy/nutrition/forages/forage-quality-physical/separator/extension_publication_file

Table 2. Recommendations for Particle Size Using the Penn State Particle Size Separator

Forage Crop	Coarse > 0.75 in. (1.9 cm)	Medium	Fine < 0.3 in. (0.8 cm)
Processed Corn Silage	20-25%	30-40%	35-50%
Unprocessed Corn Silage	10-15%	35-45%	35-45%
Hay Crop Silage	20-25%	30-40%	35-50%
Total Mixed Ration	10-15%	30-50%	40-60%

Forage Storage

Biological degradation processes that decrease forage nutrient content begin as soon as forage crops are harvested. The primary goal of storage is the preservation of nutrient quality in harvested forage crops. Preservation is usually achieved through drying (haymaking) or ensiling forage crops. The choice of method depends on various factors, with weather being the most significant.

Haymaking: The goals of haymaking are to stop growth of all bacteria/mold and to limit chemical reactions by drying the forage below 20 percent moisture content. Hay baled too wet has a higher risk of mold growth and loss of dry matter, nutrients and energy. Also, wet hay has a higher risk for spontaneous combustion. Very dry hay may have a higher level of leaf shattering conducive to protein loss.

Ensiling: Ensiling preserves nutrients by acidification and excluding oxygen (air). Silage has to be compacted quickly and sealed effectively to achieve high density, exclude oxygen and allow lactic acid bacteria fermentation to reduce the pH quickly.

A silage inoculant is a management tool used to enhance silage fermentation. Commercial inoculants usually contain two or more types of bacteria: homofermenters (such as Lactobacillus spp.) that only produce lactic acid and increase the rate of pH reduction, and heterofermenters (such as L. buchneri) that produce both lactic and acetic acids and keep silage fresh longer after feedout (i.e., increased aerobic stability). Enzymes may also be incorporated into silage inoculants to help break down complex carbohydrates and promote the silage fermentation process. Limiting oxygen penetration of silage at time of feedout minimizes secondary fermentation and associated losses.

Considerations for Forage Storage (Hay) Include:

- Note that bales wrapped too long after harvest tend to have lower forage quality and greater mold throughout the bales.
- Evaluate research results of commercially available hay preservatives and apply the best for your situation at recommended rates using carefully calibrated equipment.
- Make the bales the size and weight suggested by the wrapper manufacturer as heavier bales are more prone to tears and punctures while wrapping, stacking and storing.
- Preserve nutrient content of forage by minimizing leaf loss.
- Prevent spontaneous combustion with adequate drying of forage prior to baling.
- Target optimum hay dry matter to minimize spoilage.

Resources:

Forage Management; Proper Handling and Curing of Hay. (2002). Rayburn, E.: http://anr.ext.wvu.edu/forage

Dairy Diagnostics Tool Box Factsheet 1: Feed Storage Tables. University of Minnesota: https://www.ansci.umn.edu/extension-outreach/dairy-diagnostics-toolbox

Silage and dry hay management. (2007). Seglar, W.J.: http://articles.extension.org/pages/11070/silage-and-dry-hay-management

Considerations for Forage Storage (Silage) Include:

- Allow enough time for complete forage fermentation (especially corn silage) prior to feedout to optimize intake and digestibility.
- Analyze silages for VFA content (primarily lactic, acetic, propionic and butyric acids) to assess silage quality.
- Calculate the necessary tractor weight for effective packing of incoming forage and monitor achieved packing density.
- Conduct dry matter (DM) analyses of bagged silages and adjust feed rations when DM content changes more than two percentage units.
- Consider best type, size and number of storage structures to contain all harvested forage.
- Evaluate research results of commercially available forage inoculants and apply the best for your situation at recommended rates using

carefully calibrated equipment.
- Evaluate research results of commercially available silage plastic cover options.
- Fill the silo quickly, pack well and seal efficiently.
- Limit oxygen penetration of silage at time of feedout to minimize secondary fermentation and associated losses.
- Ensure skilled labor operates the bagging machine to encourage consistent and uniform fill with acceptable density.
- Store highly digestible forages separately to optimize usage.
- Note that the optimum moisture content for storing haylage as bales is between 40 and 55 percent, which lowers DM losses and creates ideal conditions for fermentation and longer-term storage of wrapped bales.

Resources:

Corn Silage Management. (2013). Schroeder, J.: http://articles.extension.org/pages/11070/silage-and-dry-hay-management

Dairy Focus: To Inoculate or Not To Inoculate. (2011). Schroeder, J.: www.ag.ndsu.edu/news/columns/dairy-focus/dairy-focus-to-inoculate-or-not-to-inoculate

From Harvest to Feed: Understanding Silage Management. (2004). Jones, C.M. et al.: http://extension.psu.edu/publications/ud016/view

Sealing Strategies for Bunker Silos and Drive-Over Piles. (2006). Berger L.L. et al.: http://www.cceoneida.com/assets/Agriculture-Files/Crops-files/Sealing-strategies-for-bunker-silos.pdf

Silage and Dry Hay Management. (2007). Seglar, W.J.: http://articles.extension.org/pages/11070/silage-and-dry-hay-management

Forage Loss Management

Losses in forage dry matter occur at all stages of the preservation process and contribute to feed shrink. Losses that reduce profitability and increase environmental impact can be extremely variable depending on farm.

Mechanical handling and weather damage in the field cause the majority of the losses in haymaking. Leaf loss is greater than stem loss, reducing both forage amount and quality since leaves are more protein and energy-dense than stems.

Feed shrink can account for 20-to-30 percent of the forage crop standing dry matter from harvest to feeding.

Ensiling converts readily available soluble carbohydrates to lactic acid, thus reducing the quality of the harvested forage crop. Nutrient losses in silages are most prominent during storage and feedout. Silage feedout face management is extremely important to minimize these losses.

Feedout face management focuses on maintaining a smooth and perpendicular surface to minimize silage surface area exposure to air. Silage face removal rate is another important factor in feedout management. Discarding aerobically spoiled silage during feedout prevents reducing the nutritive value of the silage-based ration and animal performance.

Considerations:

- Adjust equipment to maintain high density while bagging to lower the amount of entrapped air and rate of air infiltration when opening or if punctured.
- Assess and make adjustments as needed for available equipment and labor to harvest, transport, fill and cover silage storage facilities rapidly to reduce exposure to air.
- Closely estimate the amount of forage needed

to minimize waste and variation for all feedout methods.
- Conduct regular inspection and maintenance of silos to minimize exposure to air and precipitation.
- Consider weather conditions – silage fed in warmer weather deteriorates faster than silage fed in colder weather.
- When using bagged storage, uncover only what will be used for each feeding and close the bag after each feeding to reduce losses caused by reintroduction of oxygen.

Resources:

Determining Your Current Forage Inventory. (2012). Chase L.E. et al.: http://www2.dnr.cornell.edu/ext/EDEN/Determining%20Your%20Current%20Forage%20Inventory.pdf

Feed Inventory-Charts, Tables and Formulas. Cropp, B.: http://cdp.wisc.edu/pdf/Feed%20charts.pdf

Feedout Losses from Forage Storage Systems. (2008). Clark, J. et al.: http://fyi.uwex.edu/forage/files/2014/01/FeedoutLossFOF.pdf

Concentrate Management

Concentrate management significantly influences animal health, performance, feed utilization and costs. **By directing rumen fermentation away from methane-producing pathways, concentrates (e.g. grains, oilseeds and by-product feeds) added to dairy cattle rations also reduce enteric methane emissions per unit of FPCM.**

A large portion of concentrates are typically purchased and included in the diet to provide extra energy, protein and other macronutrients and micronutrients that may be insufficient in the forage base. Concentrates can also serve as the vehicle for supplements and feed additives. Concentrates are usually fed in mixes containing a variety of ingredients. The type of concentrate mix fed is contingent on the forage base, the animal class and target productivity range, and the availability and cost of ingredients.

Concentrate feeding helps to reduce enteric methane emissions, but feeding large amounts of concentrate in a diet with insufficient fiber may lead to ruminal acidosis and milk fat depression. These conditions reduce performance, profits and emission-mitigating effects. The object of concentrate management, rather, is to strategically feed concentrates in a balanced diet to ensure high levels of health and performance from every unit of feed offered to dairy cattle. Considerations on the most effective concentrate management strategies are discussed below, specific to each type of concentrate.

Carbohydrates

Dairy cattle can be fed energy-rich concentrates high in carbohydrates, such as starch, sugar, soluble fiber and highly fermentable non-forage neutral detergent fiber (NDF). The objective is to balance the ration of rumen-degraded carbohydrates relative to dietary effective fiber. Non-fiber carbohydrate (NFC) is commonly used in ration formulation. NFC is a diverse fraction that includes various types of carbohydrates that differ in terms of ruminal digestibility and fermentation end products. Consequently, understanding the type of carbohydrates that can be fed helps determine how concentrate feeding aids in a balanced diet.

Starch: Concentrates used to supply dietary starch include corn, sorghum, barley, wheat, oats and bakery and grain by-products (e.g. wheat midds and corn gluten feed). A high extent of starch availability is desired, but a combination of rapidly and slowly available starches will help with acidosis control and optimization of microbial growth. Grinding increases surface area and aids starch digestibility. Gelatinization increases the speed with which enzymes and microbes can break down the linkages of starch to yield energy and microbial protein. Gelatinization is caused by a combination of moisture, heat, mechanical energy and pressure. The feed industry uses steam flaking, extrusion and pelleting to gelatinize starch.

Sugars: Sugars can improve ration palatability. Sugars provide a quickly digestible source of energy in the rumen to facilitate microbial utilization of rapidly available nitrogen. In this way, sugar can help reduce nitrogen wastage in the form of urea. Concentrates commonly used as sugar sources include molasses, citrus pulp, beer pulp and bakery waste.

Non-Forage NDF: To provide energy while also improving rumen health, it may be desirable to replace some dietary starch with non-forage NDF from ingredients such as soy hulls, beer pulp or citrus pulp. Beta-glucans, galactans and pectins (also referred to as soluble fiber) can provide energy yet ferment to form the weaker acid called acetate, which reduces rumen acidosis. Soy hulls also contain NDF, which ferments to acetate.

Considerations:

- Balance non-fiber carbohydrate (NFC) to dietary neutral detergent fiber (NDF) according to the various types (starch, sugar, soluble fiber and non-forage NDF) and amounts of NFC in the concentrate.
- Consider using any available, economical starch sources with known nutrient composition and digestibility characteristics. Additionally, consider using sources of highly fermentable, non-forage NDF to partially replace both starch and less-digestible NDF for improving rumen health and DMI.
- Pay attention to starch processing and particle size to ensure a high extent of starch digestion without negatively impacting rumen pH.
- Provide a combination of carbohydrate sources from concentrate to maximize diet digestibility and microbial protein synthesis in the rumen.

Resources:

Advancements in Feeding Carbohydrates. (2007). Eastridge, M.L: www.wcds.ca/proc/2007/Manuscripts/Maurice.pdf

Carbohydrate Nutrition for Lactating Dairy Cattle. (2001). Isher, V. et al.: http://extension.psu.edu/animals/dairy/nutrition/nutrition-and-feeding/diet-formulation-and-evaluation/carbohydrate-nutrition-for-lactating-dairy-cattle-2

Optimizing Starch Concentrations in Dairy Rations. (2010). Grant, R.: http://articles.extension.org/pages/25687/optimizing-starch-concentrations-in-dairy-rations

Proteins

Creating a diet that meets, but does not exceed, each cow's need for protein helps reduce protein waste via excretion in manure, save purchased-protein costs and increase yield of milk and milk protein.

Proteins are chains of specific sequences of 50 or more amino acids. Milk protein production can be limited by a single amino acid that is in short supply in relation to the cow's requirement. That amino acid is called the "first-limiting" amino acid in the diet and will depend on the feed ingredients in the cow's ration. For dairy cows in North America, methionine and lysine are typically thought to be the most limiting amino acids.

Nutritionists estimate metabolizable protein (MP) plus amino acid delivery to the cow from estimates of rumen-degradable protein (RDP) and rumen-undegradable protein (RUP). When balancing rations, one goal should be to make as much rumen microbial protein as possible because its amino acid profile closely matches that of milk protein and it is economical. Another goal is to provide a proper blend of amino acids in RUP. Rations often appear to provide sufficient RUP, but a few amino acids in this RUP are limiting. For example, if most of the RUP comes from corn protein, production is likely being limited by the amino acid lysine.

With advanced nutrition models, diets can be balanced for MP, RDP, RUP and amino acids using combinations of vegetable proteins such as corn and soy, as well as small amounts of rumen-protected amino acids now available on the market.

Considerations:

- Consider use of any available, economical protein source with known nutrient composition and digestibility characteristics.
- Consider use of non-protein nitrogen source to partially supply rumen nitrogen needs (RDP).
- Evaluate research on available rumen-protected amino acids and RUP and consider their use to supply limiting amino acids, improve productivity and reduce waste.
- Formulate diets using an advanced nutrition model that predicts metabolizable protein (MP) and amino acid supplies and requirements.
- Optimize rumen microbial protein synthesis by maintaining optimum rumen health and synchronizing rates of protein and carbohydrate fermentation.
- Match protein in the feed to the protein requirements of the animal at each life stage to help mitigate manure ammonia and nitrous oxide emissions.[7]

Resources:

Current Status of Amino Acid Requirement Models for Lactating Dairy Cows. (2006). Hanigan, M.D. et al.: http://articles.extension.org/pages/11231/current-status-of-amino-acid-requirement-models-for-lactating-dairy-cows

Why Use Metabolizable Protein for Ration Balancing? (2010). Varga, G.A.: http://articles.extension.org/pages/26135/why-use-metabolizable-protein-for-ration-balancing

Additional resources on protein can be found in Components of Ration Formulation in **Chapter 3: Feed** on Page 20.

Lipids

Lipids (fats) are added to high-production dairy diets to supply a dense form of energy that does not ferment in the rumen. Typical lipid sources include vegetable oils, prilled fat, tallow, free fatty acids, calcium salts of fatty acids, granular rumen-inert fats and whole or crushed oilseeds (e.g. whole cottonseed, whole soybeans).

Feeding high-oil coproducts from the food, fiber and biofuel industries is a practical way to include lipids in dairy diets. This category of coproducts includes processed soybeans, rapeseed, canola, flaxseed and other oilseeds, palm oil and distillers grains.

Lipid supplementation often improves conception rates in cows by improving body condition of the cow and providing specific fatty acids needed for reproduction. Also, feeding organic oils of vegetable or animal origin is one of the most extensively studied practices for mitigating enteric methane from dairy.

Dietary lipids can reduce enteric methane emissions but must be fed in appropriate quantities so that the ether extract (EE) or crude fat concentrations in the diet do not exceed seven percent of total dry matter to avoid negative consequences on feed intake, milk production and milk fat content. High quantities of rumen-available lipid can impede fiber digestion by the rumen microbes. Additionally, excessive amounts of certain rumen-available fatty acids are known to reduce the concentration of fat in milk, decreasing the value of the milk for the farmer and processor. Typically, nutritionists take advantage of economical rumen-available lipid by taking it up to recommended limits and utilizing the more expensive rumen-inert fats if more energy or specific fatty acids are needed.

Considerations:

- Consider additional sources of lipid for increasing diet energy, especially if body condition of cows and conception rates are a concern.

- Consider partial replacement of dietary carbohydrate with lipid to aid in control of subclinical rumen acidosis.
- Evaluate research on available rumen-inert fat products to determine energy content, digestibility, fatty acids and expected production and reproduction responses.
- Utilize an advanced nutrition model to calculate quantities of rumen-available fatty acids in the ration and avoid milk far depression and fiber digestion consequences.

Resources:

Calcium Salts are Highly Digestible. (2005). Block, E.W. et al. In Feedstuffs: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.568.3845&rep=rep1&type=pdf

Feeding for Milk Components. (2012). Lock, A.L. et al.: www.wcds.ca/proc/2012/Manuscripts/Lock.pdf

Feeding Fat, in Moderation, to Dairy Cows. (2014). Eastridge, M. http://articles.extension.org/pages/71254/feeding-fat-in-moderation-to-dairy-cows

By-Product Feeds

By-products of the food and biofuel industries can supply a large portion of the carbohydrates, proteins and lipids needed by the dairy cow. By-product feeds include the rest of the plant remaining after the human edible portion is removed. In the case of biofuels, the remaining low-energy but high-protein portion of the plant remains after ethanol distillation (i.e. distillers grains).

Typical by-products fed to dairy cattle include the solids (e.g. stems, leaves, skins, pulp, etc.) that remain after processing grain, soy, potatoes, fruits and sugarcane. By-products are generally a less expensive feed than whole grains, and high-fiber by-products can partially serve as a substitute for forages in the diet. Disadvantages of by-product feeds may include additional time needed to purchase and evaluate by-product feeds as well as the possible need for specialized storage structures.

Considerations:

- Consider use of any available, economical by-product feeds with known nutrient composition and ideal digestibility characteristics.
- Consider using sources of highly fermentable fiber to partially replace both starch and less digestible neutral detergent fiber (NDF) for improving rumen health and DMI.
- Conduct regular nutrient analysis of by-product feeds and corresponding ration adjustments to promote optimum performance.
- Utilize an advanced nutrient model to determine the most beneficial amount of a by-product feed to include in the diet.

Resources:

By-product feedstuffs in dairy cattle diets in the Upper Midwest. (2008). Shaver, R.: http://cdp.wisc.edu/jenny/crop/byproduct.pdf

By-products and regionally available alternative feedstuffs for dairy cattle. (2012). Schroeder, J.W.: www.ag.ndsu.edu/pubs/ansci/dairy/as1180.pdf

Value of Distillers' Grains for Lactating Dairy Cows. (2006). Donkin, S.S. et al.: https://www.extension.purdue.edu/extmedia/ID/ID-334-W.pdf

Feed Additives

Feed additives are a category of ingredients fed at low inclusion rates to improve dairy cow performance through a variety of mechanisms. Some feed additives provide specific micronutrients such as the water-soluble vitamins biotin (vitamin B7) and niacin (vitamin B3) or amino acids. Most feed additives are not fed in significant amounts to supply nutrients required by dairy cattle. For the most part, feed additives indirectly improve animal performance (i.e. improved health, growth or milk yield) by enhancing metabolic functions leading to improved digestive function, nutrient mobilization, acid-base balance, immune response and more.

The list of feed additives for dairy includes, but is not limited to: anionic salts, protected amino acids, Aspergillus oryzae products, biotin, beta-carotene, calcium propionate, protected choline, direct-fed microbials, enzymes, magnesium oxide, methionine hydroxyl analogs, monensin, niacin, propylene glycol, sodium bentonite, sodium bicarbonate, yeast products, yucca extract and zinc methionine. The long list of feed additives and various modes of action involved requires an individual evaluation for each to be included in dairy cattle diets.

A wide variety of feed additives has been examined for their ability to inhibit methane formation in the rumen, but most of these additives have not yet proved to reduce enteric methane emissions without negatively affecting milk production. Moderate methane mitigating effects have been observed. However, feed additives present significant additional costs to farm operations; operations managers should consider cost benefit analyses before utilizing significant additives in dairy cattle feed.

Considerations:

- Carefully evaluate available research data on each feed additive for mode of action and ability to predict positive response in the feeding conditions of the operation. Research is ongoing for many feed additives.
- Consider evaluating feed additives according to the system proposed by Michael Hutjens (University of Illinois Urbana-Champaign) that includes: anticipated response, economic return, available research, field response, reliability, repeatability and relativity.
- Consider feed additives and their expected return on investment for increasing milk production and farm profitability while reducing methane emissions.
- Evaluate feed additive responses observed in a wide range of diets and consider the impact of your specific management and dietary factors.

Resources:

Feed Additives for Dairy Cattle. (2011). Hutjens, M.F.: http://articles.extension.org/pages/11774/feed-additives-for-dairy-cattle

Feed Additives – The Good, the Bad, and the Useless. (2007). Hutjens, M.F.: www.wcds.ca/proc/2007/Manuscripts/Mike2.pdf

04

Productivity

Opportunities to Reduce GHG Emissions through Managing Animal Health and Productivity

Introduction

Improving herd productivity increases profit while also reducing greenhouse gas emissions per unit of FPCM.

Successful herd management is essential to increasing lifetime productivity per cow. Strategies focus on all life stages, from newborn, to heifer, lactating, dry and transition periods. Implementing best practices around animal management may require additional financial investments. However, productivity gains can offset these costs.

If possible, work with a nutritionist, veterinarian or other animal health specialist. The chapters below can help inform conversations with the farm's hired specialist. **Chapter 2: Moving Forward** contains helpful tips on selecting a specialist.

Readers may prefer to focus only on specific sections to gain greater insight into a particular topic area. Veterinarians, nutritionists and other subject matter experts can consult **Appendix B** for a detailed list of academic resources by topic area.

The following chapter sections offer insights into management strategies for all life stages:

Lactating Cow Management

Addresses issues that influence the productivity of the lactating herd: mastitis control, cow comfort, reproduction, culling and the use of technology. Lactating cow health and productivity are essential to reducing emissions per unit of milk.

Calf and Heifer Management

Calves/heifers use resources and emit GHGs as they grow. These emissions are only offset once they become productive, so raising cows efficiently and in a timely manner reduces lifetime emissions per unit of FPCM. Topics in this section include colostrum, diarrhea, respiratory disease, vaccinations, nutrition and heifer reproduction.

Transition Cow Nutrition and Management

Addresses effective cow management during transition. By reducing involuntary culling, replacement costs and non-productive days, transition cow management can increase milk yield in the following lactation, allow for a lifetime of productivity and reduce enteric methane emissions per unit of FPCM.

In addition to the resources identified throughout this chapter, the FARM Animal Care Reference Manual should be consulted for more details on recommended approaches to animal nutrition, health and comfort (**www.nationaldairyfarm.com/resource-library**).

Key Considerations

- Work with a nutritionist, veterinarian or other specialist to manage herd health and productivity.
- Evaluate the herd's environmental conditions. For example, ensure a clean and dry bedding area.
- Consider cow comfort at all life stages.
- Ensure calves receive adequate colostrum from a cow's first milking in one or two feedings within the first 6-to-8 hours of life.
- Consider disease prevention strategies, including good ventilation practices, proper nutrition and a vaccination program.
- Consider using tools or calculators for issues like reproduction, transition cow management, culling decisions and general herd management.
- Monitor the body condition score (BCS).

Ultimately, the best strategies will depend on the farm's unique management structure, its geography, the composition of its herd, and other factors. Producers looking for more information on cow comfort and animal management are encouraged to consult the FARM Animal Care Reference Manual (**www.nationaldairyfarm.com/resource-library**).

