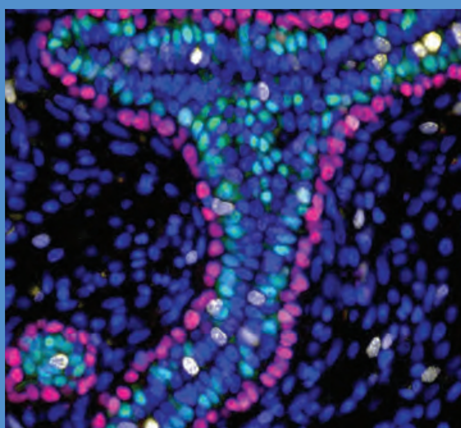
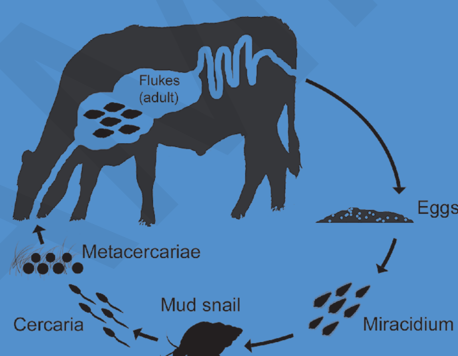
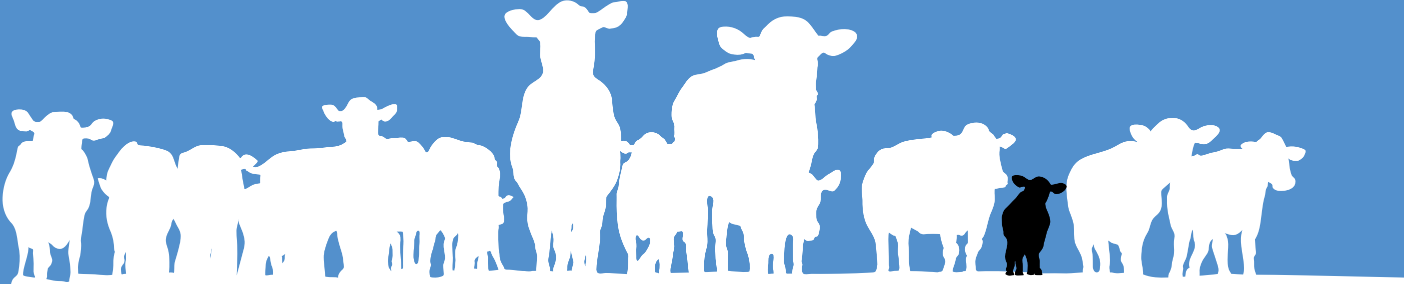
Large Dairy Herd Management

Third edition





Edited by David K. Beede



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Cover images

Top left: *Example of immunofluorescent staining in prepubertal bovine mammary tissue. The cross section of the developing duct shows the expression of p63 (red), which indicates myoepithelial nuclei, estrogen receptor (green), about 50% of the epithelial cells, and Ki67 (yellow), a marker for cell proliferation; DAPI staining (blue) is a general DNA stain that labels all cell nuclei.*
[Chapter 9-59: Mammary development in calves and heifers; Figure 4D]

Top center: *The daily trail to (and from) milking.*
[Chapter 10-67: Mastitis control in pasture and seasonal systems; Figure 3]

Top right: *Cow brushes are clearly a valued resource as they are used voluntarily by cows and are required by some voluntary assurance programs. Photo credit: DeLaval, Tumba, Sweden.*
[Chapter 11-71: Assuring and verifying dairy cattle welfare; Figure 2]

Bottom left: *The bedding material commonly recommended for controlling environmental mastitis is washed sand.*
[Chapter 10-65: Practical approaches to environmental mastitis control; Figure 3]

Bottom center: *Life cycle of a liver fluke.*
[Chapter 12-81: Parasite control in large dairy herds; Figure 2]

Bottom right: *Studies have shown that positive handling is correlated with cows having low fear responses to people and higher milk production. Some animal welfare standards now include a standardized test of avoidance distance to people as a way of screening for appropriate handling and good human–animal relationships on farms. Photo credit: University of British Columbia (UBC) Animal Welfare Program.*
[Chapter 11-71: Assuring and verifying dairy cattle welfare; Figure 3]

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Preface to the first edition (1978)

With increased specialization in most of the nation's Grade A dairies, the daily mechanics of feeding, breeding, milking, and health care of large groups of cows and the planning for labor, facilities, and capital to handle them have made management of large dairies as complex as management of large corporations. Indeed, specialization and size have developed because some efficiencies of scale exist but, as a result, dairymen managing hundreds of cows encounter problems never dreamed of by the manager of the family dairy of years past. It is to this level of dairy management (dairies with more than 200 milking cows) that this book is directed.

Florida has had a long history of large dairies. On January 1, 1978, Florida had 401 dairies averaging 491 cows per dairy with approximately 60 dairies of over 1,000 cows. Almost all other states have some dairies that are in this large-herd category and many more growing in that direction. Thus, across the nation dairy scientists and management experts have been spending proportionately more of their time in trying to advance the technology necessary to meet these management needs. This symposium was conceived to attempt to integrate the recommendations of specialists throughout the U.S. into a much more complete coverage of topics important to large dairy herd management than previously had been accomplished.

Therefore, the dairy production faculty of the Dairy Science Department of the University of Florida organized a symposium from which the proceedings could be published in book form. This book is the result of that symposium which was held January 18-21, 1976, in Gainesville, Florida. Revision and updating of the original manuscripts continued until the final setting of type, so that the information contained herein would be as current as possible.

More than 70 speakers participated in the symposium, making it truly a national meeting involving people who are well recognized experts in their fields. These speakers were asked to direct their comments toward applied objectives. Several basic science sections have been added to the book to supply the reader with background, but the goal was to provide in one text the best possible information that could be applicable to the management of large dairies. Thus, the material should be useful to teachers, extension educators, agricultural instructors, dairy herd owners and managers, and industry leaders associated with the business side of dairying.

The dairy production faculty of the Dairy Science Department of the University of Florida wishes to express appreciation to the speakers at that symposium (the authors of various chapters in this text) for their willingness to participate and for their outstanding contributions.

Several private corporations and dairy cooperatives served as contributing sponsors. They were: The Upjohn Company, Kalamazoo, Michigan; Independent Dairy Farmers Association, Ft. Lauderdale, Florida; Upper Florida Milk Producers Association, Jacksonville, Florida; Tampa Independent Dairy Farmers Association, Tampa, Florida; American Breeders Service, De Forest, Wisconsin; and Badger Northland Inc., Kaukauna, Wisconsin. Additional contributors include: Oswalt Division, Butler Mfg. Company, Garden City, Kansas; Moorman Manufacturing Company, Quincy, Illinois; Herd Reproduction Services Inc., Athens, Georgia; and NOBA Inc., Tiffin, Ohio.

Preface to the first revised edition (1992)

The editors, faculty of the Dairy Science Department, and other University of Florida authors and contributors wish to dedicate this book to the Florida Dairy Farmers whose cooperative interaction with the University of Florida programs and visionary investment through their Dairy Checkoff Programs in research and education at the University of Florida have helped faculty focus their programs on large dairy herd management. Through their marketing cooperatives, Florida dairy farmers established the Dairy Checkoff, a contribution to the University of Florida Foundation of $.01/cwt of milk sold from the farm, which is held in escrow in a University of Florida Foundation account until a dairy farmer grant review committee reviews research and education proposals and directs the funds to approved grant requests. Contributions to the Dairy Checkoff began in the funds to approved grant requests. Contributions to the Dairy Checkoff began in 1988 and have amounted to approximately $250,000 per year. These funds in partnership with base support given to faculty in dairy science, veterinary medicine, economics, agronomy, soil science, agricultural engineering, and other fields have given dairy farmers an added voice in priority setting for research programs and have given many faculty the opportunity to supplement funding of research at times when tax-related funding was decreasing. We thank them for that support and for their input into priority setting for research which the process has contributed.

This book resulted from a symposium February 19 to 21, 1992 in Gainesville, FL, which was designed to produce the book. A previous and similar venture in 1976 produced a book which has been helpful to dairy management professionals for many years. Heartfelt thanks go to the authors of the 85 chapters who accepted invitations to participate in the symposium and contribute their chapters to a book which we think is somewhat unique in its application of science and management to dairy farming.

Our thanks also go to the Management Services arm of the American Dairy Science Association who have handled printing and distribution of the book.

In many chapters of this book, it was helpful to coverage of the topics to use some references to commercial products in addition to generic compounds and products. Mention of a trade name, proprietary product, or special equipment or warranty by any of the authors does not imply its approval to the exclusion of other products that may be suitable.

Preface to the third edition (2017)

Overview

In 1976, the faculty of the Dairy Science Department at the University of Florida (UF) organized the first Large Dairy Herd Management (LDHM) symposium in Gainesville. It addressed the increasing complexity of management of many of the state's dairies as they grew. Florida had a long history of having a greater proportion of large herds than most US states, characterized by management of large groups of cows confined in open lots or in shade structures for heat stress abatement and fed totally mixed rations of harvested and stored forages and commodities. For large herds, increasing specialization, capturing some efficiencies of scale, managing more people and capital, and selecting effective new technologies became as important as managing the cows. The symposium and resulting book (*Large Dairy Herd Management*, 1st ed., 1978) were aimed at managing large herds, defined at the time as those with more than 200 milking cows. More than 70 authors contributed 85 chapters in 9 sections to provide, in one volume, the best possible information applicable specifically to large herds.

Fourteen years later, the UF dairy faculty launched the second symposium designed to capture the latest information and produce the second edition (*Large Dairy Herd Management*, 1st rev. ed., 1992), with more than 100 authors contributing 85 chapters in 9 book sections. The content was extensively updated because of the increasing importance of large herds well beyond Florida. The second edition also benefited greatly from new knowledge and practices resulting from the Florida Dairy Checkoff program that provided base support for many research and education projects of UF faculty, guided in partnership and collaboration with Florida dairy farmers during the 1980s and beyond. Professors Jack Van Horn and Charlie Wilcox edited the first two editions of *Large Dairy Herd Management*, and the American Dairy Science Association (ADSA) published and marketed the second edition.

A key mission of the ADSA Foundation is education. Now, nearly 40 years since the first edition, the Foundation identified the need for a major update and launched the formidable project to produce the third edition, beginning with an international conference in May 2016 as the tried-and-true approach to catalyze development and collection of the content, this time with production of this electronic book (e-book) format. The far-reaching changes and innovation in practices and technologies that have developed for and in large dairy herd management in the last 40 years are prodigious. This volume captures much of this change and represents the 2-year efforts of 171 authors, coordinated and cajoled by 18 section editors to present the most pertinent content in 15 topic sections totaling 97 chapters. Additionally, 73 external reviewers and many internal reviewers (from the author corps) reviewed and advised on chapters of others within their section or in other sections of the e-book.