General Productivity Resources:

Dairy Diagnostics Toolbox. University of Minnesota: www.ansci.umn.edu/extension-outreach/dairy-diagnostics-toolbox

Dairy Management. University of Wisconsin Extension: http://dairymgt.info/tools.php

Animal Care Reference Manual. (2016). National Dairy FARM Program: http://nationaldairyfarm.com/content/version-30-animal-care-reference-manual

Managing the Young Calf – Keep It Simple! McGuirk, S.: www.vetmed.wisc.edu/dms/fapm/fapmtools/8calf/calfmanag.pdf

Calf Management — Dairy Calf and Heifer Management. UW-Extension University of Wisconsin Cooperative Extension: www.uwex.edu/ces/heifermgmt/links.cfm

Dairy Extension — Transition Cows. University of Minnesota: www.extension.umn.edu/agriculture/dairy/transition-cows/

Nutrient Requirements of Dairy Cattle: Seventh Revised Edition. (2001). www.nap.edu/catalog/9825/nutrient-requirements-of-dairy-cattle-seventh-revised-edition-2001

The Dairyland Initiative. University of Wisconsin - School of Veterinary Medicine: https://thedairylandinitiative.vetmed.wisc.edu/index.htm

Gold Standards. Dairy Calf and Heifer Association: http://calfandheifer.org/gold_standards/index.php

Lactating Cow Management

Improving the efficiency of milk production on the farm increases profit and reduces enteric methane emissions per unit of FPCM. This can be achieved by optimizing milk yields and improving milk quality.

Lactating cow management must focus on: 1) preserving cow health in order to achieve high levels of milk production with high milk quality, 2) disease prevention and treatment to minimize milk loss and involuntary culling of productive animals from the herd, 3) dietary needs of early lactation when dairy cows do not yet consume enough feed to meet the large nutrient demands for milk production, and, 4) physiological changes that occur in cows as lactation progresses, with emphasis on reproductive success, pregnancy and preparation for the subsequent calving.

Mastitis prevention, identification and treatment can reduce milk wastage and losses in potential milk yield, increasing the value of a cow's productive life. Practices and facilities that improve cow comfort, cow time budgets and reproductive efficiency lead to improved milk production efficiency of the entire herd.

Mastitis Control

Mastitis is a complex condition that can impact productivity and milk quality. The condition is characterized by infection and inflammation of the mammary gland caused by a variety of microorganisms, primarily bacterial, that enter through the teat. The economic impacts of mastitis range from milk production losses, discarded milk, the costs of diagnosis and treatment, labor and culling.[8] Almost all dairy operations report at least one case of mastitis.[9] Dairy farmers can prevent mastitis by keeping bacteria away from the teat end and striving for conditions that support resistance by the cow against mastitis-causing bacteria.

An estimated $200 is lost per cow annually due to mastitis.[10]

Proper treatment depends on the distinction between contagious or environmental mastitis-causing bacteria. Contagious mastitis organisms are typically transferred from cow to cow during milking. Environmental mastitis organisms are typically associated with periods of high humidity, challenging weather conditions, mechanical actions, environmental issues and nutritional factors that affect overall immunity and udder health.

Mastitis can also be classified as clinical or subclinical. Clinical mastitis entails visible signs, such as swelling and abnormal secretions. Subclinical mastitis presents no visible symptoms but accounts for the majority of total mastitis-associated costs, including financial losses due to lower milk yield.

Cultures are a type of test used to determine the presence of infectious agents. A culturing program suitable for each farm can provide guidance on clinical mastitis treatment decisions by determining which type of organism is responsible for the infection. Timely implementation of appropriate treatments reduces milk losses and the time needed for antibiotics.

Considerations:

- Use on-farm culturing to identify mastitis-causing organisms and make more effective decisions about clinical mastitis treatment. If on-farm culturing is cost prohibitive, then access to on-time information may be suitable.
- Environmental Controls[10, 11]
  - o Ensure a clean and dry bedding area. It's important to top or change bedding regularly to address manure and organic load. Sand or other inorganic bedding material may be considered to further reduce bacterial load.[10, 11, 12, 13]
  - o Avoid overcrowding.
  - o Evaluate the environmental conditions of dry cows in addition to lactating cows.
- Milking
  - o Consider preparation that achieves clean and dry udders for milking using single-use towels or individual cloths cleaned after each milking.[10, 12]
  - o Consider pre- and post-dipping to prevent bacteria from entering the teat.[11]
  - o Use appropriately sized and well-maintained milking equipment to reduce liner slips and other teat-end impacts that can increase the risk of mastitis.[10, 12]
  - o Develop milking protocols with simple and clear steps.[11]
  - o Encourage cows to stand for 30-to-60 minutes following milking by offering fresh feed and maintaining clean, well-bedded free stalls.[11]
  - o Ensure proper implementation of milking protocols by maintaining an effective employee training program. Some farms may consider enforcement mechanisms.[13, 14]
- Nutrition
  - o Evaluate nutritional intake to help improve immunity. Nutrients of note include Vitamins A or E, selenium, copper and zinc.[12]
- Dry Cow Therapy
  - o Consider dry cow therapy and mastitis vaccination to reduce mastitis at the herd level.

Resources:

Are Your Cows Getting the Vitamins They Need? (2006). Weiss, W., and G. Ferreira.: www.wcds.ca/proc/2006/Manuscripts/Weiss2.pdf

Role of Mineral and Vitamin Status on Health of Cows and Calves. (2011). Spears, J. W.: http://www.wcds.ca/proc/2011/Manuscripts/Spears.pdf

Understanding the Basics of Mastitis. (2009). Jones, G. Virginia Cooperative Extension: http://www.pubs.ext.vt.edu/404/404-233/404-233.html

Using On-Farm Mastitis Culturing. (2011). Keefe G. et al.: http://www.wcds.ca/proc/2011/Manuscripts/Keefe.pdf

Milk Quality and Mastitis. University of Minnesota Extension: www.extension.umn.edu/agriculture/dairy/milk-quality-and-mastitis/

Tools for Detecting Mastitis. (2015). Curley, C. In Progressive Dairyman: www.progressivedairy.com/topics/herd-health/tools-for-detecting-mastitis

Cow Comfort

Cow comfort – a term broadly adopted by the dairy industry – is a key factor affecting cow welfare. Cow comfort refers to how the dairy cow copes with her environment. Most of the emphasis is placed on the areas available for feeding, lying and standing. Cow comfort is addressed at length in the FARM Animal Care Reference Manual (see **Chapters 5, 6 and 7** for more details at **www.nationaldairyfarm.com/resource-library**). In addition to impacting welfare, cow comfort is associated with productivity.

Factors normally considered when evaluating cow comfort include signs of heat stress, lameness, skin injuries and health. Facility and management factors that can affect cow comfort (and, in many cases, time budgets) include stall design, stall surface (including the amount of bedding provided), stocking density at the stall and at the feed barrier, regrouping schedules, and cow cooling and handling protocols, such as cow movement and time spent away from the pen.

Cows are herd animals. They thrive in facilities that provide sufficient space for them to eat and lay comfortably. Dairy cows are highly motivated to rest, and lack of rest will reduce time spent feeding and milk production.[15] Cows will give up feeding time in order to secure a lying space.[16] And some evidence suggests that more time spent resting is associated with higher milk yield.[17] Several factors affect resting time, such as stall availability, stall comfort and stocking density (in both feeding and resting areas). Softer bedding choices can also encourage resting time.[18]

Cows also spend some time standing idle which, ideally, would be minimized to encourage eating, resting and ruminating. It's also beneficial to minimize time spent away from the pen, such as travel time to the parlor and milking. In addition, providing cows with a dry place to stand in the pen and when they are away from the pen will dramatically improve their comfort.

Considerations:

The FARM Animal Care program addresses considerations for environment and facilities that impact cow comfort. The following are a selection of relevant management practices from FARM Animal Care:

- All age classes of animals are provided all reasonable means of protection from heat and cold.
- Protocols are in place to minimize airborne particles as a way to reduce odors, dust and/or noxious gases.
- Housing allows all age classes of cattle to easily stand up, lie down, adopt normal resting postures and have visual contact with other cattle, without risk of injury.
- All age classes of cattle have a resting area that provides cushion, insulation, warmth, dryness and traction at all times when away from the milking facility.
- The dairy farmer monitors and takes action to reduce the risk of slips and falls.
- The calving area is soft, cushioned, dry, well-lit and well-ventilated.

More information and resources can be found by consulting the FARM Animal Care Reference Manual (**www.nationaldairyfarm.com/resource-library**).

Resources:

Cow Comfort Self-Assessment Test. (2011). Endres, M. University of Minnesota: http://www.extension.umn.edu/agriculture/dairy/cow-comfort-quiz/

Cow Comfort Checklist. (2011). Bruno, R. In Dairy Herd Management: http://www.dairyherd.com/dairy-resources/nutrition/Cow-comfort-checklist-118875639.html

Design Considerations For Dairy Cattle Free Stalls. (2010). Graves R. et al. Penn State University: www.extension.org/pages/11015/design-considerations-for-dairy-cattle-free-stalls

Managing Dairy Cattle for Cow Comfort and Maximum Intake (2007). Keown, J., and P. Kononoff. University of Nebraska-Lincoln Extension: http://extensionpublications.unl.edu/assets/pdf/g1660.pdf

Sand for Bedding Dairy Cow Stalls. (2012). Gooch, C., and S. Inglis. Cornell University: www.extension.org/pages/65458/sand-for-bedding-dairy-cow-stalls

Stocking Density and Time Budgets. (2009). Grant, R.: www.wdmc.org/2009/Stocking%20Density%20&%20Time%20Budgets.pdf

Taking Advantage of Natural Behavior Improve Dairy Cow Performance. (2011). Grant, R.W. H. Miner Agricultural Research Institute: http://articles.extension.org/pages/11129/taking-advantage-of-natural-behavior-improves-dairy-cow-performance

Reproduction

Maintaining a shorter period of days to first breeding – about 40-to-60 days – means cows spend more time in the early and mid-lactation stages, increasing milk yield per cow.[11] Additionally, this reduces the number of non-productive days and the number of replacement animals needed in the herd. By improving milk productivity per cow, successful reproduction can result in reduced greenhouse gas emissions intensity.

The keys to reproductive success include effectively managing the transition period (see Transition Cow Nutrition and Management in **Chapter 4: Productivity** on Page 54), maintaining the reproductive tract free of inflammation and disease, minimizing the severity and duration of negative energy balance in early lactation, providing balanced nutrition (see **Chapter 3: Feed**) and implementing a reproductive management or breeding program.

Considerations:

- Consistently monitor and evaluate artificial insemination techniques, timing and success.
- Consider establishing a breeding program that involves evaluation of current conception rate, 21-day pregnancy rate, services per conception, days open, days to first service and calving interval. Measuring and setting goals in these areas can drive improvement.
- Evaluate herd reproductive health and the current stage of the estrous cycle at breeding time and consider strategies to reduce calving problems, metritis, clinical endometritis and fever postpartum.
- Consider systems such as estrous synchronization or timed/appointment breeding to facilitate reproduction. Detecting cows in heat accurately and promptly can improve reproductive performance.[19]
- Consider the use of various aids in estrous detection, such as a records system, mounted detector aids to supplement visual observation, the use of heat detector animals and activity monitors (such as pedometers).[19]
- To improve reproductive success overall, consider tail chalking, estrus detection patches, progesterone analyses, a synchronization program and ultrasound imaging for early diagnose of pregnancy.
- Monitor the availability and effectiveness of new technologies for incorporation into the farm's breeding program.
- Monitor body condition score as an indicator of negative energy balance in early lactation.

See more information about body condition scoring in the FARM Animal Care Reference Manual (**www.nationaldairyfarm.com/resource-library**).

Resources:

Dairy Cattle Reproduction. (2014). http://www.extension.org/pages/15604/dairy-cattle-reproduction

Reproduction and Genetics. PennState Extension: http://extension.psu.edu/animals/dairy/health/reproduction

Dairy Management. University of Wisconsin Extension: http://dairymgt.info/tools.php

Wisconsin-Cornell Dairy Repro: A Reproductive Programs Economics Analysis Tool. University of Wisconsin/Cornell University: https://ansci.cals.cornell.edu/extension-outreach/adult-extension/dairy-management/wisconsin-cornell-dairy-repro-giordano

Culling

Culling occurs when cows are removed from the herd due to sale to another dairy, slaughter-salvage or death. Management strategies to promote productivity and profitability should work to minimize forced culling by focusing on the areas of transition cow management, cow comfort, reproductive performance, mastitis, lameness and milk production.

Within the dairy literature, many experts advocate that lower annual herd turnover rates are more profitable and use less resources per unit of FPCM produced, with optimum turnover rates at 25-to-30 percent. Culling decisions, however, depend on many factors, and turnover rate alone does not indicate good management.

Because dairy farms vary widely, ideal culling rates will also vary by farm. It's important to use systematic, data-driven performance records and determine the value of each cow individually when making culling decisions. For example, each cow's retention payoff value and culling turnover rates must meet the individual farm's economic and environmental goals.

Considerations:

- Calculate individual cow profitability to determine whether it's more profitable to keep a cow or replace her. The answer depends on milk price, feed cost, the difference between cull and replacement values, and availability of capital.
- Calculate overall culling rate, number of cows leaving the heard in early lactation and cow deaths, and compare to industry benchmarks.
- Evaluate reasons for culling and, if needed, take actions to improve herd management.

Resources:

Culling Rate on Dairy Farms and Its Effect on Income Over Feed Costs and Forage Inventory Requirements. (2013). St-Pierre, N. R.: http://tristatedairy.org/Proceedings%202013/Normand%20St-Pierre.pdf

Making Informed Culling Decisions. (2005). Groenendaal, H., and D. T. Galligan: www.wcds.ca/proc/2005/Manuscripts/Groenendaal2.pdf

Tools for Making Economic Culling Decisions. (2014). Penn State Extension: http://extension.psu.edu/animals/dairy/news/2014/tools-for-making-economic-culling-decisions

Use of Technology for Cow Management

Dairy cows are typically housed in groups, yet many management decisions on the dairy farm are made at the individual cow level. The use of sensors to collect data on individual cows, coupled with software that analyzes and interprets the data in real time, can improve on-farm animal management.

For example, technologies that measure a cow's production, behavior, appearance or physiology can be used for improving detection of estrus, pregnancy and onset of calving.

Sensor systems can also improve diagnosis of ketosis (and other metabolic disorders), lameness or mastitis, and monitor rumination or body condition scoring. These systems include a variety of sensors such as pedometers, image capture systems and ruminal pH meters. New sensors will likely continue to evolve rapidly. The potential benefits of these technologies are useful to both transition and lactating cows in diagnosing, for example, either postpartum metabolic disorders or determining mastitis before clinical signs are evident.

Considerations:

- Adopt technologies to support and enhance existing good management practices.
- Consider animal management technology investments on an individual farm basis.
- Evaluate and understand existing strengths and weaknesses in animal management before making decisions on technology investments.
- Evaluate and understand the benefits and costs associated with each technology.
- Leverage technologies already in use at the farm, such as dairy records software.

Resources:

Precision Dairy. (2013). University of Minnesota: http://precisiondairy.umn.edu/DownloadProceedings/index.htm

Pre-Investment Considerations for Precision Dairy Farming Technologies. (2013). Dolecheck, C., and Bewley J. University of Kentucky: http://www2.ca.uky.edu/agcomm/pubs/asc/asc208/asc208.pdf

New Technologies in Precision Dairy Management. (2013). Bewley J.: http://www.wcds.ca/proc/2013/Manuscripts/p%20141%20-%20162%20Bewley.pdf

Calf and Heifer Management

The main objective of calf and heifer management is to raise them in an efficient and timely manner to be healthy and productive dairy cows. Keeping good records on growth, health and breeding helps evaluate and improve calf and heifer management programs.

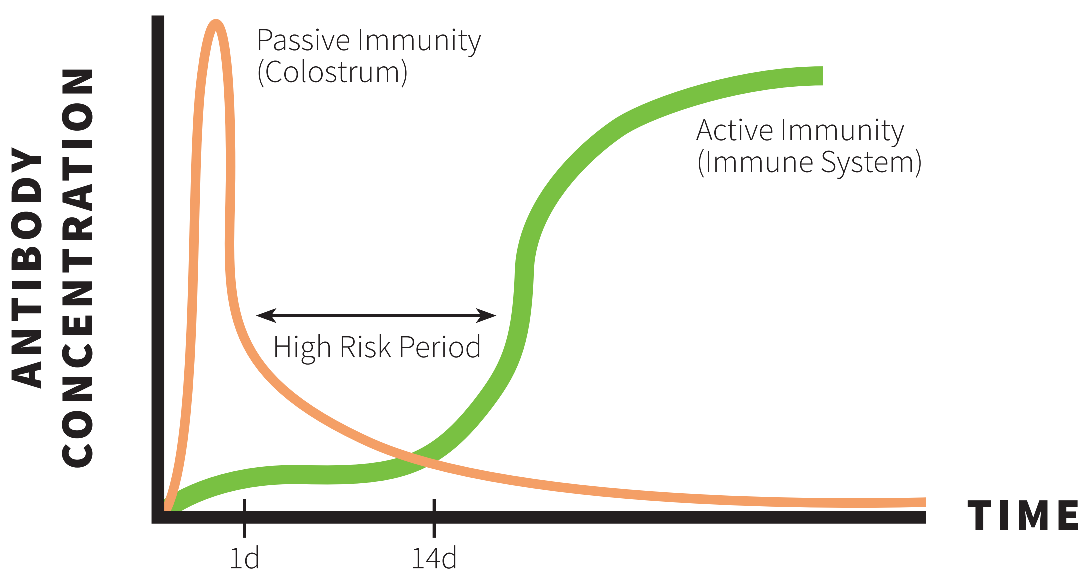
A calf consumes feed and produces enteric methane as it grows. **The economic and environmental cost of raising calves and heifers can only be offset after the bred heifer successfully calves and begins lactating. Therefore, calf and heifer health, growth rate and reproductive ability are vital to profitability and minimizing the herd's carbon footprint.**

Calf and heifer management programs must focus on numerous factors that affect the animal's ability to stay healthy, grow and reproduce. Topics covered in this section include colostrum, disease prevention and nutrition.

Colostrum

The race to claim the passive immunity provided by immunoglobulins present in colostrum starts at birth and ends at 24 hours of life. This is due to the rapid decline in the efficiency of immunoglobulin absorption in the calf's gastrointestinal tract within hours after birth. Immunoglobulins provide passive immunity to fight disease until the calf's own immune system is developed (**Figure 7**). Blood serum concentration of immunoglobulin G (IgG) less than 10.0 grams per liter (g/L) or serum total protein less than 5.5 grams per deciliter (g/dL) have been equated with poor growth rates and increased prevalence of sickness and death.[11]

FIGURE 7. IMMUNITY IN NEWBORN DAIRY CALVES



Sourced from FARM Animal Care Reference Manual.[6]

Failure of passive transfer (FPT) has been defined as blood serum concentrations of immunoglobulin G (IgG) less than 10 mg/ml at 24 hours of age.

Colostrum management within the first 24 hours of life affords a once-in- a-lifetime opportunity for a calf to become a productive and profitable member of the herd.

Timely feeding of an appropriate amount of high-quality colostrum (> 50 mg of IgG/ml, equating to a Brix value greater or equal to 22%) results in improved immunological protection, rapid early growth and higher milk production during the first lactation. Colostrum quality is highly dependent on early harvest (optimal timing is within two hours of calving).[11]

Considerations:

- Note that calves should receive 4-to-5 quarts of colostrum (3-to-4 quarts for smaller dairy breeds) from a cow's first milking in one or two feedings within the first 6-to-8 hours of life.
- Consider storing high-quality colostrum by refrigeration (for 24-to-48 hours) or freezing (pay careful attention to the thawing method before use). Using pasteurized colostrum will increase immunoglobulin G (IgG) transfer to the calf by 25 percent and is highly recommended to improve calf health.
- Feed clean, high-quality colostrum from vaccinated, disease-free cows or consider pasteurized colostrum if high quality maternal colostrum is not available or if the dam or herd is known to carry disease.
- Separate the calf from the dam and move to a clean and dry area to reduce disease transmission and ensure adequate colostrum intake.

Resources:

Colostrum Management Tools: Hydrometers and Refractometers. (2011). Heinrichs, A. J. et al.: http://extension.psu.edu/animals/dairy/nutrition/calves/colostrum/das-11-174

Heifer Raising – Birth to Weaning: Importance of Colostrum Feeding. Wattiaux, M. A.: http://www.infodairy.com/infodairy_upload_files/Cows_heifers_calves/Calves/0188Importance%20of%20colostrum%20feeding-e.pdf

Herd-Based Problem Solving: Failure of Passive Transfer. (2010). McGuirk, S.: http://www.vetmed.wisc.edu/dms/fapm/fapmtools/8calf/calf_herd_FPT_Troubleshooting.pdf

Nutrition Factors Causing Low Colostrum Production. (2009). Litherland, N.: http://www.extension.umn.edu/agriculture/dairy/transition-cows/nutrition-factors-causing-low-colostrum-production/

Pasteurizing Milk and Colostrum. (2011). Godden, S.: http://articles.extension.org/pages/21323/pasteurizing-milk-and-colostrum

Diarrhea Prevention and Treatment

Newborn calves are susceptible to neonatal calf diarrhea (calf scours), especially during their first 28 days of life. Incidence of diarrhea in calves can impact growth and mortality rates.[20, 21]

Acquired immunity obtained from colostrum is the first and most important control measure for diarrhea.

A clean environment will help limit the influence of infectious agents (bacteria, viruses and protozoa) on calf growth. Steps should be taken to limit calves' ingestion of manure and the infectious agents it may carry. Stress weakens the immune system, so avoiding stress is important for disease prevention. Stress can result from frequent housing and feeding changes, exposure to extreme temperatures or inadequate ventilation, and lack of water availability at any time.

Early recognition of diarrhea and aggressive fluid therapy are essential to its successful treatment. Consulting with the veterinarian to identify the infectious agents involved and the appropriate antibiotic treatment is also critical for successful diarrhea treatment (see **Table 3**).

Considerations:

- Note that colostrum feeding is essential for diarrhea prevention (see Colostrum on Page 46).
- Conduct laboratory tests and consult your veterinarian to determine what infectious agents are involved, and chose antibiotics accordingly.
- Provide clean and plentiful water at all times.
- Reduce environmental stress and provide consistent comfort for the calf.
- Replace lost body fluids with an electrolyte solution when fecal scores reach 2 and continue providing milk or milk replacer.
- Consult with a veterinarian about the use antibiotics if the calf has a fever (> 103°F), looks dull, is off feed, drinks slowly, has swollen navel or joints, has > 36 respirations per minute or has a heart rate < 100 beats per minute.
- Use fecal scores to evaluate calf manure, identify the onset of diarrhea early and determine if intervention is needed.
- Consider developing a cleaning and/or disinfection protocol for equipment and facilities.

Table 3. Common Infectious Agents Causing Diarrhea in Young Dairy Calves.[11]

Infectious Agent	Transmission	Age	Duration	Treatment	Prevention
E. coli (Bacteria)	Fecal/Oral Fecal/Naval	1-3 Days	24 Hours - Death	Fluid Support	Good colostrum management; vaccinate dry cows
Salmonella (Bacteria - zoonotic)	Fecal/Oral Milk Nasal/Saliva In Utero	5-14 Days	1-2 Weeks	Antibiotics if systemic; direct sunlight will kill the organism	Pasturize waste milk
Rotavirus (Virus)	Fecal/Oral	1-30 Days (3-7 usually)	Short, but intestinal recovery is necessary	Fluid Support	Colostrum from vaccinated dams will protect for 4 days
Coronavirus (Virus)	Fecal/Oral	1-30 Days (3-7 usually)	Until intestinal recovery	Fluid Support	Colostrum from vaccinated dams will protect for 4 days
Cryptosporidium (Protozoa - zoonotic)	Fecal/Oral	3-21 Days	Parasite must run its course; high fatality rates if not caught early	Fluid Support	Good colostral immunity, low stress, cleanliness
Coccidiosis - Eimeria (Protozoa)	Fecal/Oral	7 Days and 4-6 Months (weaning)	Life cycle is 21 days before signs of infection are exhibited	Difficult to treat; stunts growth; lowers resistance	Starter with coccidiostal; pre-weaning preventive treatment

Resources:

Calf Diseases and Prevention. (2011). McGuirk, S. M. et al.: www.extension.org/pages/15695/calf-diseases-and-prevention#.U6Bq-HkU9jo

CalfTrack – Calf Training Management System. (2006). Heinrichs, A. J.: http://extension.psu.edu/animals/dairy/nutrition/calves/calftrack/chore-plans-in-english

Calves – Clinical Information and Forms, Food Animal Production Medicine. University of Wisconsin - School of Veterinary Medicine: www.vetmed.wisc.edu/dms/fapm/fapmtools/calves.htm

Electrolytes for Dairy Calves. (2011). Kehoe, S. et al.: www.extension.org/pages/11361/electrolytes-for-dairy-calves#.U59TiXkU9jo

Sick Calf Protocols. McGuirk, S. M.: www.vetmed.wisc.edu/dms/fapm/fapmtools/8calf/calf_protocols_ver4.pdf

Respiratory Disease Prevention

Bovine respiratory disease (BRD) describes a variety of respiratory conditions that affect the upper or lower respiratory tract. It is also commonly referred to as bronchitis, pneumonia and shipping fever.

The causative agents for BRD can be both viral and bacterial. Stress also contributes to the onset of disease. Respiratory disease can be economically devastating because calves with BRD rarely lead healthy and productive lives even when they survive the disease.

Prevention is a more desirable outcome than treating with antibiotics. Factors that contribute to development of BRD include lack of proper immune transfer from colostrum, too much time spent with adult cattle and improper ventilation.

Protecting calves from environmental stress is very important for BRD prevention. Improper ventilation above the bedding (calf level) is associated with BRD. Bedding that allows the calf's legs to be completely covered is most effective in protecting the calf from drafts and chills.

Feeding large amounts of milk or milk replacer requires more bedding and attention to detail to prevent respiratory disease. Increased urine and ammonia result from high protein intakes.

Considerations:

- Note that colostrum feeding is essential for BRD prevention.
- Control stresses associated with feeding and handling.
- Consult with your veterinarian to implement an appropriate vaccination program that targets both viral and bacterial pathogens.
- Consult with your veterinarian to treat affected animals with appropriate antibiotics.
- House calves away from adult cattle.
- Move calves to a clean and dry area within the first 30 minutes of life.
- Provide deep and loose bedding that allows calves to nest and stay warm during cold weather.
- Provide good ventilation: consider increasing space per calf (30-to-50 square feet/calf), reducing the number of solid panels surrounding the pen, and installing supplemental, mechanical positive-pressure ventilation.

Resources:

Calf Diseases and Prevention. (2011). McGuirk, S. M. et al.: www.extension.org/pages/15695/calf-diseases-and-prevention#.U6Bq-HkU9jo

CalfTrack – Calf Training Management System. (2006). Heinrichs, A. J.: http://extension.psu.edu/animals/dairy/nutrition/calves/calftrack/chore-plans-in-english

Housing Factors to Optimize Respiratory Health of Calves in Naturally Ventilated Calf Barns in Winter. (2007). Nordlund, K. V.: www.vetmed.wisc.edu/dms/fapm/fapmtools/9ventilation/Calf_Barn_Ventilation_Text.pdf

What's in the Air? Success Strategies for Using Automated Calf Feeders. (2011). Ward, M. et al.: http://livestocktrail.illinois.edu/uploads/dairynet/papers/20%20Ward.pdf

Vaccinations

In the future, specific vaccines may help to directly reduce enteric methane emissions. Currently, vaccination programs play an important role in keeping animals healthy, especially when exposed to environmental stress.

Vaccination programs make economic sense because prevention is almost always less expensive than treatment.

Vaccinations also help decrease the intensity of enteric methane emissions by reducing morbidity and improving growth. Vaccination programs for each farm must be developed with a veterinarian.

Recordkeeping can reveal patterns in disease occurrence and the most effective past vaccination strategies. Differences exist between modified live vaccines, killed (inactivated) vaccines and genetically engineered vaccines, which must be considered when developing any vaccination program.

Considerations:

- Consult your veterinarian to develop a custom-designed vaccination program for your farm including boosters as appropriate.
- Follow vaccine label directions and administer recommended boosters at the directed times.
- Keep good records to reveal patterns in disease occurrence from year to year that may be associated with specific stress factors.
- Time vaccinations to give the most effective coverage before stress periods.
- Understand differences between modified live vaccines, killed (inactivated) vaccines and genetically engineered vaccines and use each where appropriate.
- Vaccinate healthy animals.

Resources:

Calf Diseases and Prevention. (2011). McGuirk, S. M. et al.: www.extension.org/pages/15695/calf-diseases-and-prevention#.U6Bq-HkU9jo

CalfTrack — Calf Training Management System. (2006). Heinrichs, A. J.: http://extension.psu.edu/animals/dairy/nutrition/calves/calftrack/chore-plans-in-english

Calf Nutrition

The primary goal of calf nutrition is to promote healthy, efficient, rapid growth with milk or milk replacer and enhance rumen growth and function by initiating grain intake.

Benefits of improved growth and reduced hunger can be achieved by feeding calves more milk or milk replacer equivalent.[22] Calves are motivated to consume large amounts of milk or milk replacer equivalent (for example, Holstein calves will drink in excess of eight quarts per day or more in two or more feedings per day). Feeding only four quarts per day of milk or milk replacer equivalent does not allow the calf to meet its nutritional requirements for maintenance, growth and development and is associated with hunger behavior.[23] There are no known negative side effects of feeding more milk/milk replacer. There are long-term benefits, such as earlier breeding ages and higher milk yield later in life, when calves are provided higher planes of nutrition during the first four weeks of life.[24]

There are no known negative side effects of feeding more milk/milk replacer. There are long-term benefits, such as earlier breeding ages and higher milk yield later in life, when calves are provided higher planes of nutrition during the first four weeks of life.

Data shows that slightly higher amounts of milk/milk replacer will help early calf growth as long as the levels are reduced at three weeks of age to promote grain eating. Diet and age are the two primary factors that convert the calf's biology, a characteristic of an animal with a properly functioning rumen. By eight weeks of age, calves must have a well-developed rumen that produces high-quality rumen microbial bacteria and volatile fatty acids (to use as glucose precursors).

Intake of calf starter has a positive causal relationship with ruminal tissue development and rumen function. An adequate freshwater supply also helps drive feed consumption and rumen development. Field studies by Pennsylvania State University show that total DMI at weaning has a significant and positive effect on several production parameters including first lactation milk production; therefore, promoting total (milk, grain and possibly forage) intake at weaning is of paramount importance. For more detailed guidance on calf nutrition, see **Chapter 4** of the FARM Animal Care Reference Manual (**www.nationaldairyfarm.com/resource-library**).

Considerations:

- Consider weaning calves by reducing milk feeding to one-half when they are consuming at least 3 lbs./day of starter feed and weaning when they are consuming at least 5 lbs./day of starter feed (the slow reduction in milk intake helps reduce the stress of weaning).
- Feed appropriate amounts of pasteurized milk or milk replacer.
- Limit free-choice forage feeding until grain intake is adequate.
- Offer clean, fresh, free-choice water.
- Start introducing small amounts of fresh, palatable, high-quality starter on day three and increase the amount offered as the calf consumes more over time.
- Transition weaned calves with as little dietary and handling stress as possible.

Resources:

A Guide to Calf Milk Replacers — Types, Use and Quality. (2008). BAMN: http://www.aphis.usda.gov/animal_health/nahms/dairy/downloads/bamn/BAMN08_GuideMilkRepl.pdf

Calves – Dairy Cattle Nutrition. Penn State Extension: http://extension.psu.edu/animals/dairy/nutrition/calves

CalfTrack – Calf Training Management System. (2006). Heinrichs, A. J.: http://extension.psu.edu/animals/dairy/nutrition/calves/calftrack/chore-plans-in-english

Cost-Benefit of Accelerated Liquid Feeding Program for Dairy Calves. Cabrera, V. et al.: http://www.dairymgt.info/oldtools/CostBenefit/Accelerated_000.pdf ; http://www.dairymgt.info/tools/CostBenefit/index.php

Cost Comparison of Various Calf Feeding Programs. (2015). Jones, C. and J. Heinrichs: Penn State Extension: http://extension.psu.edu/animals/dairy/news/2015/cost-comparison-of-various-calf-feeding-programs

Heifer Nutrition

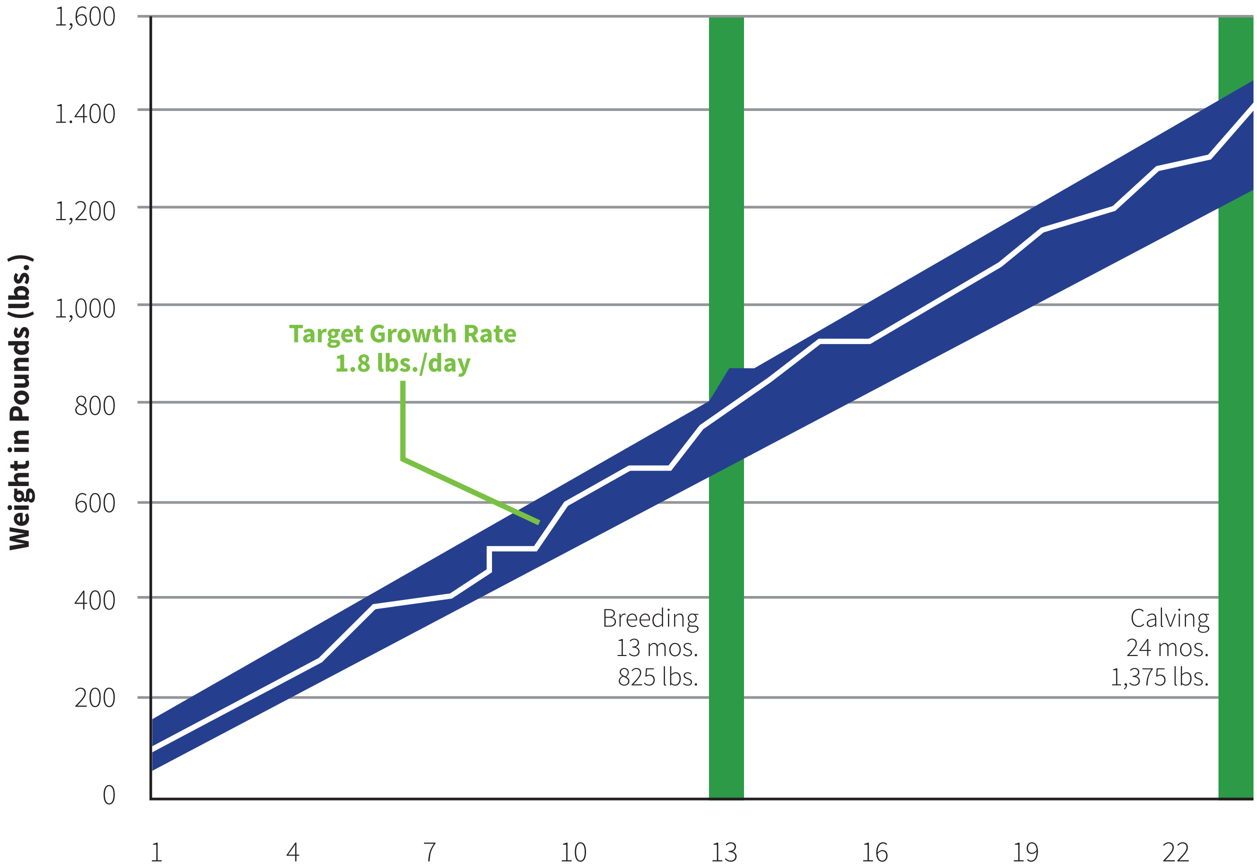
A successful heifer raising program targets an appropriate growth rate, monitors growth and manages outliers. As average daily gain (ADG) increases, age of puberty and first calving decreases. A properly conditioned heifer that is younger than her herd mates will show increased production per year of life, longevity and good health.

Providing adequate nutrition early in life has been shown to provide long-term benefits for heifers, such as earlier breeding ages and higher milk yield later in life (see the FARM Animal Care Reference Manual **Chapter 4** available at **www.nationaldairyfarm.com/resource-library**).[11]

The emphasis of heifer nutritional management should be on achieving 55 percent of projected adult weight at the time of breeding and 85 percent of projected adult weight at first calving. It's best to group heifers by size with rations that are specially formulated for each. This type of grouping will ensure that all animals receive the nutrients they need for growth without providing any excess (**Figure 8** on Page 52).

Optimum growth from weaning to breeding is just as important as optimum growth from birth to weaning. Heifers from weaning to breeding age are capable of manufacturing sufficient quantities

FIGURE 8. EXAMPLE FOR HOLSTEIN REPLACEMENT HEIFER TARGET WEIGHTS BETWEEN 1 AND 24 MONTHS OF AGE



	AGE IN MONTHS											
	1	2	3	4	5	6	7	8	9	10	11	12
Low	120	164	216	266	318	368	417	466	518	567	618	668
Average	130	175	220	275	335	410	475	520	600	655	705	775
High	158	206	262	319	376	432	491	547	606	663	720	775

	AGE IN MONTHS											
	13	14	15	16	17	18	19	20	21	22	23	24
Low	720	771	823	874	926	978	1,032	1,083	1,135	1,188	1,242	1,294
Average	825	870	940	950	990	1,070	1,130	1,185	1,210	1,265	1,300	1,375
High	883	889	945	999	1,055	1,111	1,166	1,220	1,276	1,331	1,385	1,439

Nutrition and Environment - Improving Heifer Growth. (n.d.) Homan, P. University of Wisconsin Cooperative Extension. Retrieved from http://fyi.uwex.edu/heifermgmt/files/2015/02/improvingrrowth.pdf [11] of high-quality ruminal microbial protein to meet their growth requirements. Postpubertal heifers have a lower protein requirement because their intakes increase and their muscle accretion grows at a lower rate than before puberty.

Considerations:

- Adjust dietary nutrient density to changing environmental conditions.
- Avoid supplying excess protein and minerals, which are excreted and contribute to the environmental impact without offering growth benefits from young calf through older heifer stages.
- Control dietary nutrient delivery by providing needed nutrients according to weight class.
- Manage outliers by adjusting grouping and diets for unthrifty and over-conditioned heifers.
- Monitor disease and consider culling unthrifty heifers with severe cases of respiratory disease or chronic conditions.
- Monitor weight and height of growing animals using scales or weigh tape and measuring stick.
- Target a specific growth rate to attain appropriate age at first calving goals and maximize first lactation milk yield.

Resources:

Freshening the First Calf Heifer: What the Research Shows. (2009). Litherland, N.: http://www.extension.umn.edu/agriculture/dairy/transition-cows/freshening-the-first-calf-heifer/more.html

Novel Nutrition for Dairy Replacement Heifers. (2008). Hoffman, P. et al.: http://www.dairyweb.ca/Resources/4SDNMC2008/Hoffman.pdf

Quality Control Systems in Dairy Replacement Heifer Nutrition. Quality Control Systems in Dairy Replacement Heifer Nutrition. (2005). Hoffman, P.: http://fyi.uwex.edu/heifermgmt/files/2015/02/nutrition.pdf

Replacement Heifer Management Evaluation Snapshot Worksheet. Replacement Heifer Management Evaluation Snapshot Worksheet. (2007). Conway, J. et al.: https://ecommons.cornell.edu/bitstream/handle/1813/36915/heifermgtsnapshot.pdf?sequence=1

Heifer Reproduction

Heifer reproduction programs ideally maximize profitability by maintaining or accelerating genetic progress and target a calving age of 22-to-23 months. Reducing the number of replacements needed by promoting earlier calving in bred heifers is beneficial in the mitigation of enteric methane because it minimizes unproductive time.

The keys to reaching a breeding age sooner (and having an earlier first calving) are:

1. Improving the heifer's nutritional status during the first year of age
2. Using a sound breeding program including heat detection and artificial insemination

Considerations:

- Consider using a tool or calculator to help you determine the cost of raising heifers on your farm.
- Consider using genomics to select potentially elite heifers.
- Evaluate farm records, determine current age at first calving and other heifer reproduction parameters, and compare to reasonable goals.
- To improve reproductive success, consider tail chalking, estrus detection patches, pedometers, a synchronization program and ultrasound imaging for early diagnosis of pregnancy.

Resources:

Dairy Reproduction Protocols. Dairy Cattle Reproduction Council: http://www.dcrcouncil.org/protocols.aspx

Improving Dairy Heifer Reproductive Management. (2011). Graves, W.: http://extension.uga.edu/publications/detail.cfm?number=B1235

Methods for Managing Replacement Heifer Reproduction. DCRC: http://www.dcrcouncil.org/media/Public/Methods%20for%20Managing%20Replacement%20Heifer%20Reproduction.pdf

Transition Cow Nutrition and Management

During the transition period, cows experience more stress. Effective cow management during transition will not only reduce involuntary culling, replacement costs and non-productive days, but it will also increase milk yield in the following lactation, allow for a lifetime of productivity and reduce enteric methane emissions per unit of FPCM.

Both physical and metabolic stresses occur as cows transition from milking to the dry period, through calving and into the following lactation. Proper nutrition and management of cows at each transition are essential in helping them adjust to rapid and dramatic changes in physiology and nutrient requirements.

Actions taken during transition significantly influence subsequent milk yield, lactation length, incidence of disease and reproductive efficiency, which all directly affect herd composition and profitability and indirectly influence enteric methane emissions. Management goals include: 1) preparation for a successful calving and subsequent lactation by promoting cow comfort and dry matter intake (DMI), 2) meeting, but not exceeding, transition cow nutritional requirements, and, 3) reducing the incidence of postpartum metabolic diseases.

Pre-Partum Cow Nutrition and Management

Successful lactation starts long before calving. A dry period between 45-and-65 days is necessary for replacement and repair of mammary epithelial cells and for some rejuvenation of the rumen. Energy-limited diets that are higher in forage content and encourage greater intakes as calving nears promote subsequent milk yield and help prevent physiological and infectious diseases postpartum.

Rations fed to dry cows should provide an amount of MP and amino acids as close as possible to the requirements of the dry cow and unborn calf. High milk production and low frequency of health problems can be achieved by feeding far-off (-60 to -21 days in milk) and close-up (-21 to 0 days in milk) rations or a single dry cow ration.

Grouping heifers separately can help prevent stress-related postpartum health problems. A substantial body of evidence now exists indicating that overcrowding during the prepartum period can have detrimental effects in terms of postpartum health.[25] In best practice, dry cows, particularly in the three weeks before calving, have at least 30 inches of bunk space per cow.

Proper mineral and vitamin nutrition is critical for dry cows. Any deficiencies in vitamins E and A, selenium, copper or zinc will weaken the immune response. Vitamin E and selenium help reduce the incidence of retained placentas and mastitis.

Another factor to consider is the cation-anion balance. Ions like calcium and sodium can be either positively (cation) or negatively (anion) charged. The overall balance affects processes like calcium uptake. A cation-anion imbalance can cause clinical or subclinical milk fever, reduced feed intake and rumen function, greater body fat mobilization, and increased risk for a displaced abomasum. Also, cation-anion imbalances can reduce teat sphincter muscle contractions, allowing mastitis-causing microorganisms to enter. Using forages low in potassium can help control the dietary cation-anion balance, and dietary supplementation with anionic salt mixtures (greater concentrations of chloride and sulfate) may be necessary in close-up diets.

Considerations:

- Adjust dietary energy density during late lactation and the dry period according to body condition score (BCS).
- Consider well-researched feed additives that improve rumen function, increase DMI and reduce subclinical ketosis and fatty liver.
- Determine optimum dry period length and

devise a system to manage cows accordingly.
- Formulate dry cow diets using a nutrition model that predicts metabolizable energy and protein, as well as amino acids supplies and requirements, paying attention not to overfeed energy.
- Have fresh feed available 24 hours per day.
- Maintain access to feed 24 hours a day and provide fresh feed more frequently.
- Monitor the body condition score (BCS) with the goal of maintaining cows at a score of 3.0 to 3.5 to reduce calving problems and metabolic disease.
- Monitor dry matter intake (DMI) and consider ways to increase it.
- Provide sufficient and plentiful water located in easily accessible areas with sufficient space.
- Monitor water cleanliness and clean water troughs as necessary.