Purpose

The Foundation's primary motivation for developing and publishing this third edition was to gather in one place the most up-to-date, comprehensive, science-based collection of management information for large dairy herds. Because today's dairy markets are truly global for producers in developed countries, this volume has a global scope, especially as it relates to on-farm practices that are or will be essential for participation in world markets. These requirements continue to be driven by social, consumer, and market demands. This new edition has broadened scope, with sections addressing dairy sustainability, especially as it relates to environmental challenges; characterization of some social and economic challenges and opportunities for dairying in a more global context; a deliberate emphasis to embrace a systems-based approach to management in many chapters; comprehensive coverage of the differences and nuances of herd management in different types of large herd systems—grazing, organic, automatic milking, as well as confined housing; direct emphasis on animal and herd welfare as an essential management feature and a future requisite for participation in global trade; and finally, a section on the rapidly developing area of precision management technologies.

Target audience

This edition is intended to be an international reference and textbook on dairy production and management. It provides cutting-edge information for 3 critical categories of people: progressive dairy farmers developing, expanding, or improving management of large herds; professional dairy advisors (consultants)—typically individuals with significant background and expertise in one or more areas who seek more knowledge and expertise in related areas of dairy management; and finally, and perhaps most importantly, upper-level university students, for whom the textbook can serve as a resource across multiple courses, topics, and disciplines of dairy management and science. The Foundation has committed to helping the next generation by setting a relatively nominal student price for this third edition.

Level of content

Authors and editors were selected because they are experts in their chosen fields. In writing, they were urged to use the same level of scientific rigor in collation and interpretation of the body of knowledge as would be expected in the *Journal of Dairy Science*®. However, it was not intended that they write in strict scientific format and language. They were asked to develop their sections and chapters on the premise that readers would accept their contributions as accurate, unless otherwise noted as speculation.

Some may wonder how many cows are in a large herd. Since the first edition was published in 1978, this number (200 milking cows) has grown significantly, and the proportion of total milk produced by larger herds in developed countries has increased dramatically over the last 4 decades. Whereas some of the ideas, practices, and technologies presented in the third edition were developed for specific application in large herds, much of the knowledge and ideas presented in this publication can be applied across herd sizes or, at minimum, serve as catalysts for thought about potential application and adaptation for implementation in many herds, irrespective of size.

The future

Even though the continuing trend in developing countries and even in some transitioning countries is more large herds, the amount of milk production by these herds still represents a small proportion of the world's total milk production. As reported in this edition, the average dairy farm in the world has about 3 cows. And, although global trade opportunities are very much on the minds of dairy producers in developed countries, only about 2.6% of global milk production is traded; this is projected to almost double by 2050. Even though this represents a relatively small proportion of total global production, this is still a lot of milk that offers an opportunity for additional growth if large herd systems can be developed and fostered to accomplish increased production in socially, economically, and environmentally sustainable ways.

At the same time, the vast majority of milk worldwide is produced and consumed locally. There is enormous need and potential for human nutrition benefits in developing countries to consume more milk protein and energy. For this to occur, major transformations in purchasing power (less poverty and greater disposable income) must occur and more effective preservation, storage, and distribution systems for dairy products must be developed. New herd management practices and technologies must be adopted locally. Continued development in large herd production systems will serve to present a menu of potential options and opportunities for dairy farms of any size, including those where the majority of the world's milk is and will be produced and consumed—locally.

Implementing the new electronic format for the third edition of *Large Dairy Herd Management* will make updating and adding new content easier in the future. What might be added in the future? In a professional career spanning over 40 years, and particularly in the last 2 years working on this project, it has been fascinating to imagine the global dairy industry of the future (e.g., in the year 2050) when the fourth edition of this publication is developed.

Thinking in systems and recognizing and carefully integrating practices and technologies with other components of complex systems will be paramount to the success of dairying in different countries and to participation in global dairy trade. In my view, future dairy production systems (large herds and smaller) will be soil-centric and fully integrated into larger whole agro-ecosystems. In response to increasing societal demands, large herd producers will need to engage in extensive and deliberate public discourse to develop, ensure, and improve market opportunities and secure the public's trust about production management practices, their consequences, and their acceptability.

The word "sustainability" has sometimes been vilified as a concept standing in the way of industrial progress and profit. More recently, the word and the working concept are gaining acceptance. Sustainability in dairying is defined by the continuous process towards effective integration of social, environmental, and economic values with dairy management practices and outcomes that bring valued contributions to humankind, while simultaneously regenerating the resource base and the environment. It is obvious that achieving sustainability will be essential for future successful dairy systems, large and small. If future dairy systems and their management are not socially acceptable and environmentally regenerative, they will not be economically profitable nor sustainable.

The obvious trend in some economically developed countries will be for large dairy herds to produce an even greater proportion of that country's milk solids and to capture economies of scale through adoption of new technologies and better management. However, large herds in developed countries are projected to produce less than 6% of needed milk solids for global trade by 2050. Management of large herd systems (whether based on grazing or mechanically harvested forages) will likely try to deploy "sustainable intensification" with increased production and efficiency per unit of land base, without far-reaching irreversible use of resources and deleterious environmental consequences. The concepts encompassing sustainable intensification as related to future policy direction are currently being vigorously debated in the academic research literature. Some use the "sustainable intensification" mantra to justify irreversible utilization of additional global resources, even if with some environmental damage, to justify feeding the growing world population, which is expected to reach 9 billion people by 2050. This is wrong. The more likely reality is that much more attention must and will be paid to environmental, social, and economic sustainability through regenerative land management practices rather than increasing productivity. This will be a shared transformational process among dairy sectors and societies through deliberative engagement processes.

Even with the tremendous technological advances to improve cow productivity and efficiency in the last 100 years in developed countries, most dairy systems are not especially regenerative. This must be reversed. In the future, principles and practices associated with regenerative agriculture will dominate in both large and smaller dairy herds in developed and emerging countries. As an example, recent research in other agro-ecosystems with cattle as an integral component of the production system shows that net greenhouse gas emissions can be 2- to 4-fold less with conservation grazing (e.g., adaptive multi-paddock grazing) and cropping practices such as no- or minimum-tillage, multi-culture cropping systems versus monocultures, and strategic crop rotations compared with simply removing one-half of the cattle from the system. This occurred by dramatically increasing soil organic matter content and water-holding capacity within the system. Soil organic matter regeneration will be valued in future markets as a primary agro-ecosystem service, a required social environmental responsibility and practice, and a business and environmental opportunity for dairy production systems.

As emerging countries develop dairy systems conducive to local conditions to supply the projected vast local supply of needed milk solids, it is hoped that smaller dairy herds will practice similar sustainable intensification and regenerative management to maintain viability. It will be for the "good of the commons" that the resource base and outputs will be in proximity to optimize soil organic matter regeneration and water and nutrient recycling. Future dairy production has tremendous potential opportunities to innovate and be proactive in development of systems that are regenerative and sustainable parts of whole agro-ecosystems, producing milk solids and ecosystem services.

In some chapters of the third edition, it was helpful to use specific names of commercial products, services, or equipment for clarity. Mention of trade names, proprietary products, or special equipment or warranty by any of the authors does not imply endorsement or approval to the exclusion of other products or services that may be just as effective.

Finally, a complete acknowledgments section is provided on the next page. But as a special personal note here, this project would not have been completed without the immense expertise and assiduous drive of technical editor Louise Adam and her skilled editorial and production team at FASS in all facets of the endeavor. Thank you very much!

David K. Beede
Michigan State University
June 2017

Acknowledgments

The ADSA Foundation expresses its sincere gratitude to the many people who helped plan and produce the third edition of the *Large Dairy Herd Management* e-book and associated conference. We are grateful to editor-in-chief David K. Beede, his team of section editors (page xv), chapter authors/internal reviewers (page xvii), and external reviewers (page xviii) for their work to organize and write this outstanding resource for the global dairy industry. This book would not have been possible without their diligence and perseverance. Also, gratitude is expressed to the editors and authors of the first and second editions of *Large Dairy Herd Management*, as their foresight helped establish the foundation for this third edition. Second, we thank Dr. David Beede, Dr. Larry Miller, Molly Kelley, and the FASS staff for their work in organizing the conference and producing the e-book. Countless hours were spent by members of the organizing committee, selecting chapter authors and section editors, reviewing and editing content, organizing the conference, and finding sponsors for the e-book and conference. We also thank the conference attendees for providing invaluable feedback that helped shape the final version of the e-book. The ADSA Foundation would also like to express its sincere gratitude to the sponsors of the e-book and conference (page xx)—without their support, this e-book and conference would not have been possible. Finally, the ADSA Foundation thanks the dairy farmers and those in allied roles globally for their continued labor and diligence to produce milk and dairy products for consumers worldwide.

Michael Socha
ADSA Foundation Chair
June 2017

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Abbreviations

The following abbreviations may be used without definition in the book.

AA	amino acid
ACTH	adrenocorticotropin
ADF	acid detergent fiber
ADG	average daily gain
ADL	acid detergent lignin
ADIN	acid detergent insoluble nitrogen
AI	artificial insemination
BCS	body condition score
BHB	β-hydroxybutyrate
BLUP	best linear unbiased predictor
BSA	bovine serum albumin
bST	bovine somatotropin
BTA	*Bos taurus* autosome
BUN	blood urea nitrogen
BW	body weight
CI	confidence interval
CLA	conjugated linoleic acid
CN	casein
CNS	coagulase-negative staphylococci
CoA	coenzyme A
CP	crude protein
CV	coefficient(s) of variation
DCAD	dietary cation-anion difference
DHI(A)	Dairy Herd Improvement (Association)
DIM	days in milk
DM	dry matter
DMI	dry matter intake
DNA	deoxyribonucleic acid
EAA	essential amino acid
EBV	estimated breeding value
ECM	energy-corrected milk
ELISA	enzyme-linked immunosorbent assay
ETA	estimated transmitting ability
FAME	fatty acid methyl esters
FCM	fat-corrected milk
FSH	follicle-stimulating hormone
GnRH	gonadotropin-releasing hormone
h^2	heritability
HTST	high temperature, short time
IFN	interferon
Ig	immunoglobulin
IGF	insulin-like growth factor
IL	interleukin
IMI	intramammary infection
LA	α-lactalbumin
LG	β-lactoglobulin
LH	luteinizing hormone
LPS	lipopolysaccharide
LSD	least significant difference
LSM	least squares means
mAb	monoclonal antibody
ME	metabolizable energy
MIC	minimum inhibitory concentration
MP	metabolizable protein
mRNA	messenger ribonucleic acid
MUFA	monounsaturated fatty acids
MUN	milk urea nitrogen
NAN	nonammonia nitrogen
NDF	neutral detergent fiber
NDIN	neutral detergent insoluble N
NEAA	nonessential amino acid
NE_G	net energy for gain
NE_L	net energy for lactation
NE_M	net energy for maintenance
NFC	nonfiber carbohydrates
NPN	nonprotein nitrogen
NRC	National Research Council
NSC	nonstructural carbohydrates
OM	organic matter
PCR	polymerase chain reaction
$PGF_{2\alpha}$	prostaglandin $F_{2\alpha}$
PMNL	polymorphonuclear leukocyte
PTA	predicted transmitting ability
PUFA	polyunsaturated fatty acids
QTL	quantitative trait loci
r	correlation coefficient
R^2	coefficient of determination
RDP	rumen-degradable protein
REML	restricted maximum likelihood
RIA	radioimmunoassay
RNA	ribonucleic acid
RUP	rumen-undegradable protein
SARA	subacute ruminal acidosis
SCC	somatic cell count
SCS	somatic cell score
SD	standard deviation
SDS	sodium dodecyl sulfate
SE	standard error
SEM	standard error of the mean
SFA	saturated fatty acids
SNP	single nucleotide polymorphism
SPC	standard plate count
TDN	total digestible nutrients
TMR	total mixed ration
TS	total solids
UF	ultrafiltration, ultrafiltered
UFA	unsaturated fatty acids
UHT	ultra-high temperature
USDA	United States Department of Agriculture
UV	ultraviolet
VFA	volatile fatty acids

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Section 1: Building Sustainability and Capacity

David K. Beede

This first section of *Large Dairy Herd Management* portrays current and future trends in supply and demand for milk production and addresses key challenges for providing milk protein where it is needed most. Major challenges to environmental sustainability are introduced and expanded upon in following chapters. Finally, progress to improve feed efficiency past and future will be presented.