Resources:

Feeding and Managing the Transition Dairy Cow. (2001). Schroeder, J. W.: http://library.ndsu.edu/tools/dspace/load/?file=/repository/bitstream/handle/10365/5369/as1203.pdf?sequence=1

Feeding the Dry Cow. (2011). Royón-Díaz F. et al.: http://openprairie.sdstate.edu/extension_extra/144/

Transition cow management: Dietary cation-anion balance. (2012). Hibma, J. In Progressive Dairyman: http://www.progressivedairy.com/topics/feed-nutrition/transition-cow-management-dietary-cation-anion-balance

Role of Mineral and Vitamin Status on Health of Cows and Calves. (2011). Spears, J. W.: http://www.wcds.ca/proc/2011/Manuscripts/Spears.pdf

Postpartum Nutrition and Management

Postpartum dairy cows with high yield potential cannot meet their energy demands from dietary intake alone. These cows depend on body reserves to balance the deficit between dietary intake and nutrient requirement increasing the risk for ketosis and other health problems.

Minimizing the severity and duration of a negative energy balance can be accomplished through balanced nutrition. A balanced ration for postpartum dairy cows should support increased plasma glucose and insulin concentrations and decreased plasma non-esterified fatty acid concentrations and liver fat content, and maintain rumen fill to avoid a displaced abomasum.

Grouping fresh cows separately for two to three weeks postpartum can help maximize DM and energy intake to more quickly return cows to a positive energy balance. The postpartum or fresh cow diet should be slightly lower in starch than the high-producing cow diet. Additionally, avoiding highly fermentable starch sources and providing rumen-effective fiber leads to increased DMI and reduces the risk for ruminal acidosis.

Considerations:

- Evaluate transition cow success using tools such as the Transition Cow Index™ (see Resources on Page 56) as well as by monitoring disease incidence and evaluating blood serum metabolites.
- Formulate fresh cow diets using a nutrition model that predicts metabolizable energy and protein as well as amino acids supplies and requirements (see General Feed Resources in **Chapter 3: Feed** on Page 19).
- Provide access to feed 24 hours a day.
- Routinely monitor dry matter intake (DMI) and consider ways to increase it.
- Supply combinations of energy and protein sources that maintain rumen health (see Rumen Function on Page 19).
- Consider well-researched feed additives that improve rumen function, increase DMI and reduce subclinical ketosis and fatty liver (see Feed Additives in **Chapter 3: Feed** on Page 37).

Resources:

Body Condition Scoring Penn State Extension. http://extension.psu.edu/animals/dairy/nutrition/nutrition-and-feeding/body-condition-scoring

Food Animal Production Medicine Clinical Information and Forms — Transition Cow and Transition Cow Index™. University of Wisconsin - School of Veterinary Medicine: https://www.vetmed.wisc.edu/dms/fapm/fapmtools/transition_cow.htm

Postpartum Uterine Diseases: Prevalence, Impacts, and Treatments. (2011). Dubuc, J.: http://www.wcds.ca/proc/2011/Manuscripts/Dubuc.pdf

Transition Cow Comfort

During the transition period, cows mobilize energy from body reserves, compromising the immune system and increasing the risk for disease. Stress reduces dry matter intake (DMI) and increases fat mobilization as well as the incidence of metabolic diseases. Dry and fresh cow rations may be well-balanced, but if cows are stressed and intake is compromised, metabolic diseases are more likely to occur.

In best practice, transition cows have at least 30 inches of bunk space per cow.

To ensure cow comfort, overcrowding, competition, stall size, bedding, time budgets, number of pen moves and heat stress must be considered. Dry cows need uninhibited access to feed so they can eat as much of a bulky ration as possible. In best practice, transition cows have at least 30 inches of bunk space per cow.[11] Transition cows should be lying down approximately 14 hours per day in clean, dry, well-lit stalls or pens. Overcrowding results in cows spending more time waiting to lay down and reduces the amount of time remaining to eat. In addition, improving cow comfort allows cows to reach their potential for milk yield.

The purposes for housing fresh cows in a separate pen for two to three weeks postpartum are to:

1. Minimize social stress
2. Provide a fresh cow diet
3. Facilitate fresh cow monitoring by trained farm operators

Because fresh cows are less aggressive and more easily pushed away from the feed, fresh cow pens should always be kept understocked.

Considerations:

- Assess bedding adequacy, flooring and ventilation to determine if changes can be made to improve cow comfort.
- Avoiding heat stress is particularly important for transition dairy cows.
- Compare current transition-cow stocking density, feedbunk space, freestall dimensions and cow time budgets to recommendations and take steps to improve, if necessary.
- Consider having a separate fresh cow group (from 0 to 14 or 21 days in milk) and separate first-calf heifers from mature cows if possible.
- Consider ways to limit the number of times cows move to different pens while still providing optimum nutrition, cow comfort and handling.
- Ensure access to water in the maternity pen.
- Ensure trained farm operators assess fresh cow appetite, temperature, rumen motility, vaginal discharge, manure and udder appearance, and treat appropriately.
- Ensure trained farm operators check dry cows from 21 days before calving up until calving day (prefresh cows) hourly, treat if necessary and move to appropriate pen.

Resources:

Cow Comfort Drives Transition Cow Success. (2011). Nordlund, K.: http://livestocktrail.illinois.edu/uploads/dairynet/papers/18%20Nordlund.pdf

Facility Designs to Maximize Transition Cow Health and Productivity. (2009). Cook, N.: http://www.wcds.ca/proc/2009/Manuscripts/FacilityDesignsMaximizeTransition.pdf

Design facilities to optimize transition cow comfort. (2015). Jones, G. and D. Kammel: http://fyi.uwex.edu/dairy/files/2015/05/design-facilities-to-optimize-cow-comfort.pdf

05 Manure

Opportunities to Reduce GHG Emissions through Manure Management

Introduction

Manure can be a source of methane (CH4) and nitrous oxide emissions (N2O) on dairy farms, both of which are GHGs. This chapter focuses on emissions reduction strategies relating to storage and treatment of manure. For ideas on how to reduce manure GHG emissions through ration manipulation, see **Chapter 3: Feed**.

Manure management can have multiple goals – to minimize water quality impacts, optimize nutrient utilization by crops, ensure reasonable labor requirements, and more – to achieve the best outcome for the farm. GHGs should rarely be the farm's top priority in manure management, and, managing manure solely to achieve GHG emission reductions is not recommended because of all the other factors that must be considered. Depending on the farm's location and circumstances, there may be opportunities to reduce GHG emissions that also align with the farm's profitability, water quality and other goals.

There are important tradeoffs to think through when considering a change in manure handling on the farm to reduce GHG emissions. First, altering manure handling, storage and treatment can require a significant capital investment, which may not have a sufficient return on investment. Additional labor, operations and maintenance, and repairs can amount to significant costs. The cost-effectiveness depends on several factors including the availability of financing and the opportunities for recouping costs through new revenue streams.

Secondly, nutrient management is a key consideration in most manure management decisions. Practices that reduce GHG emissions can occasionally result in adverse water quality outcomes. For example, daily spread is associated with lower GHG emissions compared to those from long-term manure storages, like anaerobic lagoons.[26, 27] However, daily spread can lead to nutrient runoff and other issues. In some watersheds and states, this practice is prohibited during certain times of the year.

Work with an engineer, consultant, vendor, nutrient management specialist or other unbiased trusted expert to evaluate manure management options. **Chapter 2: Moving Forward** contains helpful tips on selecting a specialist or vendor.

Key Considerations

- Work with an engineer, consultant, vendor, nutrient management specialist or other trusted expert to evaluate manure management options.
- Consider costs – basic and specialized equipment, labor, installation, operation, maintenance, etc. – in determining the feasibility for a given operation.
- Assess the opportunity to offset costs or generate additional sources of revenue through manure management choices.
- Evaluate the technical skill requirements with any manure management option.
- Consider the top priorities in manure management, such as water quality goals, labor requirements or nutrient utilization.
- Evaluate the tradeoffs and whole-farm implications associated with the use of any practices or technologies.
- Consider the regulatory implications of any shifts in manure management.
- Ensure safety protocols are in place.

Ultimately, the best strategies will depend on the farm's unique management structure, its geography, the composition of its herd, and other factors.

Reducing Emissions through Manure Management

Every step of a manure management system – collection, transport, storage, treatment and application – entails chemical and physical changes that can affect the production of methane and nitrous oxide. Ammonia, though not a GHG, influences nitrous oxide emissions. Additionally, ammonia is an important regulatory concern for large concentrated animal feeding operation (CAFO) dairy farms. Farms that emit more than 100 lbs. in a 24-hour period at least once a year are required by Federal law to report such emissions. In general, anaerobic conditions (no oxygen) favor methane emissions, whereas aerobic environments (oxygen rich) help prevent methane emissions. Manure stored as a solid or aerated manure may emit nitrous oxide. Important attributes of the manure to consider are its nutrient and Volatile Solids (VS) content. Avoiding storage during warmer conditions will generally result in lower emissions; however, this may not be feasible for many farms due to lack of open fields for spreading and/or concerns about water quality or neighbor relations.

In general, anaerobic conditions (no oxygen) favor methane emissions, whereas aerobic environments (oxygen rich) help prevent methane emissions.

The FARM ES tool currently focuses on the storage and treatment components of a manure management system. Manure application affects GHG emissions but is not explicitly addressed in the Reference Manual.

Manure management systems are often combined on-farm to form an integrated system. An integrated dairy manure treatment system is an assembly of manure handling/treatment processes that are arranged in a strategic fashion to accomplish identified farm, water quality and/or air quality goals and objectives. The opportunities below may likely be combined on-farm and attention should be paid to compatibility between the systems.

Given the potential for major costs and tradeoffs, prudent due diligence is needed when evaluating the options presented here with specific attention to challenges, benefits and drawbacks for each manure management system. Consulting with trusted experts – extension agents, consultants and others – can be helpful in working through the process.

Table 4 on Page 62 summarizes the GHG and cost implications associated with the manure storage and treatment approaches presented in this chapter. It's intended to convey a *general* sense of relative GHG reductions and cost, but these can vary greatly by farm and geographic location. Some of these options will directly affect the ES module results; others will not.

General Manure Resources:

Sustainable Dairy Production Best Management Practices. (2010). Scheffield, R.E., et al. LSU AgCenter: http://www.lsuagcenter.com/NR/rdonlyres/ECD1287B-8D83-493D-A8D7-8FD57D22B721/72553/pub2823DairyBMPHIGHRES.pdf

An Assessment of Technologies for Management and Treatment of Dairy Manure in California's San Joaquin Valley. (2005). San Joaquin Valley Dairy Manure Technology Feasibility Assessment Panel: www.arb.ca.gov/ag/caf/dairypnl/dmtfaprprt.pdf

Strategies for Mitigating Greenhouse Gas Emissions from Long-Term Dairy Manure Storage in New York State. (2017). Wright, P. and C. Gooch: www.manuremanagement.cornell.edu.

Nutrient Management Software. Cornell University Nutrient Management Spear Program: http://nmsp.cals.cornell.edu/software/index.html

Cornell Dairy Environmental Systems website: http://www.manuremanagement.cornell.edu/

Table 4. Relative GHG Reductions and Cost by Manage Storage and Treatment Approach		
	RELATIVE GHG REDUCTIONS	RELATIVE COST
SOLID-LIQUID SEPARATION	●	●
COMPOSTING	●●	●●
AERATION	●●	●●●
SEMI-PERMEABLE COVERS, NATURAL OR INDUCED CRUSTS	●●	Varies*
COVER AND FLARE	●●●	●●●
ANAEROBIC DIGESTER	●●●●	●●●●
MANURE ACIDIFICATION	●	●
NITRIFICATION INHIBITOR (GRAZING)	●●	Varies**

Note: Table 4 summarizes research from a number of sources.[28, 29, 30, 31] It's intended to convey a general sense of relative GHG reductions and cost. However, these can both vary greatly by farm and geographic location.

**Varies based on usage of crusts versus semi-permeable covers.*

***Varies with number of animals in pasture, the time spent, and the area of the pasture.*

Solid-Liquid Separation

The process of solid-liquid separation (SLS) can be used to separate a portion of the dry matter from liquid manure. In mechanical separation, for example, the separated solids contain about 65-to-80 percent moisture, while the liquid effluent contains about five percent total solids. Dairy operations may choose to include a SLS component in their overall integrated manure management system for a variety of reasons, including: to improve the efficiency/success in pumping liquid manure long distances, to reduce the organic loading of lagoons (i.e. reduce the frequency of sludge removal), to recover organic bedding material and to reduce crusting on long-term manure storages.

The impact of SLS on GHG emissions will depend on what system the dairy currently uses to store manure, the separation technology used and how the solids are subsequently treated. After separation, the liquid portion has a lower dry matter, carbon and volatile solids (VS) concentration. A lower VS content leads to a reduction in methane emissions potential during subsequent storage. The separated solids can be composted, directly land-applied, stored as a solid or recycled as bedding. Composting can reduce net GHG emissions, but comes with significant added costs for the farm as described in the following section.[32] Manure in solid storage can offer methane reductions because the pile may be exposed to aerobic conditions, depending on particular storage conditions.

The cost of installation of an SLS will vary with the type of solid separation treatment. Additionally, operations, maintenance and management present added costs and labor requirements. One financial benefit is the opportunity for avoided bedding costs, but this can also require added labor and management compared to other bedding alternatives. Some operations may generate an additional revenue stream by composting and selling the separated solids.

There are three primary approaches to solid separation: gravity, mechanical and chemical/physical.

Gravity systems include structures like settling basins, retention ponds and static screen separators.Gravity systems work with diluted manure such as that produced by flush or flume, or by pre-treatment systems that reduce the total solids content of the raw manure.

Screw-press, centrifuges, hydrocyclones and vibrating screens are some of the mechanical options available. Similar to the case with gravity systems, most mechanical systems typically function better with dilute manure (with the exception of screw-press separators).

Finally, certain chemicals can be used in advanced treatment systems for coagulation of dissolved solids or to convert soluble compounds into insoluble ones (flocculation). These chemicals include organic polymers, metal salts, alum and lime. Certain chemicals are quite costly to use at a commercial scale and may have unintended consequences post-separation. Chemicals are most often used to precipitate phosphorus for removal, which may facilitate management in areas with phosphorus reduction goals.

The FARM ES module does not directly capture the use of solid-liquid separation in and of itself. The impact of using solid separation would be reflected in the choice of manure management treatments following separation.

Considerations:

- Consider the available space to install a SLS between manure collection and the liquid storage area.
- Evaluate the opportunity to offset farm spending by using separated solids as bedding.
- Define the farm's goals for installing a SLS component to select the best SLS for the operation.

Resources:

Solid-Liquid Separation of Animal Manure and Water. (1999). Mukhtar, S. et al. Texas Agricultural Extension Service: http://tammi.tamu.edu/soild-liquidseparationE13%5B1%5D1999.pdf

Understanding Mechanical Solid-Liquid Manure Separation. (2014). Nova Scotia Agricultural College, Dalhousie University, and the Atlantic Swine Research Partnership, Inc.: http://www.nsfa-fane.ca/efp/wp-content/uploads/2014/07/Understanding-mechanical-solid-liquid-manure-separation.pdf

Advantages of Manure Solid-Liquid Separation. Tyson, T. W. Alabama Cooperative Extension System: http://www.aces.edu/pubs/docs/A/ANR-1025/ANR-1025.pdf

Solid-Liquid Manure Separation. (2015). VanDevender, K.: http://articles.extension.org/pages/8862/solid-liquid-manure-separation

Composting

Composting is the aerobic microbial partial decomposition of manure's organic matter under controlled conditions, creating a humus-like end product. The process can provide several benefits for farmers including odor control, pathogen control, organic matter stabilization and the possibility of an additional source of farm income.

GHG emission reductions from composting will vary depending on factors like moisture content, temperature, pH and the carbon-to-nitrogen ratio (C:N) of the starting material or feedstock.[7, 33] Methane emissions are reduced in composting compared to some anaerobic storage systems. Ammonia and nitrous oxide losses, however, are often increased. Intensive windrow composting, for example, is associated with greater ammonia losses.[7] Additionally, introducing extra oxygen through frequent turning or via pipes can increase both ammonia and nitrous oxide emissions. While composting emits carbon dioxide, this is not typically considered in GHG accounting because biogenic carbon dioxide is considered part of the short-term carbon cycle and thus carbon neutral.[34]

Composting generally has an overall positive effect on GHG emission reductions, despite the possible increase in certain types of emissions.[33] Aiming for lower moisture levels and nitrogen contents, through careful selection of bulking agents, helps manage GHG emissions during composting.

Composting may be appropriate for producers with dry manure handling systems or those using solid-liquid separation. However, labor, time, equipment and energy present significant added costs when implementing a composting treatment. Basic equipment needs include temperature gauges and oxygen sensors. Mid- and larger-sized operations may find it necessary to purchase specialized equipment, such as windrow turners. Monitoring and turning the pile will necessitate labor and fuel usage. These costs may be offset through sales of the final product. It should be stressed that the costs, technical expertise and time required to implement a composting system make it unfeasible for many farms, despite the potential GHG reductions.

Operations should consider state or local permitting and regulatory requirements associated with composting systems. Composting in some areas, for example, may require either building or installing components such as concrete pads or lining. Water quality – both groundwater and surface water – is an additional issue requiring careful compost site design and planning.

Table 5. Carbon Content and C:N Ratio of Bulking Materials

Material	% N (dry weight)	C:N
Corn stalks	0.6 - 0.8	60 - 73:1
Straw	**0.3 - 1.1 (0.7)**	**48 - 150:1 (80:1)**
Bark, hard woods	0.1 - 0.4 (0.24)	116 - 436:1 (223:1)
Bark, soft woods	**0.04 - 0.39 (0.14)**	**131 - 1285:1 (496:1)**
Newsprint	0.06 - 0.14	398 - 852:1
Sawdust	**0.06 - 0.8**	**200 - 750:1**
Wood chips	0.04 - 0.23 (0.09)	212 - 1313:1 (641:1)
Leaves	**0.5 - 0.13 (0.9)**	**40 - 80:1 (54:1)**

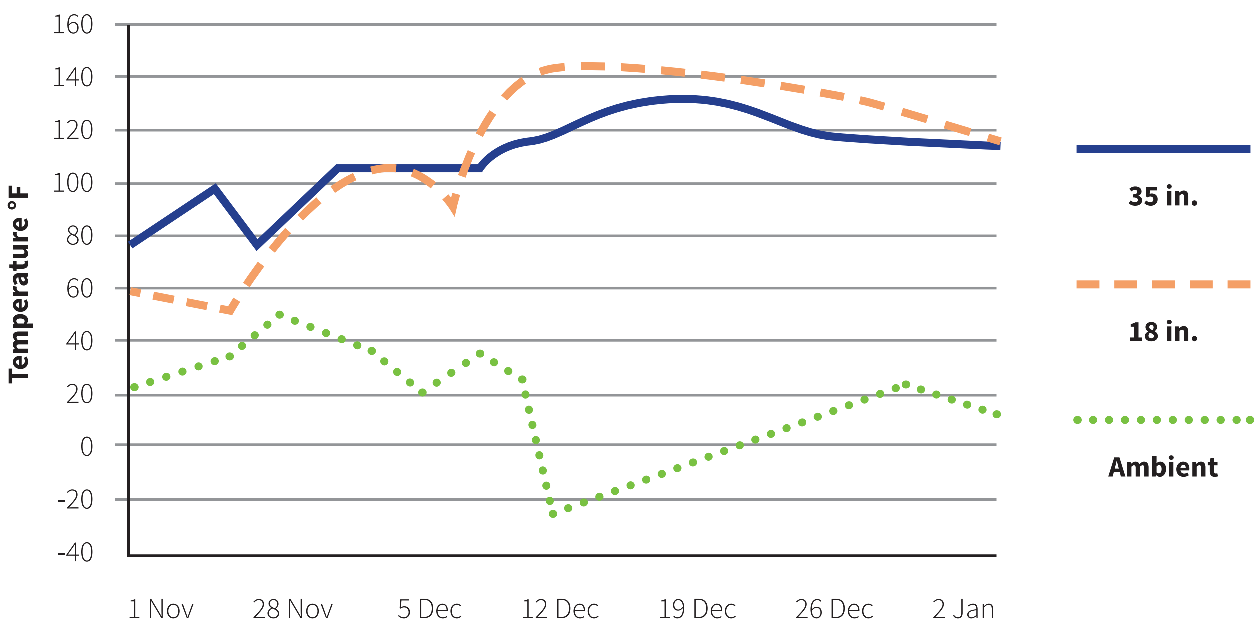
The numbers in parentheses are averages. Compiled and original data: Wortmann, C.S. et. al. Derived from Bass et al.[35]

There are five key attributes of composting that must be properly managed:

1. ***Feedstock/Nutrient Balance***
   Bulking agents are typically added to increase the solids content and manage the carbon and nitrogen ratio of the starting material or feedstock. Common additives include straw, sawdust, hay and leaves (**Table 5**). A target C:N ratio of about 30:1 can be achieved by careful selection of feedstock material.
2. ***Particle Size***
   Smaller particles have more surface area per unit of mass to facilitate microbial access to nutrients. At the same time, smaller particles can limit air flow. Optimal particle size is between 1/8 and 2 inches.
3. ***Oxygen Flow***
   Aeration of the compost pile can be achieved by mechanical turning, through air forced through pipes with holes, or with selection of certain bulking agents like wood chips. Oxygen levels should be around 5-to-20 percent and can be assessed using an oxygen meter.
4. ***Moisture***
   A moisture level of about 50-to-70 facilitates successful composting.
5. ***Temperature***
   The temperature generally rises quickly then declines gradually over time (**Figure 9**). Low temperatures indicate a problem with microbial activity and may need to be addressed by checking moisture/oxygen levels and or C:N ratio.

In the FARM ES tool, there are three composting system choices: static/in-vessel, windrows with infrequent turning and intensive windrows with frequent turning. While the emissions totals associated with the first two approaches are low in the model, intensive windrowing with frequent turning results in elevated emissions. This is because the FARM ES tool draws its factors from the IPCC 2006 guidelines, which associate the greater turning frequency in intensive windrows with higher emissions.[27]

FIGURE 9. WINDROW TEMPERATURES OVER A 5-WEEK PERIOD



Derived from Bass et al.[35]

Considerations:

- Consult various resources – extension, agricultural engineers, consultants and others – to determine the best system for your individual operation. Multiple composting systems are available to dairy farmers.
- Determine regulatory and permitting implications of starting a composting operation in the farm's state or local area.
- Consider the cost of basic and specialized equipment in determining the feasibility for a given operation.
- Evaluate the labor and technical skill requirements associated with composting before implementation.
- Determine the availability and cost of bulking agents in your area.

Resources:

Manure Composting for Livestock & Poultry Production. (2012). Bass, T., et al. MSU Extension. http://msuextension.org/publications/AgandNaturalResources/MT201206AG.pdf

Composting Manure – What's going on in the dark? (2007). Natural Resource Conservation Service: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_043439.pdf

Composting Animal Manures: A guide to the process and management of animal manure compost. (2010). Augustin, C. and S. Rahman. North Dakota State University Extension Service: https://www.ag.ndsu.edu/manure/documents/nm1478.pdf

On Farm Composting: A Guide to Principles, Planning, and Operations. (2009). Christian, A. C. et al. Virginia Cooperative Extension: https://www.pubs.ext.vt.edu/content/dam/pubs_ext_vt_edu/452/452-232/452-232_pdf.pdf

On-Farm Composting Management. (2012). Chen, L. et al. University of Idaho Extension: http://www.extension.uidaho.edu/nutrient/pdf/On-Farm%20Composting%20Managment.pdf

Slurry Aeration

The introduction of oxygen, or aeration, is frequently employed in municipal wastewater treatment systems. The goal of these systems is to reduce biochemical oxygen demand (BOD) and suspended solids to permitted levels.[31] However, aeration is generally not feasible for most dairy farms. A great deal of energy is required to take slurries to aerobic conditions to meet the BOD demand, which can result in high electricity costs. Furthermore, biosolids production is typically higher than in anaerobic systems.

The approach and its impact on GHGs is described here in brief. Advancements in technology or reductions in energy costs may make aeration a more viable option for dairies in the future.

Aeration reduces methane emissions by promoting the activity of aerobic bacteria, rather than anaerobic bacteria.[29, 32, 36] Additional benefits of aeration may include the control of odors, VOCs, ammonia and sulfur-compounds.[30, 37] In fact, swine operations have been utiliziating partial aeration strategies to control noxious odors.[31]

The impact on nitrous oxide emissions is variable. Aerobic conditions can promote nitrification that ultimately can lead to the release of nitrous oxide. Under low oxidation-reduction-potential (ORP) levels, the effect should be limited.[28, 30] Maintaining these conditions may not be realistic for all aeration systems. Forced aeration reduces GHGs overall, despite the impact on nitrous oxide emissions.[29]

Another factor to consider is the added costs and risks associated with aeration systems. Costs include the capital investment and the annual cost to operate, maintain and repair equipment. An aeration system also carries the risk of poor performance due to design flaws or errors in efficiency calculations, though this can be mitigated by using a reputable professional engineer.[30]

Considerations:

- Consider energy costs of aeration, which may be prohibitive for most dairies.
- Evaluate current research on aeration systems and their energy requirements to inform the decision to install one on your operation.
- Ensure safety protocols are in place.

Resources:

Manure Storage & Handling – Aeration Overview. (2014). Andersen, Daniel S., et al. Iowa State Extension: http://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=1206&context=extension_ag_pubs

Aeration of Liquid Manure – Factsheet. (2015). Hilborn, D. and J. DeBruyn. http://www.omafra.gov.on.ca/english/engineer/facts/04-033.htm

U.S. Environmental Protection Agency. Principles of Design and Operations of Wastewater Treatment Pond Systems for Plant Operators, Engineers, and Managers. (2011). EPA: https://www.epa.gov/sites/production/files/2014-09/documents/lagoon-pond-treatment-2011.pdf

Semi-Permeable Covers and Natural or Induced Crusts

A variety of permeable storage covers can be used in dairy manure management systems, including geo-textile, straw, wood chips, induced crusts or natural crusts. Covering long-term manure storages can effectively reduce methane, ammonia and odor.[7, 28, 29] However, semi-permeable covers create conditions that promote nitrous oxide emissions through nitrification and subsequent de-nitrification. An aerobic environment at the cover surface encourages nitrification, while the anaerobic conditions just below the surface support de-nitrification and nitrous oxide production.[28] Thus the effectiveness of manure covers will depend on thickness, degradability, porosity and permeability.[7]

Crusts form as a result of biological and physical activity in manure. A large contributing factor is the use of organic bedding for stalls. Some of the manure solids end up as a floating crust, which can become naturally thick enough to dry down. Manure crusts are more apt to form when using heavily organic bedding, a high-forage diet, less wash water, shallow storage structures with less surface area, and less wind disturbance.[38] Barley and wheat straw can both be used to cover relatively small, accessible manure storages and are applied using a straw chopper or blower.[39] Physical properties to consider in choosing a geotextile cover include tensile strength and resistance to stretching/puncture.

The costs and longevity of manure storage covers will vary with the farm and the type of cover used.

Crusts and certain covers, such as straw-based ones, must be broken up prior to application, which requires additional fuel and labor. Geotextile covers also incur maintenance costs associated with the repair of tears or punctures as well as the removal of accumulate debris.[39] During agitation, there may be elevated odor and gaseous emissions. Geotextile covers have lifespans of about three-to-five years. Straw can last up to six months. In general, geotextile and straw covers can reduce odors by 50-to-90 percent.

Considerations:

- Ensure safety protocols are in place during agitation and pumping.
- Consider the costs of maintenance and disposal when choosing a geotextile or other synthetic permeable cover.
- Evaluate the type of liquid manure storage to determine appropriate cover options. Straw, for example, is difficult to install uniformly on large anaerobic lagoons.
- Assess the desirability for short versus long-term solutions. Straw is generally short-term, lasting up to six months. Geotextile covers have a lifespan of three-to-five years. Other permeable covers, like lightweight expanded clay aggregates (LECA), can last 10 years.

Resources:

Liquid Manure Solids Management. VanDevender, K. University of Arkansas: https://www.uaex.edu/publications/pdf/FSA-1041.pdf

Using Covers to Minimize Odor and Gas Emissions from Manure Storages. (2004). Bicudo, J. R., et al. University of Kentucky, Cooperative Extension Service: http://www2.ca.uky.edu/agcomm/pubs/aen/aen84/aen84.pdf

Covers for Manure Storage Units. (2004). Nicolai, R. et al. South Dakota State University: http://openprairie.sdstate.edu/cgi/viewcontent.cgi?article=1106&context=extension_fact

Impermeable Covers, Gas Capture and Flare

Impermeable covers trap gaseous products and odor between the manure surface and the cover. They are highly effective at reducing odor, ammonia, VOCs, methane and nitrous oxide emissions.[40]

Additionally, the covers minimize the effect of wind blowing over the manure surface – reducing turbulence and agitation of the manure. They also benefit the farm by preventing rainwater from being mixed into the manure storage.[38] Impermeable covered systems can generate GHG reductions through capturing and burning methane with a flare system.

Plastic is the typical material used for impermeable covers. There are several types of covers available, including rigid, flexible and inflatable dome covers. Covers are tightly installed around the edges of the manure storage to prevent the release of gases. Biogases formed underneath the cover can be collected and removed using collection pipes.

Collected methane can be combusted to convert to carbon dioxide and generate GHG reductions. Successful combustion depends on the fuel-to-air ratio, the type of flare used and the gas flow rate.[38] Basic open-flare systems cost significantly less than highly complex enclosed systems. However, open flares are typically less successful at methane combustion and may require a pilot flame to operate.[38] In some areas of the country, it may be difficult to generate sufficient levels of biogas during cool-weather months.

The capital investment, depreciation, maintenance, repairs and disposal all contribute to the cost of an impermeable cover and flare system. In some areas, the sale of carbon credits can offset some costs as a source of additional farm revenue. Additionally, avoiding rainwater mixing with manure means less weight needs to be hauled during application – resulting in a reduction in fuel use. Cover and flare projects may trigger additional regulatory requirements in certain regions that should be taken into account when assessing costs.

The use of covered systems is reflected to some extent in the FARM ES tool in the choice of manure management systems. However, these two choices do not reflect the range of manure covers available and do not explicitly address flare systems. Furthermore, the model currently cannot account for the GHG reductions from the combustion of captured methane.

Considerations:

- When using a membrane cover, consider the weight of the materials and supports as well as the impact of wind and snow loads.
- Access to the manure must be possible for agitation, removal and sludge monitoring.
- Consider the surface area – smaller areas require less square feet of covering material.
- Evaluate options for siting the flare system where it will not present a fire hazard.
- Consult a professional engineer to help choose, design and install the optimal cover for your farm.
- Inspect regularly to ensure gas leaks are minimized.
- Ensure safety protocols are in place.
- Many of these systems require solid liquid separation as a pretreatment process.

Resources:

Covers for Long-Term Dairy Manure Storages Part 2: Estimating Your Farm's Annual Cost and Benefit. (2009). Shepherd, T. et al. Cornell University: http://db.nyfvi.org/documents/2164.pdf

Impermeable Covers for Odor and Air Pollution Mitigation in Animal Agriculture: A Technical Guide. (2011). Stenglein, R. M., et al.: https://articles.extension.org/sites/default/files/Impermeable%20covers%20FINAL.pdf

Using Covers to Minimize Odor and Gas Emissions from Manure Storages. (2004). Bicudo, et al. UK Extension. http://www2.ca.uky.edu/agcomm/pubs/aen/aen84/aen84.pdf

Covers for Manure Storage Units. (2004). Nicolai, R. et al. South Dakota State University: http://openprairie.sdstate.edu/cgi/viewcontent.cgi?article=1106&context=extension_fact

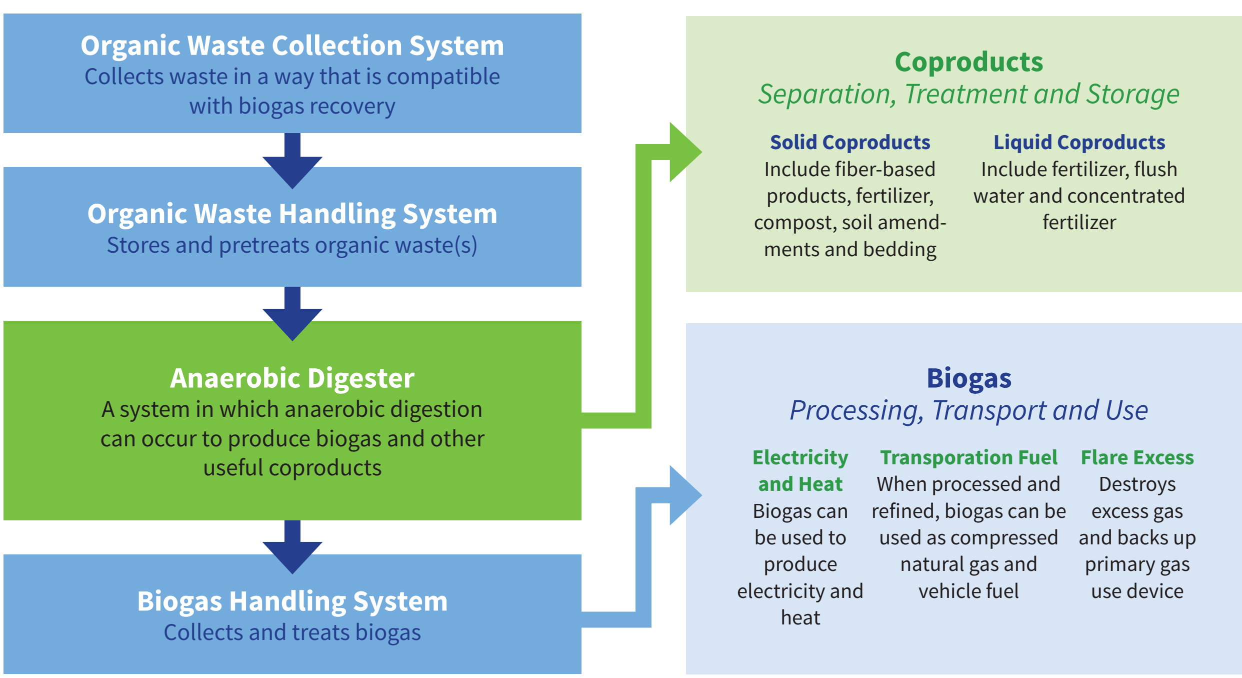
Covered Manure Storage Cost Calculator. Cornell University, College of Agriculture and Life Sciences: http://www.manuremanagement.cornell.edu/Pages/Assessment_Tools/Covered_Storage_Calculator.html

Anaerobic Digestion

Anaerobic digestion is the process in which microorganisms break down organic material in the absence of oxygen under controlled conditions targeted to maximize the production of biogas (**Figure 10**). Biogas is composed of methane, carbon dioxide, water vapor and trace gases. Biogas captured within the anaerobic digestion vessel is typically piped to end-use equipment and in most cases this is an engine-generation set.

Anaerobic digesters are considered beneficial for GHG management because they capture biogas. Some of that methane that would otherwise be released into the atmosphere is instead collected and combusted. Ideally, these digesters can serve as renewable energy sources replacing electricity or other fuel use.

FIGURE 10. THE PROCESS OF ANAEROBIC DIGESTION, DERIVED FROM EPA[41]



Biogas can also be substantially processed to produce bio-methane, sometimes referred to as renewable natural gas, and used as a natural gas replacement. Digester effluent can be treated with a solid-liquid separator to recover residual manure solids and bedding material for use as stall bedding. The liquid effluent is often stored long term until an appropriate time for it be used as a commercial fertilizer replacement. Most anaerobic digesters for commercial dairy farms are designed to work with liquid manure. There are a variety of anaerobic digester systems currently in operation on U.S. dairy farms. The most common types are complete mix and mixed plug-flow.[42]

Technical and financial feasibility must be considered. In coordination with a design engineer, producers need to evaluate the feedstock, system type and size, and onsite conditions.[43] The financial feasibility of anaerobic digesters will vary widely by farm. Costs include the capital investment and the annual cost to operate, maintain and repair equipment. Key factors to consider are the amount of biogas that will be produced, parasitic energy to operate the system, the resulting value of the energy generated, and monetary benefits that may be important to the farm. In some areas, renewable energy or carbon credits may be also available.

The FARM ES tool credits dairy farmers for the use of anaerobic digesters by reducing their GHG emissions by the amount of digester-generated energy used on the farm.

Considerations:

- Evaluate the potential for generating farm revenue or displacing costs through the sale of electricity, carbon or renewable energy credits (RECs).
- Evaluate the time and labor needs associated with installing an anaerobic digester. Significant management effort must be expended to ensure systems are properly running at all times.
- Consult with the farm's utility provider if planning to interconnect with the grid.
- Consider how the effluent will be handled after the anaerobic digester.
- Consult with an independent specialist in manure-based anaerobic digestion early in the evaluation process.
- Ensure safety protocols are in place.

Resources:

How does anaerobic digestion work? Environmental Protection Agency, AgStar: www.epa.gov/agstar/learn-about-biogas-recovery#adwork

Anaerobic Digestion: Biogas Production and Odor Reduction from Manure. PennState Extension: http://extension.psu.edu/natural-resources/energy/waste-to-energy/resources/biogas/projects/g-77

Dairy Environmental Systems.
Topics - Anaerobic Digestion. Cornell University: http://www.manuremanagement.cornell.edu/Pages/Topics/Anaerobic_Digestion.html

Other Technologies

The following practices and technologies may be of interest to certain dairy farms. However, the FARM ES tool does not currently reflect emission reductions from the use of these approaches. Farmers should evaluate the most up-to-date research on effectiveness and costs.

Nitrification Inhibitors

Nitrification inhibitors, such as dicyandiamide (DCD) and nitrapyrine, can reduce nitrous oxide emissions when used in grazed systems.[44, 45] The effectiveness of nitrification inhibitors depends on temperature, moisture and soil type.[29] Urine patches in grazed lands can be sources of high nitrogen loads. Application of nitrification inhibitors to these areas can reduce nitrogen leaching and ammonia volatilization. An added benefit is a reduction in nitrous oxide emissions. While nitrous oxide emissions are generally low in volume, they have a high global warming potential – about 300 times stronger than carbon dioxide. Continued research in this area is needed to quantify the GHG reductions and understand overall cost-effectiveness.

Manure Acidification

Manure acidification involves manipulating the pH of manure by adding acids. Studies have evaluated the effectiveness of various acids in reducing manure pH, including sulfuric acid, calcium chloride, alum and more.[7, 28] The pH level of manure is an important factor regulating GHG emissions. In particular, lowering manure pH decreases ammonia emissions. While ammonia is not a GHG, it has implications for nitrogen cycling and conversion of nitrogen into nitrous oxide.[28] One study also found that acidification drastically reduced methane emissions.[46] Acidification, however, does not directly impact nitrous oxide emissions. It should be cautioned that lower manure pH can increased hydrogen sulfide emissions. In general, strong acids were found to be more cost-effective, but handling them can be hazardous. The use of manure acidifiers has not been found to greatly impact crop production.[28] Further research is needed to evaluate the long-term impacts. Additionally, the use of manure acidification may require a permit from the state.

Resources:

Consult **Appendix B** for applicable resources.

06

Energy

Opportunities to Reduce GHG Emissions and Energy Use Intensity


3637

Introduction

From fueling tractors to lighting barns and cooling milk, energy is a critical component of dairy farm activities. Even though energy consumption contributes a relatively small portion of dairy GHG emissions, employing energy management techniques can offer significant financial savings as well as reduce a farm's carbon footprint.

This chapter highlights technologies and practices that can reduce the farm's overall energy consumption.

Appropriate and cost-effective strategies for energy reduction will vary depending on the farm's geographic location, management style, herd characteristics and more. In general, milk harvest, cooling, ventilation and lighting generally consume the most electrical energy on dairy farms (**Figure 11**).[47]

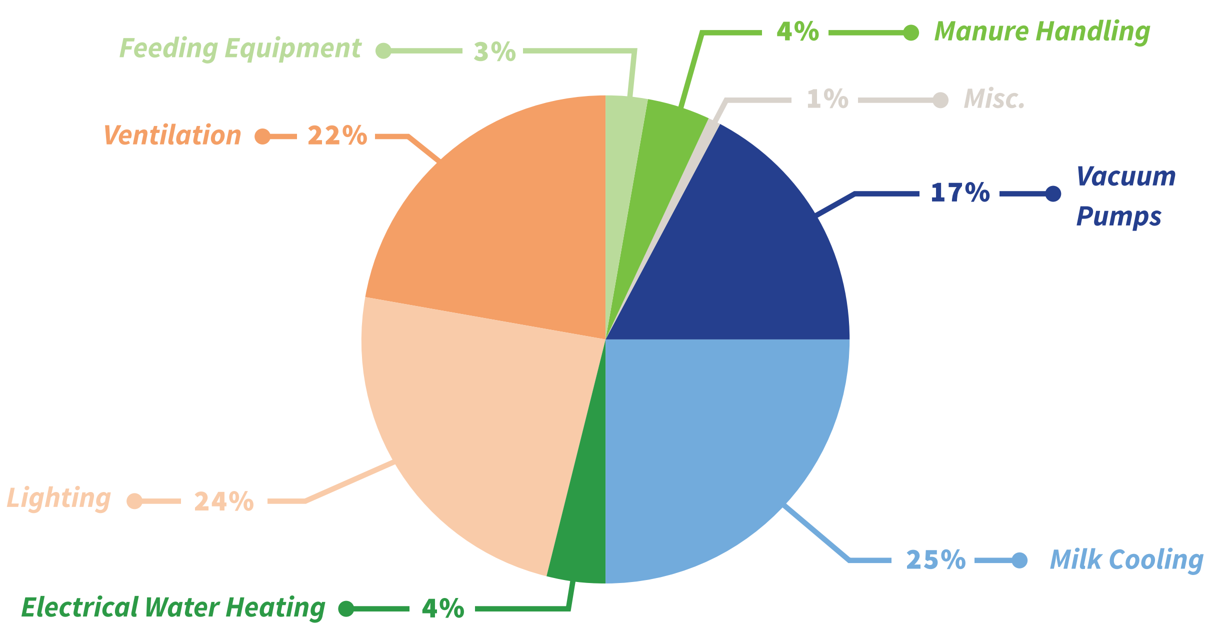
Reducing Emissions through Energy Management

Opportunities to reduce energy use exist throughout the farm. It should be noted that technologies with capital investments may see the shortest payback for farms with longer milking hours or larger volumes of output.

Farmers should work with energy professionals from extension services, utility providers, consulting firms and other relevant experts to make the best decisions for their individual farm. Such professionals can help each farm assess its current energy usage and develop a plan for moving forward. **Chapter 2: Moving Forward** contains helpful tips on selecting a specialist.

A great first step toward reducing energy use is to conduct a farm energy audit. An energy audit looks at your farm's current energy use and makes specific recommendations on how to save energy. The auditor will typically consider the farm's energy usage, all of the major activities on the farm and the energy-using equipment for each activity. The recommendations should include the estimated cost to replace equipment and the typical payback period. The local NRCS office can usually provide a list of technical service providers to contact for a farm energy audit in the area. Opportunities to fund an energy audit include the USDA Environmental Quality Incentives Program (EQIP) and incentives available through the farm's utility company (see **Chapter 2: Moving Forward**). Some states may have additional programs to fund farm energy audits.

FIGURE 11. EXAMPLE OF DAIRY FARM ENERGY USE[47]



Key Considerations

- Work with an engineer, consultant, vendor or other trusted unbiased expert to evaluate energy reduction or efficiency opportunities.
- Perform regular maintenance that includes cleaning, regular inspections, repairing parts and fixing leaks as needed.
- Choose properly sized motors and other equipment for the given task.
- Consider energy-efficient options when old equipment must be replaced.
- Consider the use of Variable Speed Drives (VSDs) for the milk vacuum pump, milk transfer pump and/or fans.
- Conduct an energy audit to establish the operation's current energy usage, where energy is being expended and opportunities for improvement.
- Replace old lighting fixtures with high-efficiency options, such as light-emitting diodes (LEDs).
- If your farm is already energy efficient, conduct a renewable energy assessment to determine the feasibility and payback of a renewable energy system.