Chapter 1-01 (Dairy sector across the world: National trends and opportunities for sustainable growth) sets the stage, considering historical, current, and future global, regional, and national trends for supply and consumption of milk and dairy products by humans. The chapter also relates prospects for international trade and concludes with a discussion on the sustainable growth of the global dairy sector. In 2013, about 2.6% of total global milk production was traded among developing, transition, and developed countries. This relative proportion is only predicted to double by 2050. Average global dairy herd size currently is just under 2.9 cows/farm (see Chapter 4-20: Changing global dairy markets: comparisons of dairy systems and economics). The vast majority of milk produced will be consumed locally. Most milk for international trade will be from developed countries where large dairy herds predominate. There is an enormous need for milk protein to meet human nutrition requirements in developing and transition countries. However, to supply more milk protein where it is needed, a major transformation in purchasing power (with less poverty and greater disposable income) and more effective preservation, storage, and distribution systems for dairy products are needed.

Chapters 1-02, 1-03, and 1-04 address the effects of dairy farming on air and water quality, environmental impacts, and opportunities to improve short-term and longer-term sustainability. Chapter 1-02 (Assessing carbon footprints of dairy production systems) addresses the modeling of and finding and using cost-effective options to reduce a dairy farm's carbon footprint. This is and will continue to be a critical management and ownership objective to enhance future sustainability and profitability of dairying. The farm-gate carbon footprint of milk, the term used in this chapter, is calculated from total net greenhouse gases (GHG) emitted by operation of the dairy farm. Major GHG include methane from ruminal fermentation (as much as 60% of the total footprint), reactive nitrogen (nitrous oxide and ammonia up to 28% of the total), and GHG generated during farming operations (e.g., fuel and fertilizer use, and production of purchased feeds; up to 25% of total carbon footprint). These GHG contribute to global warming. Management strategies to reduce GHG include feeding less forage, reducing herd replacement rate, increasing milk production per cow, and optimizing protein feeding. Reduced reactive nitrogen from manure by covered or enclosed manure storage, and on-farm anaerobic digesters to capture gas for electricity production are examples. More and more farms will adopt methods already available and new strategies will be developed and adapted as favorable policy and economic conditions evolve. This chapter also itemizes the carbon footprints of different dairy farm types, and explores the potential to reduce the footprint of milk in cost-effective ways to enhance sustainability and the economic and social capacity of dairy systems. Potential reductions of 20 to 30% in GHG emissions are possible.

Dairy cattle produce protein (milk and meat) and other essential nutrients, gases, and manure (feces and urine) containing nutrients and other chemicals. Chapter 1-03 (Water quality concerns associated with dairy farms) addresses, briefly, the benefit and mainly the issues with nutrients in manure that are associated with the water matrix in the farm system and surrounding environment. In the optimal scenario, manure serves a rich fertilizer source of carbon, phosphorus, and nitrogen for cropland. However, with intensification of dairy farms (and other livestock farms), risks of imbalance of nutrient import from feed and fertilizer compared with export as milk, animals, and manure can overwhelm crop uptake capacity. Pollutants in the water matrix affect water and soil quality. Chapter 1-03 addresses these issues, as well as nutrient management planning, best management practices, regulatory approaches, and their effectiveness to improve water quality. Mitigation strategies for both source and transport of manure are needed and discussed to prevent pollution of soil and water. The chapter concludes by addressing emerging concerns about some other chemicals and agents associated with dairy farming. Antibiotics, antibiotic-resistant bacteria, hormones, and endocrine disruptors can exist in the water matrix as pollutants. Evidence is emerging that they are significant risk factors with unintended consequences in the environment. Much more research is needed to understand their dynamics and effective approaches to reduce loading of the water matrix from dairy farms.

Typically, if “air quality” is mentioned, dairy farmers might think of carbon footprint or GHG. However, Chapter 1-04 (Impacts and mitigation of emissions from dairy feeds on air quality) describes work in California from the last decade in which additional air pollutants were discovered to be of major concern. Silage is an especially energy-dense feed effectively and economically used in many dairy systems. However, volatile organic compounds (VOCs; volatile fatty acids, alcohols, and aldehydes), and oxides of nitrogen (NOx) from silages represent major dry matter losses occurring during ensiling, removal from storage, ration mixing, feed-out, and in feed lanes. These emission losses are primarily direct economic losses to the dairy farm. They also contribute to environmental pollution and global ozone challenges and to human health concerns. Most progress to date has been to characterize the quantities of VOCs and NOx emitted from some dairies and to predict their occurrence through modeling. Current mitigation efforts should focus on reducing losses especially from feed lying in feed lanes or bunks. Strategies beyond feed management must be developed; attempts thus far are described. Reducing losses through careful management of fermented feeds is crucial to the environmental and financial viability of dairies in California and likely in other areas in the future.

The final chapter in this section, Chapter 1-05 (Feeding and breeding to improve feed efficiency and sustainability) focuses on feeding and breeding strategies to improve conversion of feed to milk and consequently dairy sector sustainability. In the United States and other developed countries, major improvements in feed efficiency have occurred in the last century. This resulted primarily from genetic selection for increased milk yield per cow, and from greatly improved nutrition and management practices. This chapter characterizes how and why this occurred: the dilution of maintenance and improvements in diet composition, digestion, and animal metabolism. Current genetic potential for milk production of most cows in developed countries challenges dairy farmers’ ability to feed and manage them optimally. Implementing nutritional management grouping to more efficiently manage the biology of the cow through lactation can be implemented now to improve herd feed efficiency. Additionally, genomic tools allow the selection of cows that have even greater feed efficiency. Improving feed efficiency for milk production by effectively using current and applying new selection and management technologies appears to be a responsible approach for greater environmental sustainability, at least for the foreseeable future.

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Section 2: Large Herd Systems of the World

Steven P. Washburn

The chapters in this section provide an overview of a range of systems of dairy production and management, the emergence and application of robotic milking systems, and dairy beef production. These chapters establish a framework around which chapters in other sections provide more detail about specific topics that have relevance to one or more of the systems described herein.

Chapter 2-06 (Large dairy herd design and systems in temperate and cold climates) defines 4 types of dairy farms: small farms in the last generation; niche dairies featuring products for specialized markets; lifestyle dairies with at least one other source of income; and large dairies producing at least a tanker load of milk in 1 to 2 d. The latter category already accounts for more than two-thirds of the total US milk supply, and larger dairy systems are expected to continue increasing market share and remain as the dominant production system. Although the chapter focuses on dairy systems in temperate and cold climates, it highlights the need for cattle to be housed in facilities designed to minimize effects of high summer temperatures, which affect milk production to a greater extent than colder temperatures. The need for innovative facility designs to meet concurrent goals of optimizing cow performance and cow comfort while ensuring efficiency of labor use is emphasized as a means of long-term profitability. A dairy herd management plan is described for an example herd with 3,500 milk cows milked 3 times per day in a rotary parlor with approximately 17 full-time employees. Understanding 24-h and annual "circles" or cycles on a dairy and monitoring the 2-year cycle from birth until a heifer calves can help managers identify weak areas and possible bottlenecks that limit a farm's potential.

Chapter 2-06 and Chapter 2-07 (Large confined dairy herd systems in hot climates) both deal with large confinement dairy herd systems that are based on use of total mixed rations (TMR) for feeding within a variety of housing systems that account for differences in climate. The approaches taken in these 2 chapters differ in that Chapter 2-07 necessarily includes a focus on ensuring access to adequate water supplies and strategies to keep cows comfortable in hot environments. Brief descriptions of a variety of housing options used in hot climates are included. Dairy production has been growing in non-traditional dairy regions. To that end, Chapter 2-07 describes pertinent criteria related to site selection, notes the importance of effective training programs for employees not having dairy experience, and points out issues associated with policies in various countries that can affect production of feedstuffs, access to water, and availability of markets. The authors note that challenges often faced for new herds that are funded by investors include unrealistic expectations of herd performance in the first few years.

Chapter 2-08 (Seasonal pasture-based dairy production systems) focuses on pasture-based dairy production, with an emphasis on seasonal breeding and calving and matching forage pasture growth to the biological demand of dairy cows across the lactation cycle. Effective use of pasture as the primary and most economical feed source is emphasized as a key to success for pasture-based systems, along with minimizing investments in depreciable assets. Infrastructure requirements include a farm layout using multiple paddocks with fencing to control grazing, travel lanes for access by cattle and machinery, readily available water sources, use of shade or cooling in some environments, and possible use of irrigation. The chapter includes discussion of stocking rate considerations as well as genetic characteristics of cows that would be expected to perform well in seasonal-calving grazing systems. Many types of forage species that can be used for pasture in dairy grazing systems are noted and a more detailed description of optimal grazing management of cool-season grass species is provided. Various hybrid systems of production that use combinations of supplemental feeding or partial TMR along with use of grazing at low to moderate levels of dry matter intake from pasture are acknowledged but not covered in detail. Such hybrid systems are potentially viable under favorable economic circumstances.

Chapter 02-09 (Organic dairy production systems) also describes a pasture-based system because of the requirement that organically managed dairy cattle have access to pasture for a significant portion of their rations. For larger organic dairy herds, meeting the required pasture requirements can be a challenge. Organic milk production has a relatively small market share but has been one of the fastest growing segments of agricultural production in the United States and is of economic importance in other areas of the world. Much organic dairy production would fit under the category of niche dairies for specialty markets, as noted in Chapter 2-06. Emphasis in Chapter 2-09 is on US organic dairy production but has relevance to other countries as well. This chapter reviews general requirements for becoming certified for organic dairy production as outlined and regulated through the National Organic Program within the United States Department of Agriculture. Organic dairy farms typically emphasize soil fertility as the basis for good forage production and as a foundation for success. Because of limitations on the use of antibiotics and hormonal interventions for reproductive management, emphasis in organic production is on use of preventive measures and management practices to ensure good herd health. Case studies from 2 large organic dairy herds that illustrate some details of organic management practices are included in this chapter.

Chapter 2-10 [Dairy systems with automatic milking (robots)] deals primarily with a relatively new technology that is in early stages of growth. About 15,000 commercial dairies are using automatic milking systems around the world. Many of the farms to first use the technology were family farms for which potential lifestyle advantages were considerations for adoption. Herds of more than 500 cows that use automatic milking systems are not yet numerous but are expected to become more common. The technology is expanding from single box systems that typically milk 55 to 65 cows per individual robot to more complex systems. Systems with up to 5 tandem boxes and rotary parlor adaptations are emerging for both interior and external rotary parlor designs. This chapter describes some of the cost considerations and tradeoffs for managing automatic milking systems. With more use and experience with automatic milking systems, improved efficiencies will likely be realized through a combination of improved technology and better understanding of the implications of various management practices. For large herds to embrace automatic milking systems, a reduction in labor aand improved cow comfort with fewer stressful group trips to the holding area and parlor need to be realized.