General Energy Resources:

Best Practices Guide: Energy Savings Opportunities for Dairy. (2014). EnSave: http://www.ensave.com/agrimark/wp-content/uploads/sites/6/2016/04/EnSave_Dairy_BPG_2014.pdf

Dairy Farm Energy Management Handbook. (2006). Wisconsin Department of Agriculture: https://datcp.wi.gov/Documents/DAD/DairyFarmEnergyManagementHandbook.pdf

Dairy Farm Energy Efficiency. (2010). Pressman, A. ATTRA – National Sustainable Agriculture Information Service: https://attra.ncat.org/attra-pub/summaries/summary.php?pub=198

Dairy Farm Energy Self-Assessment Tool. USDA Natural Resource Conservation Service: http://fyi.uwex.edu/energy/welcome/esa-tool/

Facilities. University of Minnesota – Dairy Extension: http://www.extension.umn.edu/agriculture/dairy/facilities/

Energy Efficiency on Dairy Farms: YouTube Videos, uploaded by USDairyVideo. Innovation Center for U.S. Dairy / Ensave: https://www.youtube.com/playlist?list=PLUGl3r9fIyGXfmnJpthpixJATGPRlAfQf

Milk Harvest

The milk harvesting system typically accumulates more hours of use than any other equipment on a dairy farm on an annual basis. Mindful design, selection and maintenance of milk harvesting equipment is necessary to optimize efficiency of the harvesting process and quality of the milk. The vacuum pump plays a key role in milk harvest and can consume almost 20 percent of dairy farm energy use.[47]

Using Variable Speed Drive (VSD), also known as a variable frequency drive (VFD), on the milking vacuum pump is one of the greatest opportunities

[ii]This chapter draws from EnSave's Best Practices Guide: Energy Savings Opportunities for Dairy for estimates of energy use reductions and simple payback period ranges.[49]

for energy savings at the dairy.[47] The VSD adjusts the speed of a motor to match the load required. When used with the vacuum pump, the pump and motor operate at the optimal speed needed, rather than running at consistently high speed. This reduces energy consumption. Additionally, a VSD can help reduce noise and extend the life of the vacuum pump. Milk vacuum pump VSDs typically reduce vacuum pump electricity use by 50-to-60 percent with simple payback periods ranging from three-to-seven years.[ii]

Milk vacuum pump VSDs typically reduce vacuum pump electricity use by 50-to-60 percent with simple payback periods ranging from three-to-seven years.

Considerations:

- Choose a vacuum pump of the appropriate size to reduce the initial capital investment, control operating costs and ensure proper performance.[48]
- Evaluate the efficiency of the vacuum pump and motor.
- Consider using a milk vacuum pump Variable Speed Drive (VSD).

Resources:

Energy efficiency for dairy milking equipment. (2012). Stanford, S. et al. Iowa State University: https://store.extension.iastate.edu/Product/Energy-efficiency-for-dairy-milking-equipment-Farm-Energy

Milk Transfer and Cooling

Cooling milk is vital to food safety and the efficiency of the farm operation. Milk cooling can represent approximately 25 percent of total energy use. On dairy farms without pre-cooling technologies, milk flows from the cow into a receiver and is then pumped into a bulk tank where compressors cool the milk to its proper storage temperature.

Pre-cooling, the use of variable speed drives for the transfer pump and the use of efficient compressors are options for improving energy efficiency at transfer and cooling.

Using heat exchangers to pre-cool milk prior to bulk tank storage presents an opportunity to reduce refrigeration energy consumption. Types of heat exchangers include shell-and-tube and plate coolers. Shell-and-tube systems are older in style and entail milk passing through one or more smaller tubes that are situated inside a larger tube with flowing water to provide cooling. A plate cooler system consists of multiple stainless steel plates. Milk passing in one direction through the plate cooler is cooled by cold water passing in the other direction. Plates can be added to the system to expand capacity as the dairy grows. A plate cooler can reduce refrigeration costs by up to 60 percent with simple payback periods of about three-to-five years. When well water is used for pre-cooling it may be recycled for other farm uses, such as drinking water or wash water, depending on local regulations. Some plate cooler systems use a closed-loop chilled mixture of water and chemical coolant.

A Variable Speed Drive (VSD) can be used for the milk transfer pump in conjunction with a plate cooler. The VSD can help ensure a more constant flow milk into the heat exchanger, which increases the coolant-to-milk ratio allowing for better milk cooling. Using a VSD for the milk pump combined with a plate cooler can offer energy savings of up to 30 percent.

Refrigeration compressors circulate refrigerant through the cooling system. Discus or scroll compressors are more energy-efficient options than conventional systems. These models enable capacity modulation to match the desired load. Additionally, they typically have a longer use life than older models and provide more consistent cooling. Scroll and discus compressors use about 30 percent less electricity with a simple payback period of about five-to-seven years. They also reduce noise levels, last longer and offer more consistent milk cooling.

Scroll and discus compressors use about 30 percent less electricity with a simple payback period of about five to seven years.

A compressor heat recovery (CHR) unit makes use of the heat generated during the cooling process. Captured energy can be used to pre-heat water before it enters the water heater or for space heating needs. Heat recovery units compete somewhat with milk pre-cooling systems. When milk is pre-cooled and at a lower temperature entering the refrigeration system, less heat is recovered during refrigeration. Despite the interaction between the two systems, dairies with more than around 100 to 150 cows may benefit from installing both. CHR units can improve compressor performance and prolong the life of the refrigeration system. Producers can expect a reduction in water heating cost of about 50 percent with a simple payback period of about two-to-five years.

Considerations:

- Consider the use of heat exchangers to pre-cool milk prior to bulk tank storage to reduce refrigeration energy consumption.
- Consider using a Variable Speed Drive (VSD) for the milk transfer pump in conjunction with a well water plate cooler.
- Evaluate energy-efficient options for refrigeration compressors, such as discus or scroll compressors.
- Install a refrigeration heat recovery unit to make use of the waste heat generated during the milk cooling process.

Resources:

Well Water Precoolers. (2003). Sanford, S. University of Wisconsin Extension: http://learningstore.uwex.edu/Assets/pdfs/A3784-03.pdf

Energy efficiency for dairy milking equipment. (2012). Stanford, S. et al. Iowa State University. https://store.extension.iastate.edu/Product/Energy-efficiency-for-dairy-milking-equipment-Farm-Energy

Lighting

Lighting is required for both indoor and outdoor areas. However, the amount of light required varies across the farm. Work areas such as the milking parlor generally require more lighting, whereas animal resting areas and general outdoor security lighting can function with lower intensity levels. Optimizing lighting conditions to the given area can reduce energy consumption for dairy operations. Choosing energy efficient-lighting and implementing behavioral changes can also achieve energy savings. Lighting often represents one of the best opportunities to reduce electricity use on dairy farms, and lighting retrofits typically have shorter paybacks than other energy efficiency upgrades.

The type of lighting used can make a significant impact on electricity use. Compact fluorescent (CFL), pulse-start metal halide (PSMH), light-emitting diode (LED), T-8 and T-5 lighting are all regarded as more efficient options than conventional ones. T-5 and T-8 lights, for example, use less energy than T-12s, make less noise, generate more light, run cooler and offer cost savings. **Table 6** on Page 78 summarizes typical replacement for base case lighting, efficacy, and lamp life.

LEDs have grown in popularity as technology has advanced and costs have declined. LED lights offer more direct light, which allows bulbs to be positioned to illuminate particular areas. They generate more light per watt and last longer than other lights – meaning less electricity use and reduced labor for replacement. Additionally, recent studies suggest LED lights may increase cow productivity in long-day lighting programs – where cows are exposed to 16-to-18 hours of light per day.

Table 6. Lamp Type Comparison Chart Derived from EnSave[49]

Lighting Type	Typical Photopic Lumens per Watt	Typical S/P Ratio	Typical Visually Effective Lumens per Watt	Typical Correlated Color Tempurature (CCT) (Kelvin)	Typical Lamp Life on a Dairy Farm (Hours)
Light Emitting Diode (LED)	95	2.00	190	2,500-6,500	20,000-80,000
T-8 and T-5 Fluorescent	**90**	**1.90**	**171**	**3,000-7,000**	**15,000-25,000**
Pulse-Start Metal Halide	70	1.60	112	3,800-4,500	15,000-20,000
Compact Fluorescent	**60**	**1.60**	**96**	**2,500-6,500**	**8,000-18,000**
Standard Metal Halide	50	1.50	75	3,800-4,500	8,000-12,000
T-12 Fluorescent	**70**	**1.00**	**70**	**3,000-7,000**	**7,500-12,000**
High Pressure Sodium	90	0.65	59	2,000-3,000	20,000-30,000
Mercury Vapor	**40**	**1.33**	**53**	**5,500-6,500**	**10,000-20,000**
Halogen	17	1.40	24	2,700-3,400	10,000-15,000
Incandescent	**15**	**1.36**	**20**	**2,500-3,000**	**1,000-4,000**

Considerations:

- Replace inefficient light bulbs with higher efficiency types. See See **Table 6** on Page 78 for suggestions.
- Consult third-party listings, like the DesignLights Consortium (DLC), to evaluate LED lighting options (www.designlights.org/).
- Turn off lights when not in use.
- Utilize daylight when possible.
- Consider the use of motion/occupancy sensors in areas that do not require constant lighting.
- Consider installing timers or photocells to ensure outdoor lights only operate outside of daytime hours.
- Install dimmers to enable adjustments in the intensity of light to fit current lighting needs.
- Consider careful barn design and layout, which can help maximize light distribution, reducing overall electricity needs.

Resources:

LED lighting – compare and consider for your farm. (2012). Janni, K. University of Minnesota Extension, Dairy Star: http://www.extension.umn.edu/agriculture/dairy/facilities/led-lighting/

Dairy Housing Lighting for Convenience & Performance. (2014). Ciolkosz, D. and McFarland, D. PennState Extension: http://extension.psu.edu/animals/dairy/courses/technology-tuesday-series/webinars/dairy-housing-lighting-for-convenience-performance

T-5 fluorescent lighting and lighting economics. (2012). Janni, K. University of Minnesota Extension, Dairy Star: http://www.extension.umn.edu/agriculture/dairy/facilities/t-5-fluorescent-lighting-and-lighting-economics/

Lighting Energy Self-Assessment Tool. USDA Natural Resource Conservation Service. www.ruralenergy.wisc.edu/conservation/lighting/default_lighting.aspx

Lighting Systems for Agricultural Facilities. (2014). American Society of Agricultural and Biological Engineers: http://elibrary.asabe.org/

Ventilation and Cow Cooling

Ventilation and cow cooling are essential for maintaining animal health and productivity. While individual fans do not typically require a high horsepower load, their long running times contribute to high energy consumption. Ventilation fan selection entails consideration of its fan capacity – the amount of air it can move – which is a factor of the blade size and shape, fan speed, motor horsepower and housing design.[48] In general, fan efficiency (cfm/watt) improves with greater diameters.

Thermostats can be used to operate fans only as needed. Thermostats must be carefully located to reduce exposure to sunlight and excessive air.[48] Fan Variable Frequency Drive (VFD) control systems can be used in conjunction with thermostats to match the system capacity to the actual load, thereby reducing energy consumption.

Advanced ventilation control systems provide additional opportunities to save energy. In these systems, sensors take into account temperature, wind speed, humidity and other factors to then adjust misters, fans or curtains accordingly.

Conductive cow cooling is an emerging technology that can reduce energy use and water consumption. In this system, tubes are run under the cow stalls. Cooling fluid run through the pipes pull heat from the cows. Additional research is needed to fully evaluate the commercial viability of conductive cow cooling.

Considerations:

- Evaluate the need for ventilation control systems, such as thermostats, which operate fans only as needed.
- Ensure regular and adequate ventilation maintenance – cleaning, lubricating, checking tension and alignment levels, and removing obstructions. A properly maintained ventilation system will function better and require less electricity for operation.

Resources:

Air Movement and Control Association International. http://www.amca.org/

Agricultural Ventilation Fans, Performance and Efficiencies. University of Illinois Bioenvironmental and Structural Systems Laboratory. http://bess.illinois.edu/

Washing and Water Heating

Having a reliable supply of hot water is integral for a dairy farm to clean milking systems. Water heaters are typically powered by fuel oil, propane, natural gas or electricity. Energy used on heating water will vary by farm, but can be as high as 25 percent.[48]

A properly sized water heater that matches the operation's needs is ideal.[49] This can be determined by the quantity of hot water required over a given time period. The water heater's energy factor (the amount of hot water produced per unit of fuel consumed over a typical day) can be used to evaluate efficiency. This value takes into account the water heating efficiency as well as standby losses. The higher the energy factor, the more efficient the water heater. High-efficiency electric and gas heaters have an energy factor (EF) of at least 0.91 or 0.8, respectively.[49]

As previously described, a refrigeration heat recovery unit can make use of the heat generated during the milk cooling process. Captured energy can be used to pre-heat water before it enters the water heater. Pre-heating can reduce the energy consumption needs of the water heater.

Considerations:

- Consider a water heater's Energy Factor (EF) to evaluate efficiency.
- Adjust the water temperature to suit the given activity. Pre-rinses, for example, may require only warm water rather than hot.[48]
- Choose a properly sized water heater that matches the operation's needs.
- Inspect the water heating system on a regular basis for leaks to help reduce energy loss due to inefficient systems.
- Consider insulating the water heater and lines to reduce heat loss.

Resources:

Economics of Heating Water on the Dairy Farm. (2011). Buffington, D. Penn State Extension: http://extension.psu.edu/animals/dairy/news/2011/economics-of-heating-water-on-the-dairy-farm

Energy-Efficient Hot Water for Farms. (2012). Beard, R.: http://articles.extension.org/pages/31803/energy-efficient-hot-water-for-farms

Energy Saver – Water Heating. U.S. Department of Energy: https://energy.gov/energysaver/energy-saver

Heating Water on Dairy Farms. (2003). Sanford, S. University of Wisconsin Extension: http://learningstore.uwex.edu/Assets/pdfs/A3784-02.pdf

Tractors and Implements

Farm equipment should be regularly maintained to optimize performance and fuel usage. In addition, various practices can lead to fuel and cost savings.

Considerations:

- Minimize idling time to limit unnecessary fuel usage.
- Keep tires at the appropriate pressure.
- Combine trips where possible, but avoid excess weight on vehicles.
- Use an engine block heater with a timer to limit engine warming time.
- Perform regular maintenance, which can include tune-ups, wheel alignment, replacement of air, oil and fuel filters on a regular basis, and oil changes as recommended by the manufacturer.
- Use equipment with the appropriate horsepower for the given task.

Resources:

Conserving Fuel on the Farm. (2007). Svejkovsky, C. ATTRA: https://attra.ncat.org/attra-pub/viewhtml.php?id=303

Fuel Conservation Strategies for the Farm. (2006). Fulton, J. et a. Alabama Cooperative Extension: http://www.aces.edu/pubs/docs/A/ANR-1303/ANR-1303.pdf

Reducing Energy Use on the Dairy Farm. UMass Extension Crops, Dairy, Livestock, Equine: https://ag.umass.edu/sites/ag.umass.edu/files/fact-sheets/pdf/ReducingEnergyUseontheDairyFarm%2811-55%29.pdf

Renewable Energy

Various forms of renewable energy have been successfully implemented to support energy independence. On the whole, renewable energy projects have longer payback periods than other energy efficiency projects. Cost-share programs may help offset some of the investment. Additionally, certain areas offer net metering or other energy generation incentives.

Renewable energy technologies include anaerobic digesters, solar, geothermal and wind. Solar-powered well pumps, for example, have recently grown in popularity. Farms using anaerobic digesters receive a reduction in manure-related GHGs in their FARM ES results. Other renewable energy sources, such as on-farm solar panels, do not directly impact GHG emissions results in FARM ES at this time. However, FARM ES does capture reductions in electricity or fuel use that result from using renewable energy technology.

Producers interested in learning more about renewable energy options are encouraged to consult an energy consultant or other specialist.

Resources:

Farm Energy Alternatives. ATTRA – National Sustainable Agriculture Information Service. https://attra.ncat.org/attra-pub/farm_energy/

Database of State Incentives for Renewables & Efficiency. http://www.dsireusa.org/

Energy. USDA National Agricultural Library. https://www.nal.usda.gov/afsic/energy-1

Solar Energy Industries Association (SEIA). http://www.seia.org/

GLOSSARY

Aerobic: In the presence of oxygen.

Anaerobic: In the absence of oxygen.

Average Daily Gain (ADG): Rate of weight gain by an animal per day.

Body Condition Score (BCS): Five-point scale used for the evaluation of the fatness of a dairy cow. Both visual and tactile evaluation of body fat reserves are used. A score of 1 represents an emaciated or very thin cow and a score of 5 represents an excessively overweight cow. A score of 3 represents average body condition.

Body Weight (BW): The weight of an animal's body.

Bovine Respiratory Disease (BCD): General term describing a variety of respiratory conditions affecting a cow's upper or lower respiratory tract; causative agents can be both viral and bacterial, with stress contributing to the onset of disease.

CO2e (Carbon Dioxide Equivalent): For any quantity of a particular greenhouse gas, CO2e is the amount of carbon dioxide that would cause the same level of warming a specified time frame.

Coliform Counts (CC): Estimates the number of coliform bacteria that originate from contaminated environments or manure in a milk sample. It is obtained by plating a milk sample on Violet Red Bile agar or MacConkey's agar and counting the typical coliform colonies that grow after incubation. CC is quantified as colony forming units (CFU) per ml.

Compressor Heat Recovery: A process by which the heat removed from milk in the cooling stage of production is reused to heat water for cleaning purposes on the farm.

Crude Protein (CP): Amount of true protein and non-protein nitrogen in feed that is calculated from the measurement of nitrogen content in feed multiplied by 6.25.

Days in Milk (DIM): Number of days from calving date.

Digestible Energy (DE): Amount of energy absorbed by an animal that is calculated as the difference between the energy content in feed and feces.

Dry Matter (DM): The part of a feedstuff that remains when all its water content is removed.

Dry Matter Intake (DMI): The total amount of feed dry matter an animal consumes in a day.

Enteric Fermentation: Part of the digestive process for ruminant animals. In this process methanogens (a type of anaerobic microbe) decompose and ferment food in the cow's digestive tract, producing compounds that are absorbed by the animal, but releasing methane as a byproduct.

Ether Extract (EE): Proportion of feed soluble in ether that consists primarily of fats and fatty acids.

Failure of Passive Transfer (FPT): Inadequate transfer of immunity to a calf resulting from inappropriate colostrum intake or colostrum quality that reduced a calf's ability to fight disease during the first weeks of life.

Fat- and Protein-Corrected Milk (FPCM): Milk that has been corrected for fat and protein content, typically to the standard of 4.0 percent fat and 3.3 percent protein. This standard is used for comparing milk with different fat/protein contents. Using this method helps evaluate milk production of different dairy animals in a standardized method.

Feed Conversion/Feed Efficiency: Relative measurement of the efficiency of feed energy use, calculated for lactating cows by dividing the amount of FPCM by the amount of dry matter intake.

Feed Shrink: Feed waste and losses. The amount of feed shrink varies widely from farm to farm, and it would be impossible to have zero feed shrink on a livestock facility. Reductions in feed shrink will reduce the amount of nutrients entering the environment including phosphorus.

Global Warming Potential: A measure of the quantity of heat a greenhouse gas traps in the atmosphere. It compares the quantity of heat trapped by a certain amount of the greenhouse gas in comparison to the amount of heat trapped by a similar amount of carbon dioxide. Expressed as a factor of carbon dioxide.

Greenhouse Gas (GHG): An atmospheric gas that absorbs and emits radiation within the thermal infrared range.

Gross Energy (GE): Total amount of energy in feed delivered to a cow.

Heat Recovery Unit: A piece of equipment on dairy farm operations that captures wasted heat from other processes on the farm, such as milk cooling. The captured heat is then used for another purpose, such as heating water to clean milking equipment.

Income Over Feed Cost (IOFC): The difference between the value of product and total feed cost.

Income Over Purchased Feed Cost (IOPFC): The difference between the value of product and purchased feed cost.

Laboratory Pasteurization Counts (LPC): Estimate of the number of bacteria in a milk sample that can survive pasteurization temperatures. It is obtained by counting bacterial colonies that grow on agar plated with a laboratory pasteurized milk sample. LPC is not a required regulatory test and is quantified as colony forming units (CFU) per ml.

Life Cycle Assessment: A technique that assesses the environmental impacts associated with all stages of a product's life, from raw material extraction to processing of those materials, manufacturing, distribution, consumption and disposal.

Metabolizable Energy (ME): Amount of energy remaining after subtracting gas and urinary losses from DE.

Metabolizable Protein (MP): True protein that flows from the rumen and is digested and absorbed from the small intestine as amino acids.

Milk Urea Nitrogen (MUN): Concentration of urea in milk that may be used to indicate excess nitrogen in a lactating dairy cow diet.

Net Energy (NE): Amount of dietary energy available to the animal for productive purposes; it is calculated by subtracting energy loss due to heat production resulting from digestion and metabolism from ME.

Net Energy for Lactation (NEL): Amount of net energy available to the animal to produce milk.

Neutral Detergent Fiber (NDF): Proportion of feed insoluble in neutral detergent and primarily composed of fibrous carbohydrates that include cellulose and hemicellulose, plus the indigestible compound lignin; forages are major contributors of dietary NDF.

NH3 (Ammonia): Produced by ruminal microbes during protein digestion in the rumen.

Non-Fiber or Non-NDF Carbohydrate (NFC): Diverse fraction of carbohydrates soluble in neutral detergent and provides energy to ruminal microbes, calculated as 100 percent.

Non-Protein Nitrogen (NPN): Refers collectively to nitrogen-containing compounds in feed that are not proteins but can be converted into proteins by microbial activity in the rumen.

Plate Cooler: Also known as a milk pre-cooler, a plate cooler is a set of stainless steel plates installed in the milk line before the bulk tank. Well water passes through the plate cooler in one direction and absorbs heat from the warm milk pumped through the plate cooler in the opposite direction, cooling the milk.

Rumen: The first stomach of a ruminant (including dairy cattle), which receives food or cud from the esophagus, partly digests it with the aid of bacteria and passes it to the reticulum.

Rumen-Degradable Protein (RDP): Feed protein digested by the ruminal microbes.

Rumen-Degraded Carbohydrates: Carbohydrates in feed digested by the ruminal microbes.

Rumen-Undegradable Protein (RUP): Protein that escapes microbial digestion in the rumen.

Somatic Cell Counts (SCC): Refers to the concentration of somatic cells, primarily leukocytes or white blood cells, present in a milk sample. It is a measure of the response to pathogenic bacteria in the udder and an indicator of milk quality. SCC is quantified as cells per ml.

Subclinical Acute Acidosis (SARA): A disorder of ruminal fermentation that is characterized by extended periods of depressed ruminal pH below 5.5 resulting from feed ration imbalances.

Total Mixed Ration (TMR): A method of feeding dairy cattle whereby all feedstuffs, including forages, grains and supplements, are weighed and blended into a complete ration providing all nutrients required by the animal.

Variable Speed Drive (VSD): A digital controller that regulates the speed of various pieces of milking equipment such as the vacuum pump motor and milk transfer pump. This technology gives a dairy operation the ability to control the energy output of its equipment and reduce energy consumption by measuring how much power each system requires and subsequently regulating the speed of the equipment.

Volatile Fatty Acids (VFAs): Energy-rich products of microbial fermentation of feed that are a main energy source for dairy cattle.