Chapter 2-11 (Beef production from the dairy herd) covers an important aspect of any dairy production system through the sale of cows as well as the many male calves that are born on most dairy farms. Use of sexed semen increases potential replacement heifer populations and potentially allows for dairy cows of lower genetic merit to be bred to sires of various beef breeds. This chapter is focused on concepts and challenges that apply to management of dairy beef production systems. For dairy beef production to be successful, neonatal calves need to receive care, including adequate and timely intake of colostrum, similar to that of their herdmates destined to become lactating cows. Although 2 options for veal production are mentioned, the emphasis is on dairy or crossbred calves from weaning through harvest at various ages and weights depending on the type of feeding system and the intended market. This chapter includes some historical perspective of dairy beef production and provides an overview of feeding requirements as well as use of anabolic growth stimulants. A description of carcass characteristics, pricing structure and marketing strategies including specialty or niche markets are featured in the chapter. As with any business venture, risk management is a critical consideration.

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Section 3: Facilities and Environment

Joseph M. Zulovich and Joseph P. Harner

Dairy facilities include the feed center, housing area, milking center, and processing and storage of manure nutrients. Good design of dairy facilities involves a team of individuals with expertise in finance, labor management, nutrition, animal health and welfare, regulations, and engineering. These individuals integrate thoughts and ideas on developing the best possible dairy for the location. One of the most important conversations when considering new or expanding dairy facilities revolves around the availability of local resources and the impact of the dairy on the local community. These discussions focus on the cropland available and the ability to appropriately deal with the manure nutrients, an adequate water supply without affecting the water supply of others in the region, ability to obtain necessary stable electrical power, effect of increased local traffic on the community, and available milk marketing outlets. Because of constraints including site boundaries, natural resources, finances, management style, feed types, the outcome of dairy facility design is often not the "ideal" dairy but rather a "compromise" dairy. The welfare of the animals, safety of employees, or protection of natural resources should never be compromised in the design process.

Dairy facility design ultimately has to move from a "conceptual" phase to a "challenge" phase to a "construction" phase if animals (cows or heifers) are raised on site. The conceptual phase explores the different types of parlors, housing types, manure handling options, and feed center layouts. In this phase, questions are answered through conversations with experts, visits to recently constructed dairies, and existing management experiences. The length of this phase depends on previous experience with managing and operating a dairy. It is critically important to document (in writing, pictures, and videos) these discussions of likely more than 10,000 decisions that go into designing a dairy.

Next is the challenge phase. During this period, the dairy design focuses on the "system" in which the 10,000 decisions are made and must work together. Often, a change in one area affects another area. A team approach ensures that all decisions and changes made during this process are viewed from different vantage points so as to not overlook a major negative impact. Additionally, changes in the basic design may result having to start over to make sure the entire dairy system functions as unit. In some cases, the "perfect" dairy may be designed based on the best scientific data available, only to reach the end of the challenge phase and have to start over due to cost constraints. The challenge phase ends with a signed contract for project construction. It is important to remember that although this might be a long process, it is still easier to make changes on paper than after construction of facility that will likely have a life of 20 to 40 years.

The construction phase begins when all questions have been answered and a contractor has the drawings and specification details needed to begin constructing the dairy. Some minor changes might still be made but once the contractor is on site and construction has begun, major changes are not possible without redesign and increases in cost.

The chapters in this section are focused on the conceptual phase of dairy design. The information provided addresses core decision areas in the feed center, housing area, milking center, and processing and storage of manure nutrients.

A systems approach to each of the individual systems results in an integrated, efficient, and functional dairy design. A farmstead designed with a systems approach enhances the opportunity to take advantage of excellent dairy herd management and supports a profitable dairy business. Chapter 3-12 (A systems approach to dairy farmstead design) introduces such a system approach to farmstead design.

Chapter 3-13 (Systems approach to designing milking centers and other dairy systems) focuses on designing for specific herd and housing group sizes, parlor size, and design of the milking center, often the focal point of the dairy operation.

Chapter 3-14 (Whole-farm nutrient balance: Systems approach to dairy nutrient planning) details how the sustainability and environmental footprint of a dairy operation should include an assessment of the whole dairy system using nutrient tools such as whole-farm nutrient balance. A comprehensive systems approach for nutrient planning on dairies reduces environmental risks associated with dairy and increase nitrogen (N) and phosphorus (P) use efficiency.

A basic understanding of the capabilities and limitations of various manure management technologies will generate realistic expectations, investments that better address the needs of the farm and more successful systems. Chapter 3-15 (Manure handling, treatment, and storage systems) reviews the basic technologies and principles of manure handling from barn to storage.

The transition cow facility developed by the dairy team should allow the cow to express her genetic potential and be designed with flexibility to accommodate changing recommendations. Properly designed transition cow facilities should consider cow comfort, cow behavior, worker safety, and labor efficiency for managing and caring for these cow groups. Chapter 3-16 (Transition cow barn design and management) reviews the principles of transition cow housing.

Chapter 3-17 (Mature cow housing systems) discusses the basic housing requirements of a modern dairy herd. The focus is on the theory behind the design of a confinement dairy housing system with natural ventilation to be used in climates comparable to the northeastern and Upper Midwest regions of the United States. Many of the recommendations presented for hot weather design are currently used for freestall barns located in hot and humid climates of the southeastern United States.

Well-designed facilities for dairy calves and heifers are key elements to ensuring healthy, well-grown heifers ready to enter the milking herd by 24 mo of age. Along with a productive environment, facility choices need to reflect the farm's management plan, consider the changing needs of growing calves and heifers, provide safe working conditions for the caregivers, protect the environment, and be cost effective. Chapter 3-18 (Replacement heifer facilities) reviews facility design for the replacement heifer herd.

Feed center design is typically based on a feed management plan developed by a dairy management team. The feed center design is based on efficient mass flow, in which harvested crops and off-farm feedstuffs are moved and stored at the feed center, and rations are formulated, mixed, and delivered to animal housing barns. Chapter 3-19 (Feed center system design and management) reviews these principles of feed center design.

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Section 4: Milk Markets and Marketing

Normand R. St-Pierre

No farm can operate in a vacuum: every farm must exchange goods and services with the outside world to remain economically sustainable. A century ago, the "outside world" of a dairy farm was quite small and very local. The perishable nature of fluid milk, which was then the most common form of dairy food consumption, and transportation limitations forced numerous relatively small dairy markets in developed countries. Changes in consumption patterns coupled with advances in transportation and preservation technologies have shattered many market barriers, both domestically and internationally.

Economic changes induced by trade liberalization and globalization have resulted in a substantial increase in world dairy demand from developing countries. Throughout the world, a variety of dairy systems are used to supply the demand for fluid milk and manufactured dairy products. The economic competitiveness of the various systems used are compared in Chapter 4-20 (Changing global dairy markets: Comparison of dairy systems and economics).

Large dairy-producing countries such as the United States, which used to rely almost exclusively on their domestic markets to find a home for their dairy products, are now becoming increasingly dependent on exports. The historical evolution of milk production and changes in the trading patterns are reviewed in Chapter 4-21 (International and domestic dairy market landscapes).

Domestically, a large portion of US dairy policies date back to 1935 when Federal Milk Marketing Orders (FMMO) were established. The FMMO rules are designed to ensure an orderly marketing of milk and set minimum pay prices for more than 80% of grade A milk produced in the United States. The mechanism by which the United States Department of Agriculture (USDA) establishes minimum prices to dairy producers is the focus of Chapter 4-22 (Pricing farm milk in the United States).

Ultimately, all dairy producers around the world are exposed to the influence of large, worldwide, external forces. Understanding these external factors, most of them coming from beyond the boundaries of their own country, is becoming increasingly important to the successful management of all dairy enterprises.

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Section 5: Genetic Selection Programs and Breeding Strategies

Kent Weigel

The objective of genetic improvement programs for dairy cattle is to enhance the profitability and sustainability of dairy farms and the health and well-being of their cattle. This objective is accomplished by selection of superior males and females as parents of the next generation of replacement heifers, utilizing genetic variation within or among breeds for traits that contribute to net profit by increasing income or decreasing expenses. Dairy cattle selection programs rely heavily on collection and analysis of vast quantities of pedigree and performance data, coupled with the use of assisted reproductive technologies and, more recently, genomic information.

Chapter 5-23 (Improving production efficiency through genetic selection) describes the evolution of milk recording and selection for increased income, through higher milk yield, improved milk composition, and enhanced feed efficiency. Gains in the productivity of dairy cows due to selection have been remarkable, and this progress has come from many decades of partnership between milk recording organizations, dairy records processing centers, AI companies, breed associations, land-grant universities, and the USDA Agricultural Research Service. The focus of selection has evolved through the years, with an initial emphasis on increasing milk yield per cow, followed by a shift toward efficient production of milk components and improved animal health. Managing inbreeding and maintaining genetic diversity requires vigilance and must be balanced with the competing goal of maximizing response to selection, particularly with high selection intensity and widespread use of advanced reproductive technologies. Genomic selection has been fully implemented by the dairy industry, and this will enable more rapid genetic progress, while also presenting opportunities to select for novel traits that were too difficult or expense to improve in conventional progeny testing schemes.

Chapter 5-24 (Improving health, fertility, and longevity through genetic selection) focuses on decreasing expenses by enhancing fitness traits through genetic selection. Efforts to improve dairy cow longevity initially focused on physical conformation, through breed association type classification programs, but the emphasis has shifted to direct measures of fertility, productive life, udder health, and early postpartum metabolic disorders. Challenges exist in utilizing field data to select for improved animal health, due to issues such as incomplete reporting of health data, inconsistent diagnosis of disease events, and variation in exposure to specific pathogens. Nordic countries have led the development of selection programs for improved dairy cow health and fertility, due largely to the existence of national veterinary recording systems, but recently vast quantities of reproductive and disease data have become available from on-farm herd management databases in North America. Significant between-family variation exists in functional traits, despite large environmental influences, enabling improvement of such traits through genetic selection. Most selection programs now focus on general measures of fitness, such as length of productive life or number of days from calving to pregnancy, but new technologies will allow selection for specific immunological or physiological traits in the future.

Chapter 5-25 (Making effective sire selection and corrective mating decisions) covers the "nuts and bolts" of how dairy producers can use the tools of genetic selection to improve their herds. Selection of elite sires for AI, for the purpose of creating the next generation of replacement heifers, has provided an inexpensive and highly effective means of improving the genetic potential of dairy herds worldwide. Dairy farmers have many tools at their disposal for maximizing net profit, with the goal of increasing revenues from milk sales while decreasing expenses due to feed, veterinary, labor, and replacement costs. Index selection is preferable to independent culling levels, because of its ability to accommodate objective economic weights, account for genetic relationships between traits, and allow vast superiority in one trait to make up for a slight deficiency in another. Computerized mate selection programs are used widely; such programs are useful for controlling inbreeding and avoiding inherited defects, but careful selection of service sires is more important than allocation of individual sires to specific mates.

Chapter 5-26 (Capitalizing on breed differences and heterosis) presents options for farmers who wish to improve profitability of their herds by crossbreeding, typically by exploiting breed differences and capturing hybrid vigor for health and fitness traits. Genetic improvement of dairy cattle has largely relied on within-breed selection, but challenges with managing inbreeding and maintaining fitness have led to increased interest in crossbreeding systems. Although the Holstein breed still enjoys a significant advantage in milk yield, there are opportunities to improve calving ability, female fertility, early postpartum health, and milk composition by crossing with the Alpine, Red Dairy Cattle, and Jersey breeds. Successful crossbreeding schemes combine intense within-breed sire selection with careful matching of key breed attributes with farm-specific management practices and economic objectives. Maintaining heterosis (hybrid vigor) in second and later generations of a crossbreeding program is critical, and 3-breed rotational systems provide an excellent opportunity to balance breed selection, hybrid vigor, and simplicity.

Chapter 5-27 (Genomic selection and reproductive technologies to optimize herd replacements) talks about how modern genomics tools can be applied on commercial farms that focus solely on the production and sale of milk, rather than elite breeding stock. Inexpensive low-density genomic tests, coupled with subsequent imputation of genotypes to higher density, have facilitated rapid implementation of this technology—tens of thousands of dairy calves are now tested each month. Detailed knowledge about the genetic merit of heifer calves, coupled with the availability of gender-enhanced semen, has created opportunities to optimize the management of replacement heifer inventories. Early culling of heifer calves with poor genetic merit is the "low-hanging fruit" in terms of genomic selection on commercial dairy farms, and this practice can improve the efficiency of utilizing land and feed resources. The long-term impact of genomic selection will depend on the development and implementation of new tools and strategies for using this information, such as mate allocation programs and genome-guided management systems.

Chapter 5-28 (Genomic selection and reproductive technologies to produce elite breeding stock) discusses options for farms that seek to move into the genetic improvement "fast lane" using modern genomic tools and assisted reproductive technologies. Genomic selection allows early identification of animals with outstanding genetic merit, creating new options for enhancing genetic progress in economically important traits. Genomic testing of potentially elite young males and females has become commonplace, and this has revolutionized dairy cattle breeding programs that were built on a foundation of progeny testing bulls for sex-limited traits expressed in their daughters. Dairy genetics companies, as well as some leading pedigree breeders, have invested heavily in programs that seek to maximize the synergies between genomic testing and assisted reproductive technologies. Genomic selection will enable improvement of traits that are expensive and difficult to measure on the general population, such as feed utilization efficiency, while also allowing the identification of families with attributes that are valuable in specific markets or management conditions.

Collectively, these 6 chapters describe the past, present, and future of genetic selection programs for dairy cattle. There is something for everyone: farms that want to develop and market elite breeding stock using genomic and reproductive technologies; farms that seek to maximize the amount of milk shipped per day through genetic selection and intensive nutrition and management; and farms that seek to sell more modest quantities of milk while reducing costs associated with labor, facilities, replacement animals, and veterinary interventions. The modern dairy cow is marvelously adaptable, in the sense that she can perform in intensive systems with year-round housing and stored feed, as well as under extensive management conditions with seasonal calving and pasture-based production. Genetic variation exists in essentially every biological trait that contributes to dairy farm profitability and sustainability, so the key is to develop effective data collection systems for these traits, weight them appropriately in an economic index, and ensure that selection goals are in line with market demands and environmental conditions.

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Section 6: Calves and Replacements

Robert E. James

The herd replacement enterprise represents a major expense on the dairy. In addition, it has a major effect on future herd productivity and profit. An aggressive colostrum management program and a high-quality feeding program support genetic potential for growth and enhance resistance to morbidity and mortality. Housing and management systems should enhance the animal's environment and promote labor efficiency. After weaning, the challenge is to provide conditions that encourage uniform growth at the most reasonable cost. Well-grown heifers achieve a high level of reproductive efficiency and calve at an early age with the ability for high milk production and longevity.

The objectives of a herd replacement program are to provide a sufficient supply of replacement animals to enter the herd on a timely basis with the body size and condition to enable them to produce to their genetic potential. Chapters 6-29 (Management of the newborn calf) and 6-33 (Disease prevention and control for the dairy heifer) cover essential aspects of this critical early period. There is no single best system of rearing heifers because "success" is predicated upon the most effective use of the resources available to the dairy. Extensive systems utilizing more pastoral resources can be just as successful and profitable as more intensive confinement systems. However, any system should be focused around critical times of the heifer's life: birth to weaning, during transition from a liquid diet to a ruminant diet, and from about 6 mo of age until the heifer enters the milking string.

Research and practical experience of progressive dairy farms has demonstrated the importance of an effective colostrum management program on not only health and growth of the preweaning calf but also on mammary development and productive performance once the heifer enters the milking herd (Chapter 6-30: Nutrition of the preweaned calf). The calf should be born in a clean environment with a minimum of stress and consume sufficient colostrum to deliver more than 150 g of immunoglobulin G (IgG) within the first few hours of birth. Additionally, non-IgG components may affect development of the absorptive abilities of the intestine, as has been observed when calves are fed "transition milk" for the first few days of life.

Meeting the nutritional requirements of the calf for maintenance and growth requires a diet comprised primarily of milk or milk replacer early in the preweaning period with consideration of the effect of environment on maintenance requirement. Colder temperatures (below the calf's thermoneutral zone) and suboptimal bedding and ventilation may require feeding in excess of 8 L of milk or milk replacer to support desired growth to enable the calf to double its birth weight within 56 d. In addition to supporting a reasonable rate of gain the calf should be fed to stimulate development of the digestive system from a monogastric to a ruminant system capable of digesting more fibrous feeds (Chapter 6-31: Calf transition: Managing and feeding the calf through weaning). This is achieved by feeding a palatable calf starter concentrate containing ~18% to 22% crude protein with sufficient levels of starch and fermentable carbohydrate to stimulate the growth of fermentative bacteria and rapid differential growth of the ruminant digestive system. Limiting the intake of the liquid diet after 4 to 5 weeks of age stimulates the calf to consume dry feed. Successful transition feeding management can be achieved with pelleted or textured calf starters, provided that they are palatable and possess the desired levels of nutrients.

Provision of fibrous feeds such as hay, straw or other high fiber feeds can be included in the diet before and just after weaning as long as it does not restrict energy intake and growth.

Weaning is a potentially stressful time and can predispose the calf to respiratory or other diseases if the transition to the diet comprised solely of dry feeds is too abrupt or there are behavioral or environmental stresses.

After weaning and when calves are consuming sufficient dry calf starter grains to maintain desired growth, calf starter may be replaced with less expensive "grower concentrates," and forages may be introduced to the diet in larger amounts (Chapter 6-31). Forage quality for younger calves is important and forage should be palatable, with a minimum of dustiness, and provide sufficient nutrients to complement the grower concentrate.

From about 6 mo to weaning, the priorities for success change. These older heifers are consuming more daily DM, and excellent BW gains can be obtained with an increased proportion of forages and byproduct feeds. The primary consideration for this period is to achieve a rate of gain that enables the heifer to be bred at the desired age (Chapter 6-32: Feeding management of the dairy heifer from 4 months to calving; and Chapter 6-34: Economic considerations regarding the raising of dairy replacement heifers). Composition of gain (lean vs. fat tissue) is determined by the proportion of protein and energy in the diet. Reproductive management determines the days on feed, which is a major determinant of age at first calving, length of the rearing period, and, therefore, rearing expenses. In most breeds of dairy cattle, there is an optimum range for first calving age. Calving at the extremes involves risk of decreased milk yield, excessive rearing expenses, or other issues that may affect animal health. Calving at an earlier age requires higher average daily gains and more expensive, nutrient-dense rations. Excessive weight gains before puberty have been associated with impairment of mammary development, increased calving difficulty, and reduced first lactation yield. The advantage of earlier calving (within the optimum range) is fewer days on feed and earlier income from milk sales. Calving beyond the desired range involves more days on feed and higher rearing expenses that frequently are not offset by higher milk yield.

Achieving calving at the desired age and BW can be achieved in a variety of management scenarios. Less extensive systems involving pasture can provide economical BW gains, but the challenge of providing consistent gains and achieving the desired age at calving is a challenge, especially in many colder or extremely dry climates. High-forage diets and those utilizing byproduct feeds can reduce feed cost per unit of diet intake, but usually at higher levels of daily intake. Research has shown that formulating diets to provide required nutrients at less than ad libitum intake can lead to improved nutrient efficiency and reductions in manure nutrient excretion, which affects whole-farm nutrient balance.

The dairy industry must continue to support research to ensure that the dairy cow is an efficient producer of food for our growing world population. This research should be focused on improving our knowledge of the biology of the dairy animal and in improving management systems that ensure the dairy industry is a good steward of the world's resources and that dairy animals are cared for in a manner that enhances their welfare. Recent research is finding that the prepartum environment and immediate postpartum experiences of the calf can have lasting effects upon growth, development, and immune function. We are learning that consumption of fresh colostrum from the dam can enhance immediate and later immune function. In addition, other non-immunoglobulin components of colostrum can enhance development of the digestive system when colostrum and transition milk are consumed for several days. Future research should be directed toward determining how we might enhance the diet of the calf before weaning to enhance its growth and development. Early neonatal nutrition through more liberal feeding of milk or milk replacer enhances growth but also appears to enable some genes to be expressed in a manner that may enhance the future productivity of the animal. This will likely be an active field of research.

Chapter 6-35 (Facility systems for the young dairy calf: Implications for animal welfare and labor management) discusses housing options for calves. Traditionally, calves have been housed individually in a variety of systems with the logic that this limits spread of disease and facilitates disease detection and feeding management. However, recent research has demonstrated that housing calves in pairs or groups after weaning promotes improvements in calf behavior and may be a more desirable housing system. Providing an opportunity to interact with other calves encourages earlier consumption of dry feed and minimizes the drop in body weight gain commonly observed when calves housed individually before weaning are placed into groups. New group housing systems such as those utilizing mob feeders, acidified free-choice systems, or computerized calf feeders enable calves to consume greater quantities of their liquid diet, which facilitates calf growth during the first few weeks of a calf's life. Adoption of these group-housing systems has revealed that designing facilities that are well ventilated and drained are essential to achieving desired growth and a low incidence of morbidity and mortality. Group-housed calves may improve labor efficiency, but in more cases, they reduce the mundane tasks involved with calf feeding and enable the calf manager to spend more time addressing the needs of the calves.

The transition to group housing from individual housing systems is likely to continue (Chapter 6-35). Research from leading behaviorists is demonstrating actual and perceived benefits to animal welfare. Many group-housing systems also provide an environment more favorable to calf caregivers. As more calf and heifer record systems become automated, more information will be available to determine the effect of management decisions not only upon rearing expenses but also on productivity and profitability.

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Section 7: Reproduction and Reproductive Management

William W. Thatcher

Dairy production systems evolved dynamically to a point that scientists, producers, veterinarians, and allied industries have a clear awareness that fertility of the lactating cow and the herd underwent a period of subfertility. This is evident by a phenotypic decline in daughter pregnancy rate (DPR) from the mid-1970s, a nadir in the late 1990s, followed by an increase in DPR to a level in 2010–2012 comparable to what was achieved in the late 1970s. This dynamic trend of reproductive performance occurred in contrast to a steady increase in milk production per cow. The recrudescence of improved reproductive performance reflects the needs and challenges to integrate the disciplines of physiology, management, nutrition, genetics, economics, veterinary herd health/production medicine, and inputs of allied industries. The integration of these systems reflects the multifactorial challenges to integrate reproductive processes of the cow. The major objective of the Reproduction and Reproductive Management section is to provide the dairy industry with holistic science-based approaches that affect the totality of the dairy operation in making decisions to enhance reproductive efficiency and health and well-being of the dairy cow and herd. Such improvements enhance overall economic profitability of the dairy operation.