Volatile Solids: A measure of the organic matter content of manure.

APPENDIX A

The Dairy Industry and Greenhouse Gas Emissions

FARM Environmental Stewardship estimates greenhouse gas emissions and energy intensity from dairy production at the farm level. This chapter outlines the sources of GHG emissions associated with dairy farming and discusses past performance of the dairy industry in GHG emissions as well as the motivations for future engagement in this area.

Greenhouse Gases[50]

A greenhouse gas (GHG) is a type of gas found in the atmosphere that traps and re-emits heat in the Earth's atmosphere. The major types of GHG emissions associated with agriculture are:

- Methane (CH_4): Livestock production and other agricultural activities can release methane. Other activities, like fossil fuel production and the decomposition of organic waste result in methane emissions.
- Nitrous Oxide (N_2O): Similarly, nitrous oxide can be emitted by the ag sector. For example, it can be released by manure during storage and treatment as well as during manure or fertilizer application. Industrial activities, combustion of fossil fuels and waste can result in nitrous oxide emissions.
- Carbon Dioxide (CO_2): Burning fossil fuels (natural gas, oil, coal), solid waste, trees and wood products releases carbon dioxide into the atmosphere.

Greenhouse gases differ in their ability to trap heat and in how long they stay in the atmosphere. Therefore, in order to compare impacts across the gases, they are discussed in terms of Global Warming Potential (GWP). GWP measures how much energy one ton of each gas will absorb over a given period of time compared to one ton of carbon dioxide. In other words, GWP is an index where carbon dioxide has a value of 1 and other gases are assigned a GWP value based on the amount of energy they absorb compared to carbon dioxide. Emission amounts are converted into units of CO_2e, carbon dioxide equivalents, to facilitate measurement and discussion. The conversion to CO_2e depends on the GWP. Methane, for example, has a GWP of about 25.[27] So one ton of emitted methane (CH_4) can be expressed as 25 tons of CO_2e.

Methane is the primary greenhouse gas associated with dairy farming, though nitrous oxide is also noteworthy because it has a high GWP. Emissions from enteric fermentation and manure management on dairy farms represents about 10 percent of U.S. methane emissions and 1.5 percent of U.S. nitrous oxide emissions.[51] Overall, these combine to 1 percent of total GHG emissions in the U.S. – which does not include emissions from the rest of the dairy supply chain, such as hauling or processing. While this is a small percentage of U.S. emissions, there has been growing interest in the dairy industry to address emissions within its operational control. Retailers and dairy buyers have also made commitments to reduce emissions across their supply chain – resulting in pressure on farmers and other suppliers. In many cases, pursuing emissions reductions at the farm level can also improve farm profitability. Increasing productivity per cow and feed efficiency are two promising areas that reduce emissions and boost revenue.

Sources of Emissions from Dairy Farming

Enteric fermentation and manure management are the primary sources of GHG emissions at the dairy farm-gate.[4] The production of feed as well as fuel and electricity use for dairy activities also contribute to emissions. Emissions associated with crop production come from fuel and electricity use, the manufacturing and use of inputs, and emissions from soil management and fertilizer application.

Because the focus of FARM Environmental Stewardship is on dairy activities, the following sections provide more context on emissions that occur after feed production.

Enteric Emissions

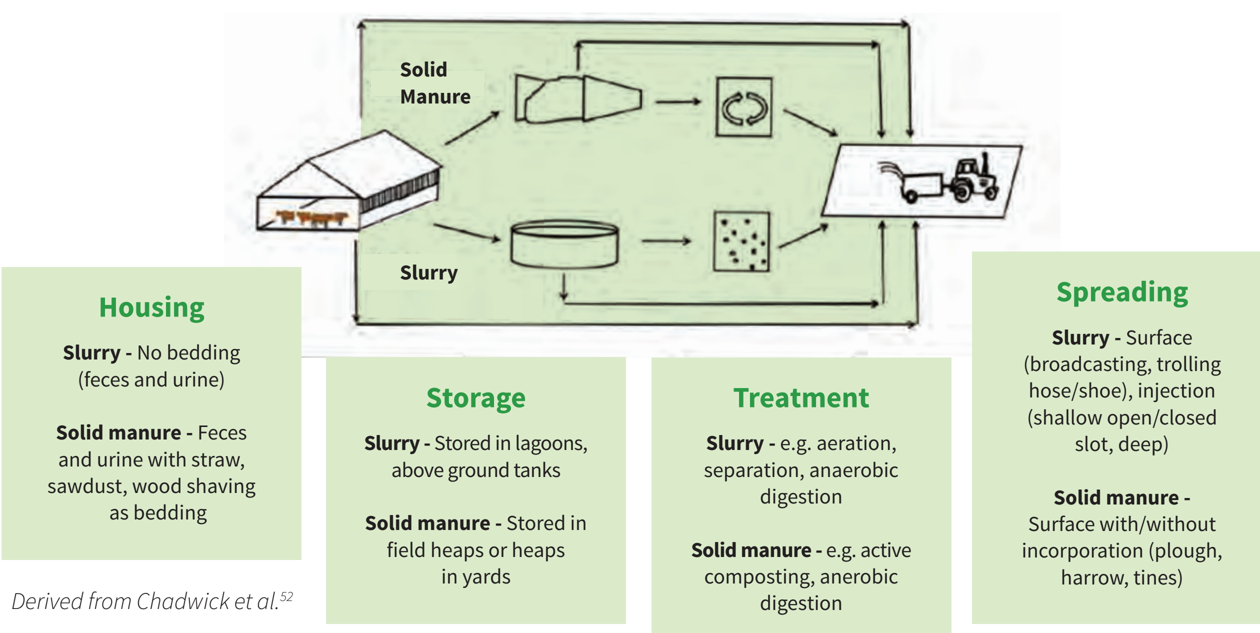
Enteric emissions are the single largest source of greenhouse gas emissions in the fluid milk chain. Ruminant livestock have four compartments in their stomachs: reticulum, rumen, omasum and abomasum. The structure of their digestive system allows for microbial fermentation of feed. This process breaks down fibrous plant material and helps ruminant livestock draw energy from their diets. At the same time, fermentation releases methane. The level of emissions depends on factors like the age and weight of the animal as well as the quantity, quality and composition of feed.[3, 27] Generally, lower feed quality or higher feed intake is associated with greater methane emissions.

Manure

Manure can be a source of methane and nitrous oxide emissions on dairy farms. Every step of a manure management system – collection, transport, storage, treatment and application – entails chemical and physical changes that can affect the production of methane and nitrous oxide (**Figure A1**). Additionally, fuel used to transport and spread manure impacts a farm's carbon dioxide footprint.

Methane emissions are determined by the total amount of manure produced and the rate of anaerobic decomposition of the manure. Total manure output is a factor of the number and size of animals present and the amount of feed consumed. The rate of anaerobic decomposition is influenced by the manure's composition, how it is stored and treated, as well as the storage time and

FIGURE A1. SCHEMATIC REPRESENTATION OF THE SOURCES OF NITROUS OXIDE AND METHANE FROM THE MANURE MANAGEMENT CONTINUUM



Derived from Chadwick et al.[52]

temperature. The cow's diet will impact the volatile solids content of the manure – which affects the amount of methane released during manure management.

Nitrous oxide emissions from manure depend on its nutrient composition, the type and duration of storage and treatment, the climate, and soil characteristics of the land receiving the manure. These emissions are categorized as either direct or indirect. Direct nitrous oxide emissions occur when the nitrogen in manure undergoes the processes of nitrification and denitrification.[28] Nitrification entails the conversion of ammonium or ammonia into nitrate, which is further oxidized to nitrite – both occurring as aerobic processes. Denitrification happens in anaerobic conditions when the nitrite and nitrate are subsequently reduced to N2, with the production of nitrous and nitric oxide. Nitrous oxide emissions from manure occur primarily in manure-amended soils.[28] However, emissions during storage and treatment are not insignificant. Indirect emissions occur through the volatilization of nitrogen as either ammonia or NOx and through the runoff and leaching of manure nitrogen.[51]

Energy Use

Greenhouse gases are emitted from the burning of fossil fuels for electricity, heat and transportation.[50] Each phase of milk production utilizes energy and emits greenhouse gases, either directly or indirectly.

Electricity use leads to indirect GHG contributions because power plants burn fossil fuels and release GHGs.

Direct contributions to greenhouse gas emissions on dairy farms stem from the direct burning of combustible fossil fuels, such as diesel, biodiesel, fuel-oil, propane, natural gas and gasoline. These fossil fuels are made up of hydrogen and carbon; when they are burned, the carbon combines with oxygen to create carbon dioxide. The amount of carbon dioxide produced depends on the carbon content of the fuel.

APPENDIX B

Supplemental Resources

Chapter 3: Feed

Ration Formulation

Rumen Function

From Feed to Milk: Understanding Rumen Function. PennState Extension. http://extension.psu.edu/animals/dairy/nutrition/nutrition-and-feeding/rumen-function/from-feed-to-milk-understanding-rumen-function

Subacute Ruminal Acidosis in Dairy Cattle. (2003). Oetzel, G.R.: http://www.wcds.ca/proc/2003/Manuscripts/Chapter%2024%20Oetzel%20.pdf

New Developments in TMR Particle Size Measurement. (2011). Kononoff, P.J. et al.: http://articles.extension.org/pages/26270/new-developments-in-tmr-particle-size-measurement

Carbohydrate Nutrition and Manure Scoring, Part II: Tools for Monitoring Rumen Function in Dairy Cattle. (2007). Hall, M.B.: https://conservancy.umn.edu/handle/11299/109852

Components of Ration Formulation

Refining the Net Energy System. (2010). Weiss, W.P.: http://www.wcds.ca/proc/2010/Manuscripts/p191-202Weiss.pdf

Balancing Diets for Amino Acids: Nutritional, Environmental and Financial Implications. (2010). Schwab, C.G.: http://www.tristatedairy.org/Proceedings%202010/Chuck%20Schwab%20paper.pdf

Challenges in Protein Nutrition for Dairy Cows. (2006). Doepel, L. et al.: http://www.wcds.ca/proc/2006/Manuscripts/Doepel.pdf

Feeding Low Crude Protein Rations to Dairy Cows – What Have We Learned? (2012). Chase, L. et al.: http://dairy.ifas.ufl.edu/rns/2012/3ChaseRNS2012.pdf

Relative Forage Quality. (2010). Undersander, D. et al.: http://fyi.uwex.edu/forage/files/2014/01/RFQ-FOF.pdf

Optimizing Starch Concentrations in Dairy Rations. (2005). Grant, R.: ftp://s173-183-201-52.ab.hsia.telus.net/Inetpub/wwwroot/DairyWeb/Resources/3SDNC2005/Grant.pdf

Mitigation of Enteric Methane Emissions through Improving Efficiency of Energy Utilization and Productivity in Lactating Dairy Cows. (2010). Yan, T. et al.: http://www.journalofdairyscience.org/article/S0022-0302(10)00267-5/abstract?cc=y=

Major Advances in Nutrition: Relevance to Sustainability of the Dairy Industry. (2006). VandeHaar, M.J. and N. St-Pierre: http://www.journalofdairyscience.org/article/S0022-0302(06)72196-8/abstract

Increasing Efficiency of Nutrient Use to Enhance Profit and Environmental Stewardship. (2011). VandeHaar, M.: http://dairy.ifas.ufl.edu/rns/2011/1vandehaar.pdf

Feeding Management

Stocking Density and Feed Barrier Design Affect the Feeding and Social Behavior of Dairy Cattle. (2006). Huzzey, J.M. et al.: http://www.journalofdairyscience.org/article/S0022-0302(06)72075-6/abstract

Associations Between Nondietary Factors and Dairy Herd Performance. (2008). Bach, A. et al.: http://www.journalofdairyscience.org/article/S0022-0302(08)71122-6/abstract

Forage Management

Forage Importance and Contributions to the Diet

Creating a System for Meeting the Fiber Requirements of Dairy Cows. (1997). Mertens, D.R.: http://www.journalofdairyscience.org/article/S0022-0302(97)76075-2/abstract

The Impact of Improving NDF Digestibility of Corn Silage on Dairy Cow Performance. (2011). Oba, M. et al.: http://dairy.ifas.ufl.edu/rns/2011/10Oba.pdf

Maximizing Forage Use by Dairy Cows. (2009). Mertens, D.R.: http://www.wcds.ca/proc/2009/Manuscripts/MaximizingForageUsage.pdf

Using Forages in Dairy Rations: Are We Moving Forward? (2009). Cherney, D. et al.: https://ecommons.cornell.edu/bitstream/handle/1813/36420/cnc09web.pdf?sequence=1#page=208

Grazing

Effect of Pregrazing Herbage Mass on Methane Production, Dry Matter Intake, and Milk Production of Grazing Dairy Cows during the Mid-Season period. (2010). Wims, C.M. et al.: http://www.journalofdairyscience.org/article/S0022-0302(10)00529-1/abstract

Invited Review: Production and Digestion of Supplemented Dairy Cows on Pasture. (2003). Bargo, F. et al.: http://www.journalofdairyscience.org/article/S0022-0302(03)73581-4/abstract

Nutritional Limitations to Increased Production on Pasture-Based Systems. (2003). Kolver, E.S.: https://www.cambridge.org/core/journals/proceedings-of-the-nutrition-society/article/div-classtitlenutritional-limitations-to-increased-production-on-pasture-based-systemsdiv/29D008AAAE84440AEE02D03212FBD424

Profitable Grazing-Based Dairy Systems. (2007). NRCS, USDA-Natural Resources Conservation Service: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044245.pdf

Pasture for Dairy Cattle: Challenges and Opportunities. (1997). Amaral-Phillips D.M. et al.: http://www2.ca.uky.edu/agcomm/pubs/asc/asc151/asc151.pdf

Forage Harvest and Processing

Evaluation of the Importance of the Digestibility of Neutral Detergent Fiber From Forage: Effects on Dry Matter Intake and Milk Yield of Dairy Cows. (1999). Oba, M. and M.S. Allen: http://www.journalofdairyscience.org/article/S0022-0302(99)75271-9/abstract

Invited Review: Role of Physically Effective Fiber and Estimation of Dietary Fiber Adequacy in High-Producing Dairy Cattle. (2012). Zebeli, Q. et al.: http://www.journalofdairyscience.org/article/S0022-0302(12)00063-X/abstract

Nutritive Value of Corn Silage as Affected by Maturity and Mechanical Processing: a Contemporary Review. (1999). Johnson, L. et al.: http://www.journalofdairyscience.org/article/S0022-0302(99)75540-2/abstract

Forage Storage

Silage Zone Manual. (2014). Mahanna B. et al.: https://ca.pioneer.com/east/media/1274/2014_silage_zone_manual-2.pdf

Concentrate Management

Carbohydrates

Effect of Molasses Supplementation on the Production of Lactating Dairy Cows Fed Diets Based on Alfalfa and Corn Silage. (2004). Broderick, G.A. et al.: http://www.journalofdairyscience.org/article/S0022-0302(04)73431-1/abstract

High Methanogenic Potential of Sucrose Compared with Starch at High Ruminal pH. (2009). Hindrichsen, I.K. et al.: http://onlinelibrary.wiley.com/doi/10.1111/j.1439-0396.2007.00779.x/full

Liquid Feeds and Sugars in Diets for Dairy Cattle. (2011). Firkins, J.L.: http://dairy.ifas.ufl.edu/rns/2011/7firkins.pdf

Ruminal Acidosis in Dairy Cows: Balancing Physically Effective Fiber with Starch Availability.

(2007). Beauchemin, K.A.: http://dairy.ifas.ufl.edu/rns/2007/Beauchemin.pdf

Working with Non-NDF Carbohydrates with Manure Evaluation and Environmental Considerations. (2002). Hall, M.B.: http://www.txanc.org/docs/Non-NDF-Carbohydrates.pdf

Proteins

The Principles of Balancing Diets for Amino Acids and Their Impact on N Utiliztaion Efficiency. (2012). Schwab C.G.: http://dairy.ifas.ufl.edu/rns/2012/1SchwabRNS2012.pdf

Lipids

Crushed Sunflower, Flax, or Canola Seeds in Lactating Dairy Cow Diets: Effects on Methane Production, Rumen Fermentation, and Milk Production. (2009). Beauchemin, K.A. et al.: http://www.journalofdairyscience.org/article/S0022-0302(09)70526-0/abstract

Net Energy for Lactation of Calcium Salts of Long-Chain Fatty Acids for Cows Fed Silage-Based Diets. (1991). Andres S.M. et al. Journal of Dairy Science: http://www.journalofdairyscience.org/article/S0022-0302(91)78437-3/abstract

Supplementation with Whole Cottonseed Causes Long-Term Reduction of Methane Emissions From Lactating Dairy Cows Offered a Forage and Cereal Grain Diet. (2010). Grainger, C. et al.: http://www.journalofdairyscience.org/article/S0022-0302(10)00265-1/abstract

The Value of Different Fat Supplements as Sources of Digestible Energy for Lactating Dairy Cows. (2011). Weiss, W. et al.: https://www.ncbi.nlm.nih.gov/pubmed/21257061

Invited Review: Enteric Methane in Dairy Cattle production: Quantifying the Opportunities and Impact of Reducing Emissions. (2014). Knapp, J.R. et al.: http://www.journalofdairyscience.org/article/S0022-0302(14)00289-6/abstract

Methane Output and Diet Digestibility in Response to Feeding Dairy Cows Crude Linseed, Extruded Linseed, or Linseed Oil. (2008). Martin, C. et al.: https://www.animalsciencepublications.org/publications/jas/abstracts/86/10/0862642

By-Product Feeds

Formulating dairy rations with non-forage fiber sources: Where to begin? (2011). Bradford, B. et al. (Page 101): https://ecommons.cornell.edu/bitstream/handle/1813/37187/All%20Proceedings.web.pdf?sequence=2

Utilization of By-Products from Human Food Production as Feedstuffs for Dairy Cattle and Relationship to Greenhouse Gas Emissions and Environmental Efficiency. (2012). Russomanno, K.L. et al.: https://ecommons.cornell.edu/bitstream/handle/1813/36469/cnc2012_VAmburgh.txt.pdf?sequence=1

Feed Additives

Long-Term Effects of Feeding Monensin on Methane Production in Lactating Dairy Cows. (2007). Odongo, N.E. et al.: http://www.journalofdairyscience.org/article/S0022-0302(07)71665-X/abstract

A Meta-Analysis of the Impact of Monensin in Lactating Dairy Cattle. Part 2, Production Effects. (2008). Duffield, T.F. et al.: http://www.journalofdairyscience.org/article/S0022-0302(08)71262-1/abstract

Chapter 4: Productivity

Lactating Cow Management

Mastitis Control

Decision Tree Analysis of Treatment Strategies for Mild and Moderate Cases of Clinical Mastitis Occurring in Early Lactation. (2011). Pnizon-Sanchez C. et al.: http://www.journalofdairyscience.org/article/S0022-0302(11)00156-1/fulltext

Invited Review: Mastitis in Dairy Heifers: Nature of The Disease, Potential Impact, Prevention, and Control. (2012). De Vliegher S. et al.: http://www.journalofdairyscience.org/article/S0022-0302(12)00062-8/fulltext

Current Status and Future Challenges in Mastitis Research. (2011). Hogeveen H. S. et al. In National Mastitis Council Annual Meeting Proceedings (pp. 36-48): http://library.wur.nl/WebQuery/wurpubs/fulltext/216755

The Environmental Impact of Mastitis: A Case Study of Dairy Herds. (2005). Hospido, A., and U. Sonesson: http://www.sciencedirect.com/science/article/pii/S0048969704007119

Cow Comfort

Effect of Heat Stress During the Dry Period on Mammary Gland Development. (2011). Tao S. et al.: http://www.journalofdairyscience.org/article/S0022-0302(11)00631-X/fulltext

Effect of Lameness on Culling in Dairy Cows. (2004). Booth C. J. et al.: http://www.journalofdairyscience.org/article/S0022-0302(04)73554-7/fulltext

Economic Losses from Heat Stress by US Livestock Industries. (2003). St-Pierre N. R. et al.: http://www.journalofdairyscience.org/article/S0022-0302(03)74040-5/fulltext

Herd-level Risk Factors for Lameness in Freestall Farms in the Northeastern United States and California. (2012). Chapinal N. et al.: http://www.journalofdairyscience.org/article/S0022-0302(12)00826-0/fulltext

Invited Review: The Welfare of Dairy Cattle — Key Concepts and the Role of Science. (2009). von Keyserlingk M. A. G. et al.: http://www.journalofdairyscience.org/article/S0022-0302(09)70735-0/fulltext

The Effect of Lameness on Milk Production in Dairy Cows. (2001). Warnick L. D. et al.: http://www.journalofdairyscience.org/article/S0022-0302(01)74642-5/pdf

The Feeding Behavior of Dairy Cows: Considerations to Improve Cow Welfare and Productivity. (2010). Botheras, N.: http://articles.extension.org/pages/25472/the-feeding-behavior-of-dairy-cows:considerations-to-improve-cow-welfare-and-productivity

Quantifying Heat Stress and its Impact on Metabolism and Performance. (2012). Collier R. J. et al.: http://dairy.ifas.ufl.edu/rns/2012/6CollierRNS2012a.pdf

Effects of Cow Comfort on Milk Quality, Productivity and Behavior. (2009). Krawczel, P., and R. Grant: http://articles.extension.org/pages/70107/effects-of-cow-comfort-on-milk-quality-productivity-and-behavior

Reproduction

Invited Review: Milk Production and Reproductive Performance: Modern Interdisciplinary Insights into an Enduring Axiom. (2012). Bello N. M. et al.: http://www.journalofdairyscience.org/article/S0022-0302(12)00484-5/fulltext

Invited Review: Treatment of Cows with an Extended Postpartum Anestrous Interval. (2003). Rhodes F. M. et al.: http://www.journalofdairyscience.org/article/S0022-0302(03)73775-8/fulltext

The Effect of Subclinical Ketosis in Early Lactation on Reproductive Performance of Postpartum Dairy Cows. (2007). Walsh R. B. et al.: http://www.journalofdairyscience.org/article/S0022-0302(07)70090-5/fulltext

The Environmental Impact of Fertility in Dairy Cows: A Modelling Approach to Predict Methane and Ammonia Emissions. (2004). Garnsworthy, P.: http://www.animalfeedscience.com/article/S0377-8401(03)00304-3/fulltext

Feeding n-6 and n-3 Fatty Acids to Dairy Cows: Effects on Immunity, Fertility and Lactation. (2009). Silvestre F. T. et al.: http://dairy.ifas.ufl.edu/rns/2009/Silvestre.pdf