Contributions in this section comprise a cross-section of excellent and prominent scientists that collectively integrate the development and implementation of reproductive management. The material and recommendations presented are predicated on science-driven basic and applied research proven to be applicable for the dairy operation. The material presented builds on prior editions of *Large Dairy Herd Management*, the scientific literature, and joint experiences between allied industries, dairy producers, veterinarians, and investigators. It represents a status report as of 2016, comprising 9 chapters with links to other collateral chapters and topics that specifically affect reproduction and reproductive management.

The basic components of the estrous cycle of heifers and lactating dairy cows (Chapter 7-36: The estrous cycle of heifers and lactating dairy cows) focuses on ovarian (follicle and corpus luteum) and hormonal dynamics, as well as estrous cycle abnormalities. The basic normal biology of the estrous cycle is developed, which is essential for producers, managers and staff to understand the components of reproductive management strategies to optimize fertility. Likewise, an understanding of the normal biology allows for dealing with the estrous cycles of high-producing dairy cattle and a major syndrome of "anovular cows" that affects reproductive success at the time of the programmed voluntary waiting period.

A basic understanding of the estrous cycle is the foundation for development of aggressive reproductive management programs (Chapter 7-37) to inseminate dairy cows at a precisely controlled time with good fertility (i.e., pregnancy per AI). This coupled with either early diagnosis of pregnancy by ultrasound or plasma measurements of pregnancy-associated glycoproteins permit an efficient resynchronization of cows failing to conceive to the first service. Understanding of the various programs is essential to tailor a program that best fits the characteristics of the dairy operation. Novel systems for automatic detection and prediction of estrus offers the producer a complementary component within the reproductive management system (Chapter 15-94: Automated detection and prediction of estrus as a complementary technology for reproductive management). In 2015, well-managed dairy operations reached annual 21-d pregnancy rates ranging from 32 to 39%. Overall reproductive management is an essential component of this success.

Reproductive management of dairy cows for seasonal breeding, associated with pasture-based dairy systems, is an alternative and challenging mindset compared with challenges of intensive dairy management systems. Pasture-based dairy systems are typical in New Zealand, Ireland, and some areas in the southern United States. Reproductive management of seasonal calving systems requires a high level of reproductive performance to sustain a 365-d herd calving interval that is coupled with nutrient requirements and availability of pasture. Factors associated with reproductive success are the focus of Chapter 7-38. Reproductive constraints are quite comparable between extensive and intensive dairy systems, but overall management systems are more holistic seasonal systems to meet the challenges of environment, nutrition, and breeding systems (AI and natural service). Herd benchmarks for success in seasonal calving systems are tailored, rightfully so, to the inherent availability of pasture (i.e., quality and quantity), management of pasture and cow, the integrated breeding program, and "Fertility Focus" reports for herd improvements.

The most critical window in the life cycle of dairy cows is the peripartum period associated with birth of the calf and subsequent vulnerability of the cow to postpartum uterine and metabolic diseases. Understanding and managing postpartum uterine diseases (Chapter 7-39) is critical to potential reproductive success. Complexity of postpartum management is also affected by nutritional management during the transition and postpartum periods (Chapter 8-57: Ensuring access to feed to optimize health and production of dairy cows, and Chapter 12-75: Behavior of Transition Cows and Relationship with Health). Of course, skilled assistance and good hygiene at calving are critical in reducing subsequent bacterial challenges to all cows at the time they undergo a transitional reduction in immune function. Careful monitoring of postpartum uterine status is essential for diagnosis to target therapy to cows that will benefit from appropriate treatments. Future development of vaccines and tools for genetic selection likely will reduce the incidence of postpartum reproductive diseases and further improve reproductive performance.

Essential to evaluation of reproductive performance is the ability to monitor and quantify the economic value of change in reproductive management (Chapter 7-40). The economic response not only resides on the specific reproductive management program and its biological effectiveness (i.e., pregnancy rate of eligible cows followed through lactational time over sequential 21-d periods) but also needs to encompass the basic parameters within which the dairy operates, accurate farm-level records, and expected market-specific parameters. Adjustable and adaptable decision-support tools are now available for producers to evaluate the economic impact of changes in reproductive management.

Optimal integration of the AI center and dairy producer is essential for effective selection and use of the bull to achieve high herd fertility (Chapter 7-41). In the early decades of the 21st century, a thorough understanding of the journey of sperm to subsequent performance value of offspring is a combination of utilizing well-established procedural processes combined with technological breakthrough. All of these components are available to the producer for effective utilization, and a clear sequential platform of opportunities is provided and complements a link with Chapter 5-27 (Genomic selection and reproductive technologies to optimize herd replacements).

Heat stress is a major limitation to optimal reproductive performance of the lactating dairy cow that disrupts many of the early reproductive processes of follicle and embryo development. Furthermore, seasonal periods of heat stress reduce both detection of estrus and duration of estrous behavior, as well as semen quality and libido in the male. Chapter 7-42 addresses the physiological thermo-regulatory responses of the cow and reproductive biological windows that are adversely affected that lead to temporal periods of reduced fertility. Although modified housing systems that cool cows improve milk production, the benefits on reproductive performance are not profound, even when coupled with the use of reproductive management such as timed AI. Additional strategies of embryo transfer and treatments with antioxidants and hormones are evaluated. Furthermore, the prospects of developing dairy cattle with a greater genetic potential to produce large amounts of milk and an enhanced ability to regulate body temperature are addressed. This includes introduction of specific gene variants for thermal tolerance through the use of traditional breeding or genomics and possible gene editing technology as applied to the early embryo (Chapter 7-44).

It is now recognized that heat abatement management during the dry period (i.e., late gestation) has marked benefits on subsequent performance and health of the cow in the subsequent lactation. Furthermore, reduction in heat stress during late gestation has profound and far-reaching programming effects that are beneficial to the health and well-being of the calf, its subsequent growth, as well as milk production during first lactation. This biological phenomenon in late gestation and its regulation is the focus of Chapter 7-43. Late gestation is a physiological window that can be improved markedly when producers provide adequate cooling of cows in the dry period.

A repertoire of assisted reproductive technologies (ART) are used in dairy production, as new avenues to enhance genetic merit of dairy cattle. Chapter 7-44 provides a clear description of the reproductive technologies, strategies for their utilization, and an objective assessment of the pros and cons for utilization. The dairy industry has pioneered the use of ART with the extensive use of artificial insemination. Additional technology and advancements have evolved that include sexed semen, ovum pick-up (OPU) through ultrasound guided removal of the oocyte, superovulation, embryo transfer, in vitro fertilization (IVF), and cloning via somatic cell nuclear transfer. These technologies combined with genomic typing and gene editing offer new on farm strategies to increase the genetic merit of cows for production and reproduction (Chapter 5-27) and reducing the generation interval.

Continued progress in the areas of cell biology, nutraceuticals to optimize reproduction and lactation, novel and biocompatible delivery systems of biological regulatory factors, genomic selection within the biological networks of the bull and cow, use of computer technology to monitor biological processes and forecast treatment-management needs, viable offspring produced from custom tailored embryos with high fertility are but a few examples for the future.

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Section 8: Nutrition and Nutritional Management

R. J. Grant and H. M. Dann

Nutritional Applications for a Progressive Dairy Industry

Nutrition is central to the productivity, health, and well-being of dairy cattle. For most dairy farms, feed costs represent approximately 40 to 60% of total costs. Therefore, successfully feeding the dairy herd requires integration of the latest research knowledge and economics to optimize income over feed cost and dairy farm efficiency.

In the years since the second edition of *Large Dairy Herd Management* (ADSA, 1992) was published, nutrition research and peer-reviewed studies have continued to add to the published database available to the dairy industry. However, much of the latest nutritional research may be found in scientific journals that are rarely read by dairy producers and allied industry. Therefore, a primary goal of this publication is to package important nutrition information in an applied format, with practical implications, and bring it to progressive dairy producers, consultants, university students, and other allied industry. The authors of the chapters in this section have provided a cutting-edge review of their nutrition topic along with their insight on how to best take advantage of the information on farm.

One important note: there are no tables of feed ingredient composition or systematic tables of nutrient requirements by physiological stage in these chapters. This information can be readily found in publications such as the National Research Council *Nutrient Requirements for Dairy Cattle* (NRC, 2001).

A review of published dairy nutrition research by Eastridge (2006) found that forages have been researched more extensively than any other type of feed. Thus, it is no surprise that we have chapters on forage harvesting and storage (Chapter 8-53) plus a carbohydrate chapter (Chapter 8-47) that focuses particularly on forage quality and its influence on metabolic and productive responses of dairy cattle. Another chapter delves into optimal feed and forage sampling on-farm (Chapter 8-52) to provide the best analytical values for ration formulation. For farms of any size, but especially for larger farms, accurate feed and forage sampling and analysis represent a substantial opportunity.

Grain processing continues to generate voluminous amounts of byproduct feeds that economically provide valuable dietary nutrients and reduce the overall environmental footprint of food production systems. In this section, the reader will find a chapter devoted to effectively feeding byproducts and non-forage sources of fiber (Chapter 8-54).

Eastridge (2006) points out that the major feeding system in the United States is the total mixed ration, although pasture systems are used in geographical regions where the land and other resources allow. Grazing systems are covered in another section of this book, but the reader will find a chapter in the nutrition section focused on total mixed ration feeding and delivery systems (Chapter 8-55). Successful feeding of dairy cows requires accurate mixing and delivery of rations so that the diet fed and consumed is the same as the diet formulated. This chapter summarizes years of on-farm experiences across the entire spectrum of feeding systems.

The feeding environment may have as much, if not more, influence on the cow than the diet itself and so we focus also on feeding system management (Chapter 8-57). Management factors such as feeding frequency, feed availability, and stocking density all will affect the competition for feed and cow productive and health responses to the formulated ration.

Research continues that should enhance our ability to efficiently use protein and amino acids, carbohydrates, lipids, minerals, and vitamins in dairy cattle diets. A series of 5 chapters summarize the latest information for each of these nutrients with an emphasis on practical applications and field implementation of the information (Chapters 8-46, 8-47, 8-48, 8-49, and 08-50). Much of the emphasis is on optimizing ruminal carbohydrate, protein, and lipid digestion to boost flow of microbial protein as this remains fundamental to predicting dairy cow performance.

Water is the most important nutrient for dairy cattle and they suffer more quickly and severely from inadequate water than any other nutrient (NRC, 1978, 2001). Consequently, a chapter focuses specifically on water requirements and on-farm considerations to optimize water consumption (Chapter 8-45). Importantly, the chapter recommends new water intake prediction equations to use on-farm that improve on the commonly used prediction equations reported by the NRC (2001) dairy model.

Over the past decades, research aimed at the transition period has exploded. The periparturient period provides nutritional challenges that must be met to minimize the incidence of metabolic and other diseases. Two chapters in the nutrition section are devoted to transition cow nutrition (Chapter 8-51) and nutritional diagnostic troubleshooting (Chapter 8-56). Finally, the well-known interaction between nutrition and reproduction has been updated with specific recommendations on feeding strategies to enhance the herd's reproductive performance (Chapter 8-58).

Practical Application and Implementation of Nutrition Concepts

A strength of each nutrition chapter includes its focus on practical, on-farm implementation of current research. Key examples include the following:

- Water needs to be routinely tested, and the most common challenges include salinity, high concentrations of sulfates, iron, nitrate, and microbial contamination.
- Optimizing nitrogen efficiency on a dairy farm requires a commitment to using nutritional models and amino acid balancing.
- Properly measuring fiber digestibility and taking advantage of it will continue as a major focus of farm profitability. This will be especially critical when high-forage diets are fed.
- Properties of fat sources must be understood, with ruminally available fat sources used first, and then specific inert fats selected based on the goals of the individual farm's feeding program.
- A variety of nutritional management approaches can be used for dry and fresh cows—no single optimal strategy will work for every farm.
- Basic operating protocols need to be in place on all dairy farms to ensure the proper implementation of the ration and feeding system. These protocols are explained in detail in this section.

Future Needs and Developments in Nutrition

The chapters in this section provide the latest information on a wide range of nutrition topics. As we look to the future, we will certainly continue to learn more about better measuring the content and availability of dietary nutrients, and the implications for cow responses at various stages of the cow's life cycle. Nutrition models will become increasingly dynamic and accurate, and their usefulness as educational and on-farm ration formulation tools will expand. Already today, and even more so in the future, required inputs for nutrition models will likely drive development of new or improved laboratory feed and forage assays.

Precision management will also increasingly impel nutrition research as the focus on efficiency of nutrient use intensifies. A critical research area will be to better understand the interaction between the formulated diet and the management environment. Factors within the social and physical environment modulate the cow's responses to the diet and greatly affect our ability to precisely and economically feed the dairy herd.

Although no crystal ball is perfect, it seems safe to predict that forages will continue to play a major role in nutritional schemes for dairy cattle, together with targeted use of regionally economical nonforage sources of fiber. In many ways, research published to date has only scratched the surface of understanding ruminal dynamics and associated cow productivity and health. Similarly, the burgeoning research on ruminal modifiers and other feed additives will continue as the dairy industry searches for tools that improve cattle digestive efficiency.

The chapters in this section provide a comprehensive, practical, cutting-edge review of dairy cattle nutrition. The information contained in these chapters provides an essential foundation for the reader to understand and anticipate future developments in the field of nutrition and feeding management.

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Section 9: Lactation and Milking Systems

Rupert M. Bruckmaier

The milk produced in the cow's udder is the basis for the income of a dairy farm. On the other hand, milking is usually the process with the highest daily working time on a dairy farm. The choice of an adequate milking system related to the individual requirements of the farm and the optimal interaction between the cow's physiological regulation, the technical specifications of the milking system, and the quality of the work of the employees are all crucial in optimizing the quantity and quality of the harvested milk, udder health, and daily working time invested for milking.

Basic research with new analytical approaches continues to create new insights on the biological processes and their interaction with on-farm technology. This new knowledge can be used to adjust or develop management strategies of mammary gland function from rearing to lactation, as well as milking technology. This section includes current knowledge on the physiological regulation of mammary gland development during rearing, and the endocrine, autocrine, and paracrine regulation of the mammary gland during lactation. Although the milking system with vacuum-based milk removal and cyclic opening and closure of a soft liner in the teat cup was introduced more than 100 yr ago, milking machines have not yet reached the goal of optimally mimicking a sucking calf. The current state of the art in milking technology and its interaction with physiological regulation is an important topic to optimize dairy farming. The milking machine can only suck the milk out of the udder that has been ejected into the udder cistern through a neuro-endocrine reflex of the cow.

Finally, an enormous variety of milking systems are available on the market. The success of a dairy farm depends of the selection of the most suitable system designed for the conditions of a particular farm and its herd and group size, environmental conditions, and availability of labor.

Chapter 9-59 (Mammary development in calves and heifers) describes the management of rearing calves and heifers to optimize the milk production in the adult cow. Besides the genetic merit of a cow, the potential for milk production can be influenced by management strategies long before the first lactation. The development of the mammary gland starts in the fetal stage and continues during the early life of the calf, influenced by the management of pre- and post-weaning nutrition. Later on, during the period before and around puberty, and during pregnancy, feeding and housing management has again considerable influence on milk production. This chapter clearly reemphasizes that dairy animals are not rodents, and that research in laboratory animals is not sufficient to explain the developmental processes of a dairy cow. The dairy industry needs research performed in dairy animals to ensure success in the future.

Chapter 9-60 (Regulation of the lactating mammary gland) focuses on regulatory mechanisms of milk synthesis and their manipulation during ongoing lactation. Several management strategies have been adopted to maximize milk production, most of them based on endocrine, autocrine, and paracrine mechanisms. The authors of this chapter highlight methods including the administration of hormones such as somatotropin or prolactin and prolactin inhibitors. Important methods to optimize milk production are the manipulation of day length during dry period and lactation, and the management of negative regulators of milk synthesis through the adjustment of milking frequency.

Chapter 9-61 (Oxytocin and the regulation of milk ejection during machine milking of dairy cows) shows the importance of milk ejection because only up to 20% of the milk is immediately available for the milking machine, whereas the main portion of milk is fixed by capillary forces as in a sponge. Only tactile teat stimulation induces the release of oxytocin and alveolar contraction to shift the milk into the udder cistern. The importance of pre-stimulation to avoid milking of empty teats and premature climbing of the teat cup, or possible alternative strategies such as reduced teat-end vacuum and short b-phase of pulsation before milk ejection are discussed. Aspects of disturbed milk ejection due to lacking oxytocin release and use of exogenous oxytocin are discussed as well.

Chapter 9-62 (Milking machine management) explains the fundamental biomechanics of milk removal by the milking machine. Machine milking is a compromise of the 3 most important goals, maximum milking speed, and completeness and gentleness of milk removal. The chapter explains the consequences if one of these goals is not sufficiently considered or is impossible to reach. The chapter describes the development of teat-end hyperkeratosis because of high mechanical load on the teat and the related scoring of severity. Consequences of overmilking, the interaction of milking machine characteristics and risk of mastitis, as well as cleaning and sanitation of the milking machine are further topics.

Chapter 9-63 (Milking systems for large dairy herds) presents guidelines to choose the right milking system for the circumstances of each individual farm with respect to herd and group size, environment, and available labor. The available systems are traditional parlors (herringbone or parallel) of different sizes, rotaries, and automatic milking systems. The systems may be equipped with automatic pre-stimulation, automatic cluster detachment, automatic dipping, and so on. Different automatic detection systems for udder health parameters are discussed, as well as different types of holding pens and cow traffic to optimize the throughput and capacity of a milking system.

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Section 10: Mastitis and Milk Quality

Joseph Hogan

Mastitis is the inflammation of a mammary gland almost exclusively caused by an infectious bacterial agent entering the gland, multiplying, evading the cow's host defenses, and ultimately causing harm to the host. Harm to the host is manifested by reduced milk production, reduced quality of the milk produced, and impairment of the animal's well-being. The economic impact of mastitis affects all aspects of the dairy industry from the individual dairy producer throughout the processing and marketing of milk products. Although great strides have been made in controlling mastitis, the disease continues to present producers and veterinary health professionals with evolving issues as dairy herds increase in size and complexity of operation. Mastitis and milk quality management practices in the next 10 years will continue to focus on applications to ensure that safe, nutritious milk products are available to consumers. Current political trends indicate these practices will be less dependent on the use of antimicrobials to treat and prevent intramammary infections, a cornerstone of mastitis control during the last half century. Prevention of mastitis will remain the primary emphasis by applying management practices that ensure well-being of cows and minimize possibility of adverse effects on the consumers and the environment.

The central key elements to controlling bovine mastitis (or any other infectious disease) are to either reduce exposure of the cow to potential pathogens or to enhance the cow's host defenses against the agents if preventing exposure fails. By far, the greatest advances in controlling mastitis have been gained by reducing exposure of cows to potential pathogens by eliminating the source of pathogens and reducing the transmission of pathogens to uninfected mammary glands from sources that cannot be eliminated. This is true for both contagious mastitis pathogens transferred from infected glands to uninfected glands (Chapter 10-64) and environmental pathogens transferred to uninfected glands from the cow's surroundings (Chapter 10-65). Culling chronically infected cows and antibiotic therapy of infected mammary glands at the end of each lactation are effective means of reducing infected glands in the herd that serve as the source of contagious pathogens in the herd. Milking hygiene reduces the likelihood that contagious pathogens are transferred from infected to susceptible glands. Control of exposure to environmental pathogens has similar applications. Bedding materials are a primary source of environmental mastitis pathogen; thus, the type of bedding chosen for cows to lie upon will greatly affect the amount of exposure to these bacteria. Many common bedding materials have low mastitis pathogen populations before use but bacteria from feces contaminate and multiply rapidly in bedding. Management practices that stress bedding hygiene and selection of bedding materials not conducive to bacterial growth will help minimize exposure to these mastitis pathogens. As the number of cows in a dairy herds increases, any source of either environmental or contagious mastitis pathogens has the potential to negatively affect a greater number of animals and their resulting milk production. Future considerations in minimizing exposure to mastitis pathogens will continue to explore biosecurity measures for detecting and monitoring levels of contamination in both infected animals and inert material brought onto farms serving as potential sources of pathogens to the herd. Also, likely in the future is an increase in mechanization of tasks to ensure that sources of mastitis pathogens present in the herd will have minimal risk of transfer to uninfected cows.

Successful management practices to enhance the host defenses of the bovine mammary gland against intramammary infections and inflammation have generally been those targeting a short period within the lactation cycle (Chapter 10-66). The susceptibility of cows to intramammary infections and mastitis is greatest during active involution from lactating to nonlactating and during the periparturient period. Innate and inducible host defenses are compromised during these stages of lactation compared with those during lactation and steady state involution. The lactational periods of heightened susceptibility to mastitis coincide with physiological events resulting in oxidative damage of cells associated with mammary defenses. Increasing physiological concentrations of anti-oxidant micronutrients by dietary supplementation during the dry period reduces severity and duration of cows infected in the periparturient period. Likewise, administration of exogenous immune simulators such as recombinant cytokines have shown potential for short-term mediation of reduced immune competency during times of heightened mastitis susceptibility.

The individual dairy herd continues to be the focal point of application for management practices and strategies to control mastitis (Chapter 10-67). How animals are grouped for feeding, reproductive functions, and exercise also affects mastitis control procedures. A major struggle for controlling mastitis in large dairy herds is the determination of optimum cow density while minimizing exposure to pathogens and maintaining mammary host defenses. Globally, pasture-based systems are part or the total management scheme for cows in many large dairy herds. Pasture-based systems need to include adequate time for pathogens loads on paddocks to decrease between grazing periods. Management systems integrating either confinement or pasture-based systems must offer adequate area per cow, allowing for the changes in host defenses associated within the lactation cycle of cows. Sacrifice paddocks used to congregate seasonal-calving herds during the parturition season often deteriorate whereby pathogen exposure increases and the condition of teat skin deteriorates to hasten intramammary infections. Future emphasis in large dairy herds managing cows in both confinement and pasture-based systems will be to optimize environmental conditions for cows and heifers at calving. Maintaining stocking rates to minimize pathogen exposure and to maximize the cow's host defenses will be essential to reduce mastitis and assure milk quality.