Management Strategies to Improve Fertility in Lactating Dairy Cows .(1999). Fricke, P., and R. Sterry: http://www.wcds.ca/proc/1999/Manuscripts/Chapt%2009%20-%20Fricke.pdf

Nutrition and Reproduction Efficiency: Transition Period Management, Energy Status, and Amino Acid Supplementation Alter Reproduction in Lactating Dairy Cows. (2015). Wiltbank, M. et al.: http://dairy.ifas.ufl.edu/rns/2015/04.%20Wiltbank.pdf

Culling

Effect of Lameness on Culling in Dairy Cows. (2004). Booth C. J. et al.: http://www.journalofdairyscience.org/article/S0022-0302(04)73554-7/fulltext

Invited Review: Culling: Nomenclature, Definitions, and Recommendations. (2006). Fetrow J. et al.: http://www.journalofdairyscience.org/article/S0022-0302(06)72257-3/fulltext

Cow Culling Decisions: Costs or Economic Opportunity? (2007). Dhuyvetter K. C. et al.: http://www.wdmc.org/2007/dhuyvetter.pdf

Mortality, Culling by Sixty Days in Milk, and Production Profiles in High-And Low- Survival Pennsylvania Herds. (2008). Dechow, C., and R. Goodling: http://www.journalofdairyscience.org/article/S0022-0302(08)70930-5/fulltext

Successful Control of Johne's Disease in Nine Dairy Herds: Results of a Six-Year Field Trial. (2010). Collins M. T. et al.: http://www.journalofdairyscience.org/article/S0022-0302(10)00137-2/fulltext

Use of Technology for Cow Management

Invited Review: Sensors to Support Health Management on Dairy Farms. (2013). Rutten C. J. et al.: http://www.journalofdairyscience.org/article/S0022-0302(13)00140-9/fulltext

Calf and Heifer Management

Colostrum

Passive Immunity In Newborn Calves. (2002). Quigley, J.: http://www.wcds.ca/proc/2002/Manuscripts/Chapter%2023%20Quigley.pdf

The Role of Oral Immunoglobulin in Systemic and Intestinal Immunity of Neonatal Calves. Quigley, J.: http://www.extension.umn.edu/agriculture/dairy/beef/the-role-of-oral-immunoglobulins.pdf

Respiratory Disease Prevention

Calf Respiratory Disease and Pen Microenvironments in Naturally Ventilated Calf Barns in Winter. (2006). Lago, A. et al.: http://www.journalofdairyscience.org/article/S0022-0302(06)72445-6/fulltext

Ventilation Retrofits of Calf Barns. (2011). Nordlund, K. V.: http://livestocktrail.illinois.edu/uploads/dairynet/papers/17%20Nordlund.pdf

Calf and Heifer Nutrition

A Prospective Study of Calf Factors Affecting First-Lactation and Lifetime Milk Production and Age of Cows when Removed from the Herd. (2011). Heinrichs, A. J. et al.: http://www.journalofdairyscience.org/article/S0022-0302(10)00700-9/fulltext

Effect of Different Forage Sources on Performance and Feeding Behavior of Holstein Calves. (2012). Castells, L. et al.: www.journalofdairyscience.org/article/S0022-0302(12)00031-8/abstract

Preweaning Milk Replacer Intake and Effects on Long-Term Productivity of Dairy Calves. (2012). Soberon, F. et al.: http://www.journalofdairyscience.org/article/S0022-0302(12)00031-8/abstract

Review of Recent Research Investigating Effects of Calf Feeding Program on First Lactation Performance. (2011). Heinrichs, A. J. et al.: http://extension.psu.edu/animals/dairy/nutrition/calves/feeding/das-11-172

Effect of Nutrition and Management of Dairy Heifers on Resultant Cow Longevity. (2005). Chester-Jones, H. et al.: http://www.extension.umn.edu/agriculture/dairy/calves-and-heifers/effect-of-nutrition-and-management-on-longevity.pdf

Feeding Strategies for Post-Weaned Dairy Heifers, 2 to 6 Months of Age. (2011). Broadwater, N. et al.: http://articles.extension.org/pages/11779/feeding-strategies-for-post-weaned-dairy-heifers-2-to-6-months-of-age

Heifer Reproduction

Strategies for Optimizing Reproductive Management of Dairy Heifers. (2004). Fricke, P. M.: http://www.wcds.ca/proc/2004/Manuscripts/163Fricke.pdf

Transition Cow Nutrition and Management

Pre-Partum

Back to a Traditional Approach: Re-Evaluating the Use of a Single Dry Period Diet. (2011). Drackley, J. K.: http://www.wcds.ca/proc/2011/Manuscripts/Drackley.pdf

Nutritional Management of Transition Dairy Cows: Strategies to Optimize Metabolic Health. (2004). Overton, T. R. et al.: http://www.journalofdairyscience.org/article/S0022-0302(04)70066-1/fulltext

Optimizing Intake in Dry and Prefresh Cows. (2011). Overton, T. R.: http://www.wdmc.org/2011/Optimizing%20Intake%20in%20Dry%20and%20Prefresh%20Cows%20pg%20195-206.pdf

Revisiting Negative Dietary Cation-Anion Difference Balancing for Prepartum Cows and its Impact on Hypocalcaemia and Performance. (2011). Block, E.: http://dairy.ifas.ufl.edu/rns/2011/5block.pdf

Post-Partum

Early Lactation Diets for Dairy Cattle–Focus on Starch. (2011). Dann, H. M. et al.: https://ecommons.cornell.edu/bitstream/handle/1813/37187/All%20Proceedings.web.pdf?sequence=2

Major Advances in our Understanding of Nutritional Influences on Bovine Health. (2006). Goff, J. P.: http://www.journalofdairyscience.org/article/S0022-0302(06)72197-X/fulltext

The Effect of Subclinical Ketosis in Early Lactation on Reproductive Performance of Postpartum Dairy Cows. (2007). Walsh, R. B. et al.: http://www.journalofdairyscience.org/article/S0022-0302(07)70090-5/fulltext

Meeting the Energy and Protein Challenges of Post-Fresh Transition Cows. (2012). Grummer, R. R. et al.: http://www.txanc.org/docs/4_Grummer_Meeting-the-Energy-and-Protein-Challenges_2012-MSRNC_FINAL.pdf

Metabolic Implications for Transition Cow Immunity. (2011). Waldron, M. R.: http://livestocktrail.illinois.edu/uploads/dairynet/papers/3%20Waldron.pdf

Transition Cow Comfort

Effect of Heat Stress During the Dry Period on Mammary Gland Development. (2011). Tao, S. et al.: http://www.journalofdairyscience.org/article/S0022-0302(11)00631-X/fulltext

Transition Cow Research – What Makes Sense Today? (2010). Block, E.: http://www.highplainsdairy.org/2010/18_Block_Transition%20CowResearch_FINAL.pdf

Creating the Physical Environment for Transition Cow Success. (2010). Nordlund, K.: http://extension.psu.edu/animals/dairy/courses/dairy-cattle-nutrition-workshop/previous-workshops/2010/materials-from-main-sessions/penn-state-nutrition-workshop/creating-the-physical-environment-for-transition-cow-success

Reducing Between-Cow Variation in Nutrient Intake Through Feed Bunk Management. (2011). DeVries, T.: http://livestocktrail.illinois.edu/uploads/dairynet/papers/16%20DeVries.pdf

Chapter 5: Manure

General

Technical options for the mitigation of direct CH4 and nitrous oxide emissions from livestock: a review. (2013) Gerber, P. J., et al.: https://www.cambridge.org/core/services/aop-cambridge-core/content/view/S1751731113000876

SPECIAL TOPICS – mitigation of methane and nitrous oxide emissions from animal operations: II. A review of manure management mitigation options. (2013). Montes, Felipe, et al.: https://dl.sciencesocieties.org/publications/jas/abstracts/91/11/5070

Mitigation of GHG emissions in livestock production – A review of technical options for non-CO2 emissions. (2013). Hristov, A. N., et al.; Gerber, P.J, Henderson, B. and P.S. Makkar (Eds.): http://www.fao.org/3/a-i3288e.pdf

CH4, nitrous oxide and ammonia emissions during storage and after application of dairy cattle slurry and influence of slurry treatment. (2006). Amon, Barbara, et al.: http://www.sciencedirect.com/science/article/pii/S0167880905004135

Manure management: implications for GHG emissions. (2011). Chadwick, Dave, et al.: http://www.sciencedirect.com/science/article/pii/S0377840111001556

Evaluation of Dairy Manure Management Practices for GHG Emissions Mitigation in California – Final Technical Report to the State of California Air Resources Board, Contract #14-456. (2016). Kaffka, et al.: http://biomass.ucdavis.edu/wp-content/uploads/2016/06/ARB-Report-Final-Draft-Transmittal-Feb-26-2016.pdf

Solid-Liquid Separation

Effect of cattle slurry separation on GHG and ammonia emissions during storage. (2008) Fangueiro, David, et al.: https://dl.sciencesocieties.org/publications/jeq/abstracts/37/6/2322

Composting

GHG balance for composting operations. (2008) Brown, et al.: https://dl.sciencesocieties.org/publications/jeq/abstracts/37/4/1396

Environmental impacts of farm-scale composting practices. (2004) Peigné, J., and P. Girardin.: https://link.springer.com/article/10.1023%2FB%3AWATE.0000019932.04020.b6?LI=true

Aeration

Performance characteristics of three aeration systems in the swine manure composting. (2004). Zhu, Nengwu, et al.: https://www.ncbi.nlm.nih.gov/pubmed/15288275

Covers

Crusting of stored dairy slurry to abate ammonia emissions. (2005). Misselbrook, T. H., et al.: https://dl.sciencesocieties.org/publications/jeq/abstracts/34/2/0411

Permeable synthetic covers for controlling emissions from liquid dairy manure. (2010). VanderZaag, A. C., et al.: https://dalspace.library.dal.ca/bitstream/handle/10222/38803/Appl.%20Environ.%20Microbiol.-2009-Saleh-Lakha-3903-11.pdf?sequence=1&isAllowed=y

Other Technologies

How does the application of different nitrification inhibitors affect nitrous oxide emissions and nitrate leaching from cow urine in grazed pastures? (2012) Di, H. J., and K. C. Cameron: http://onlinelibrary.wiley.com/doi/10.1111/j.1475-2743.2011.00373.x/full

Effects of cattle slurry acidification on ammonia and CH4 evolution during storage. (2012). Petersen, S. O., A. J. Andersen, and J. Eriksen.: https://dl.sciencesocieties.org/publications/jeq/abstracts/41/1/88

Manure Storage and Handling – Acidification. (2014). Andersen, A., et al.: http://www.agronext.iastate.edu/ampat/storagehandling/acidification/homepage.html

Ammonia volatilization losses from surface-applied urea with urease and nitrification inhibitors. (2012). Soares, J. R., et. al.: http://www.sciencedirect.com/science/article/pii/S0038071712001587

Nitrate leaching losses and pasture yields as affected by different rates of animal urine nitrogen returns and application of a nitrification inhibitor—a lysimeter study. (2007). Di, H. J. and K. C. Cameron.: https://link.springer.com/article/10.1007/s10705-007-9115-5

A lysimeter study of nitrate leaching from grazed grassland as affected by a nitrification inhibitor, dicyandiamide, and relationships with ammonia oxidizing bacteria and archaea. (2009). Di, H. J., et al.: http://onlinelibrary.wiley.com/doi/10.1111/j.1475-2743.2009.00241.x/full

The mobility of nitrification inhibitors under simulated ruminant urine deposition and rainfall: a comparison between DCD and DMPP. (2016). Marsden, K. A., et al.: https://link.springer.com/article/10.1007/s00374-016-1092-x

WORKS CITED

1. The environmental impact of dairy production: 1944 compared with 2007. (2009). Capper et al.: https://www.ncbi.nlm.nih.gov/pubmed/19286817

2. Greenhouse Gas Emissions from the Dairy Sector, a Life Cycle Assessment. FAO Food and Agriculture Organization of the United Nations. (2010). Gerber, P., et al.: http://www.fao.org/docrep/012/k7930e/k7930e00.pdf

3. Greenhouse gas emissions from milk production and consumption in the United States: A cradle-to-grave life cycle assessment circa 2008. (2013). Thoma, Greg, et al.: http://www.sciencedirect.com/science/article/pii/S0958694612001975

4. Regional analysis of greenhouse gas emissions from USA dairy farms: A cradle to farm-gate assessment of the American dairy industry circa 2008. (2013) Thoma, Greg, et al.: S29-S40. http://www.sciencedirect.com/science/article/pii/S0958694612002051

5. Feed Nutrients. University of Minnesota.: http://www.extension.umn.edu/agriculture/dairy/feed-and-nutrition/feeding-the-dairy-herd/feed-nutrients.html

6. Animal Care Reference Manual. (2016). National Dairy FARM Program. www.nationaldairyfarm.com/resource-library

7. Mitigation of GHG emissions in livestock production – A review of technical options for non-CO2 emissions. (2013). Hristov, A. N., et al.; Gerber, P.J, Henderson, B. and P.S. Makkar (Eds.): http://www.fao.org/3/a-i3288e.pdf

8. Decision tree analysis of treatment strategies for mild and moderate cases of clinical mastitis occurring in early lactation. (2011). Pinzón-Sánchez, C., V. E. Cabrera, and P. L. Ruegg.: http://www.sciencedirect.com/science/article/pii/S0022030211001561

9. Dairy 2014, Milk Quality, Milking Procedures, and Mastitis in the United States, 2014 USDA–APHIS–VS–CEAH–NAHMS. (2016). USDA: http://www.aphis.usda.gov/animal_health/nahms/dairy/downloads/dairy14/Dairy14_dr_Mastitis.pdf

10. Bovine Mastitis and Milking Management. (2012). Schroeder, J. W.: https://www.ag.ndsu.edu/publications/landing-pages/livestock/mastitis-control-programs-bovine-mastitis-and-milking-management-as1129

11. Considerations and Resources on Feed and Animal Management – Cow of the Future Report to Improve Business Value and Reduce Greenhouse Gas Emissions. (2014). Innovation Center for U.S. Dairy.: https://www.ag.ndsu.edu/publications/landing-pages/livestock/mastitis-control-programs-bovine-mastitis-and-milking-management-as1129

12. Dairy Cattle Mastitis and Milking Management. (2015). Erskine, R. Ed. : http://articles.extension.org/pages/15600/dairy-cattle-mastitis-and-milking-management

13. Herd management and social variables associated with bulk tank somatic cell count in dairy herds in the eastern United States. (2015). Schewe, R. L., et al.: http://www.sciencedirect.com/science/article/pii/S0022030215005937

14. Cultural lag: a new challenge for mastitis control on dairy farms in the United States. (2015). Erskine, R. J., R. O. Martinez, and G. A. Contreras:

http://www.sciencedirect.com/science/article/pii/S0022030215006463

15. The effect of reward duration on demand functions for rest in dairy heifers and lying requirements as measured by demand functions. (2005). Jensen, M. B., Pedersen, L.J., and Munksgaard, L.: http://www.sciencedirect.com/science/article/pii/S0168159104001790

16. Quantifying behavioural priorities-effects of time constraints on behaviour of dairy cows, Bos taurus. (2005). Munksgaard, L., Jensen, M.B., Pedersen, L.J., Hansen, S.W., and Matthews, L.: http://www.sciencedirect.com/science/article/pii/S0168159104002795

17. Taking advantage of natural behavior improves dairy cow performance. (2007). Grant, R.: http://articles.extension.org/pages/11129/taking-advantage-of-natural-behavior-improves-dairy-cow-performance

18. Cow comfort in tie-stalls: Increased depth of shavings or straw bedding increases lying time. (2009). Tucker, C. B., et al.: https://www.ncbi.nlm.nih.gov/pubmed/19448001

19. Reproduction and Genetics. PennState Extension.: http://extension.psu.edu/animals/dairy/health/reproduction

20. Factors associated with morbidity, mortality, and growth of dairy heifer calves up to 3 months of age. (2014). Windeyer, M. C., et al.: https://www.ncbi.nlm.nih.gov/pubmed/24269039

21. Dairy 2007, Heifer Calf Health and Management Practices on U.S. Dairy Operations, 2007 USDA:APHIS:VS, CEAH. (2010). USDA.: http://www.aphis.usda.gov/animal_health/nahms/dairy/downloads/dairy07/Dairy07_ir_CalfHealth.pdf

22. Invited review: Effects of milk ration on solid feed intake, weaning and performance in dairy heifers. (2011). Khan, M., et al.: https://www.ncbi.nlm.nih.gov/pubmed/21338773

23. Behavioural indicators of hunger in dairy calves. (2008). de Paula Vieira, A., et al.: http://www.sciencedirect.com/science/article/pii/S0168159107000780

24. Preweaning milk replacer intake and effects on long-term productivity of dairy calves. (2012). Soberon, F., et al.: http://www.sciencedirect.com/science/article/pii/S0022030212000318

25. Lying behavior and postpartum health status in grazing dairy cows. (2014). P. Sepúlveda-Varas, et al.: https://www.ncbi.nlm.nih.gov/pubmed/25151885

26. New York dairy manure management greenhouse gas emissions and mitigation costs (1992–2022). (2016) Wightman, J. L., and P. B. Woodbury.: https://www.ncbi.nlm.nih.gov/pubmed/26828182

27. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme. (2006). Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds).: http://www.ipcc-nggip.iges.or.jp/public/2006gl/

28. SPECIAL TOPICS – mitigation of methane and nitrous oxide emissions from animal operations: II. A review of manure management mitigation options. (2013). Montes, Felipe, et al.: https://dl.sciencesocieties.org/publications/jas/abstracts/91/11/5070

29. Technical options for the mitigation of direct CH4 and nitrous oxide emissions from livestock: a review. (2013) Gerber, P. J., et al.: https://www.cambridge.org/core/services/aop-cambridge-core/content/view/S1751731113000876

30. Evaluation of Dairy Manure Management Practices for GHG Emissions Mitigation in California – Final Technical Report to the State of California Air Resources Board, Contract #14-456. (2016). Kaffka, et al.: http://biomass.ucdavis.edu/wp-content/uploads/2016/06/ARB-Report-Final-Draft-Transmittal-Feb-26-2016.pdf

31. An Assessment of Technologies for Management and Treatment of Dairy Manure in California's

San Joaquin Valley. (2005). San Joaquin Valley Dairy Manure Technology Feasibility Assessment Panel.: https://www.arb.ca.gov/ag/caf/dairypnl/dmtfaprprt.pdf

32. Methane, nitrous oxide and ammonia emissions during storage and after application of dairy cattle slurry and influence of slurry treatment. (2006). Amon, B., et al.: http://www.sciencedirect.com/science/article/pii/S0167880905004135

33. Greenhouse gas balance for composting operations. (2008). Brown, et. al.: https://dl.sciencesocieties.org/publications/jeq/abstracts/37/4/1396

34. Greenhouse gas from organic waste composting: emissions and measurement. 2015. Sánchez, Antoni, et al. https://link.springer.com/chapter/10.1007%2F978-3-319-11906-9_2

35. Manure Composting for Livestock & Poultry Production. (2012). Bass, T., et al.: http://msuextension.org/publications/AgandNaturalResources/MT201206AG.pdf

36. Effects of anaerobic digestion and aerobic treatment on the reduction of gaseous emissions from dairy manure storages. (2008). Zhang, R., et al.: https://ijabe.org/index.php/ijabe/article/view/47

37. Manure Storage & Handling—Aeration Overview. (2014). Andersen, Daniel S., et al.: http://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=1206&context=extension_ag_pubs

38. Strategies for Mitigating Greenhouse Gas Emissions from Long-Term Dairy Manure Storage in New York State. (In Press). Wright, P. and C. Gooch: http://www.manuremanagement.cornell.edu/

39. Covers for Manure Storage Units. (2004). Nicolai, R. et al.: http://openprairie.sdstate.edu/cgi/viewcontent.cgi?article=1106&context=extension_fact

40. Impermeable Covers for Odor and Air Pollution Mitigation in Animal Agriculture: A Technical Guide. (2011). Stenglein, R. M., et al.: https://articles.extension.org/sites/default/files/Impermeable%20covers%20FINAL.pdf

41. How does anaerobic digestion work? Environmental Protection Agency, AgStar.: https://www.epa.gov/agstar/learn-about-biogas-recovery#adwork

42. Livestock Anaerobic Digester Database. (2016). Environmental Protection Agency, AgStar.: https://www.epa.gov/agstar/livestock-anaerobic-digester-database

43. Environmental Protection Agency, AgStar. https://www.epa.gov/agstar

44. How does the application of different nitrification inhibitors affect nitrous oxide emissions and nitrate leaching from cow urine in grazed pastures? (2012). Di, H. J., and K. C. Cameron: http://onlinelibrary.wiley.com/doi/10.1111/j.1475-2743.2011.00373.x/full

45. Repeated annual use of the nitrification inhibitor dicyandiamide (DCD) does not alter its effectiveness in reducing N2O emissions from cow urine. (2011). De Klein, C. A. M., et al.: http://www.sciencedirect.com/science/article/pii/S0377840111001957

46. Effects of cattle slurry acidification on ammonia and CH4 evolution during storage. (2012). Petersen, S. O., A. J. Andersen, and J. Eriksen.: https://dl.sciencesocieties.org/publications/jeq/abstracts/41/1/88

47. Dairy Farm Energy Audit Summary. (2003). Ludington, D. and E. Johnson (DLtech, Inc.). New York State Energy Research and Development Authority.: https://www.nyserda.ny.gov/-/media/Files/Publications/Research/Energy-Audit-Reports/dairy-farm-energy.pdf

48. Dairy Farm Energy Efficiency. (2010). Pressman, A.. ATTRA – National Sustainable Agriculture Information Service.: https://attra.ncat.org/attra-pub/summaries/summary.php?pub=198

49. Best Practices Guide: Energy Savings Opportunities for Dairy. (2014). EnSave: http://www.usdairy.com/~/media/USD/Public/BestPracticesGuideEnergySavingsOpportunitiesforDairy.pdf

50. Overview of Greenhouse Gases. US Environmental Protection Agency: https://www.epa.gov/ghgemissions/overview-greenhouse-gases

51. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2013. (2015). US Environmental Protection Agency: https://www.epa.gov/sites/production/files/2016-03/documents/us-ghg-inventory-2015-main-text.pdf

52. Manure management: implications for greenhouse gas emissions. (2011). Chadwick, Dave, et al.: http://www.sciencedirect.com/science/article/pii/S0377840111001556

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