Vaccines against specific mastitis pathogens have been used decades with consistent results (Chapter 10-68). Those vaccines that elicit adaptive immunity against infectious agents result in a reduction in severity and duration of mastitis. This positive effect of mastitis vaccines is most evident when maximum humoral responses coincide with time of heightened susceptibility, such as parturition. However, mastitis vaccines have not been shown empirically to prevent intramammary infections. Future advancement in increasing cow resistance to mastitis will progress only as our understanding of the cow's host defenses and mastitis pathogen virulence traits progress. Successful development of strategies to enhance resistance against mastitis will also need to include logical means of application to cows in large dairy herds and assurance of minimal risk to the safety cows and the human consumers of milk from these cows.

Mastitis, milk quality, and food safety are interrelated (Chapter 10-69). Many common mastitis pathogens can also cause diseases in humans, but pasteurization of milk effectively eliminates most of the potential transfer of pathogens from milk to human. Despite the documented safety of pasteurized milk and dairy products for human consumption, an increasing number of consumers are consuming unpasteurized milk products at a heightened risk of pathogen transfer. The effect that mastitis has on this risk to human health is obvious by the positive correlation between incidence of mastitis increasing in a herd and the risk of milk being contaminated with pathogens. Two additional potential health risks to consumers of milk that increases with increased incidence of mastitis in a herd are the possibilities of antibiotic contamination of milk and increased antimicrobial resistance of mastitis pathogens. Consumer pressure has necessitated development of practical mastitis treatment protocols for large dairies that are effective, economical, and minimize non-essential usage of antimicrobial products. Animal health managers should perform mastitis treatment protocols in consultation with herd veterinarians. Future advances in this area likely as societal expectations for large dairy herds focus on ensuring animal welling while reducing antibiotic usage.

Mastitis is an important failure cost on dairy farms. In Chapter 10-70, the authors present a 10-step plan for analysis of records on somatic cell counts and mastitis using the DairyComp 305 dairy management information program and custom Microsoft Excel charts. Concepts are illustrated with data from 22 herds. The authors lead the reader through the interpretation of the results and give benchmarks as triggers for action. The authors give the DairyComp commands to create most of the charts.

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Section 11: Animal and Herd Welfare

Trevor J. DeVries

The idea of maintaining and improving the welfare of dairy cattle is not new. As stated by von Keyserlingk et al. (2009) "producers have always been concerned about the condition of animals in their care and have tried to ensure that they are healthy and well nourished." In fact, as mentioned by von Keyserlingk and Weary (2016), keeping cows healthy and productive has long been a cornerstone of good husbandry, and thus viewed as part of ensuring good welfare. Nonetheless, we know that concerns of animal welfare go beyond ensuring good animal function.

Two decades ago, Fraser et al. (1997) introduced the concept that animal welfare includes 3 types if concern: (1) is the animal functioning well (biological functioning), (2) is the animal feeling well (affective state), and (3) is the animal able to live a reasonably natural life (natural living). Dairy producers are naturally concerned with sustaining good animal function, in terms of growth, reproduction, production, and health, to maintain farm economic viability. However, there is growing concern from those not directly involved in primary agricultural production, and arguably by a growing proportion of producers, that cattle must be cared for in a manner that minimizes any unpleasant feelings such as pain, fear, or hunger (Weary et al., 2016). More recently, we see an increasing interest that animals, including cattle, should also have opportunities to experience positive emotions (Proctor and Carder, 2015). Further, there also is growing concern over whether cattle are kept under conditions that may limit their ability to perform natural behaviors, which they are highly motivated to perform. These concerns were highlighted in a recent survey performed by Cardoso et al. (2016), where public citizens indicated that "providing assurances that animals are well treated, developing methods to incorporate pasture access, and ensuring healthy products without relying on antibiotics or hormones" are all characteristics of an ideal dairy farm.

It is not surprising, therefore, that the 3 key concepts of animal welfare are included in definitions held by various legal, regulatory, and oversight bodies; for example, the World Organization for Animal Health (OIE) defines good welfare for an animal if it is "healthy, comfortable, well nourished, safe, able to express innate behavior, and it is not suffering from unpleasant states such as pain, fear, and distress" (OIE, 2013). As such, these concepts are shaping industry standards, regulations, and laws pertaining to care and welfare of dairy cattle.

In this section, we have addressed issues pertaining to animal and herd welfare that go beyond that covered in other sections of this book, specifically those pertaining to providing good nutrition, housing, management that not only minimize risk of disease or injury, but optimize growth, reproduction, productivity, and, thus, welfare of dairy cattle. This section includes chapters focused on 4 specific topics related to animal and herd welfare: (1) on-farm assurance of dairy cattle welfare (Chapter 11-71), (2) protocols for dealing with compromised cattle (Chapter 11-72), (3) proper handling techniques of cattle (Chapter 11-73), and (4) managing and avoiding pain associated with elective procedures (Chapter 11-74). The contents of these chapters are briefly summarized below.

Dairy cattle welfare assurance programs exist in various formats including industry-based, non-mandatory welfare codes, government regulations, product-differentiation (labeling programs), and corporate specifications. Chapter 11-71 gives examples of such programs, outlining their various strengths and weaknesses for assuring dairy cattle welfare. Also described is the need for all standards, including thresholds, targets, or recommended practices, to be science based. The authors argue that because welfare priorities vary among stakeholders, assurance standards should be developed with as many different stakeholders to ensure wide acceptance. A final key component to ensuring animal welfare discussed in this chapter is the need for all humans involved in animal care to be trained and motivated to carry out that task.

Despite best management practices, there are situations where dairy producers have to deal with compromised cattle, that is, those cattle that are in a weakened, debilitated, or non-ambulatory state usually as result of illness or injury. Chapter 11-72 describes the various factors that may lead to cattle becoming compromised, and provides detailed standard operating procedures for dealing with those cattle, including required equipment, training, and documentation.

Stockmanship, or effective cattle handling, is crucial for the health and productivity of dairy cattle as well as injury prevention. Chapter 11-73 describes how natural behavior of cattle is used to efficiently move and care for animals. Further, the author describes how effective cattle handling may be learned, and highlights the need for proper training on farm to ensure animal care workers have the proper skills and attitude for working with cattle.

Dairy cattle of all ages have the ability to feel pain and experience stress, fear and frustration as well as excitement and pleasure. Chapter 11-74 describes how painful or stressful procedures should only be undertaken when there is an indisputable need and preferably adequate scientific evidence available to support the practice. For those required practices, examples of the least painful method as well as medications to relieve the pain are provided in this chapter. The authors also describe how sustainable practices in animal agriculture must not only avoid negative welfare states, but also aim to promote positive welfare states.

These chapters described above are all focused on describing and addressing issues of dairy cattle welfare, which not only relate to promoting good health and productivity, but also promoting positive affective states, and allowing for natural behavior of cattle. The solutions described for these issues are win-win, that is, they are focused on improving not only the lives of cattle, but also the people who work with them.

It is important to remember that high standards of animal welfare have been, and will continue to be, important to the dairy industry in the future. In the near future, the dairy industry will, no doubt, be asked to provide documented assurance that farms are adhering to specific animal welfare standards. Ensuring animal welfare is not only a concern for dairy producers, but it is an important social concern. As such, as stated by von Keyserlingk and Weary (2016), it can be argued that animal welfare needs to be integrated into our concept of sustainable agriculture (von Keyserlingk et al., 2013), aligning with both environmental (Hötzel, 2014) and economic (von Keyserlingk and Hötzel, 2015) goals. To achieve this, all stakeholders (including consumers of milk products) must be involved in discussions on appropriate animal care. To facilitate these discussions new research has focused on investigating stakeholder views on dairy farming and common industry practices (reviewed by Weary et al., 2016). To ensure the sustainability of the dairy industry, von Keyserlingk and Weary (2016) argue that we need to embrace all stakeholders, as only by understanding the attitudes of people both directly involved and not involved with the dairy industry will we be able to identify contentious topics, as well as areas of agreement. This is important, as industry practices that are in line societal expectations will ensure the long-term sustainability of the dairy industry.

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Section 12: Herd Health

Carlos A. Risco

Optimal animal health is essential for the economic sustainability of a dairy herd. In addition to lowering milk production, poor health increases drug costs, culling, and lowers reproductive efficiency. A well-designed herd health program allows dairy producers to maintain animal health at an optimal level to produce milk at the most efficient level to maximize economic returns. The aim of this section is to provide practitioners and farm advisors information on management practices that have both positive and negative influences on health. Information on the frequency of disease, the biologic effect of disease on productivity, and effective control procedures are presented to allow dairy producers and their consultants to design a herd health program that will enhance animal welfare and the profitable production of milk.

Behavior of transition cows and relationship with health is covered in Chapter 12-75. In this chapter, normal changes in behavior that occur gradually over the transition period and those that change dramatically during the process of parturition are discussed. Changes in behaviors, similar to sickness behaviors, have also been observed to occur well in advance to disease diagnosis, and in some cases before parturition. Assessment and evaluation of these behavioral or "attitude" changes would allow for detecting cows at-risk for illness or those in early stages of disease, allowing for prompt treatment intervention and assessment of treatment efficacy.

Chapter 12-76, on management of transition cows to optimize health and production, discusses opportunities to implement management strategies to mitigate the negative effects on health from physiological changes that occur from late gestation to lactation. A framework is provided to evaluate clinical disease incidence, diet formulation, and stocking density to allow for timely interventions to ensure the dairy is proactively addressing transition cow management opportunities to improve health.

Dairy cattle are at risk to develop metabolic disorders after calving due to the sudden outflow of calcium and energy that occurs at the onset of lactation. These disorders affect the immune status of the cow at a time that she is most vulnerable to develop diseases that lowers milk production and reproductive performance. Chapter 12-77, on minimizing postcalving metabolic disorders, reviews the cause, treatment, and prevention of the 6 most common metabolic disorders of dairy cows: hypocalcemia, hypophosphatemia, hypomagnesemia, ketosis, hypokalemia, and displaced abomasum.

The application of a sound vaccination program can have dramatic effects on the health and profitability of the dairy and needs to be well planned. Chapter 12-78, on immunology and vaccination, covers the essential components of a vaccination program; choosing the appropriate vaccine, when to vaccinate, and the importance of a booster to achieve full protection. Management decisions that may not maximize the potential of the vaccine chosen and realistic expectations from vaccination to protect the herd from infectious diseases are also discussed.

Chapter 12-79 describes management of the herd to minimize lameness. An understanding of lameness conditions, in terms of why they occur and how to prevent them, is an essential component of a herd health program to minimize production losses as well as the loss of cows. Producers need to be aware of the important roles that nutrition and good body condition have in maintaining healthy feet and legs. Facility design and management to maximize cow comfort and reduce time standing are essential to minimizing lameness. The establishment of a foot health program that provides routine claw trimming and correction of claw lesions at an early stage is also critical for the prevention of lameness.

Chapter 12-80 covers paratuberculosis (Johne's disease) management. Paratuberculosisis a costly disease that is characterized by profuse diarrhea and progressive weight loss. Limitations on the diagnostic tests currently available make it difficult to evaluate the utility of control practices and to estimate the economic impact of paratuberculosis. However, the application of biosecurity and disease control programs can reduce the risk of introducing not only paratuberculosis but other infectious diseases into the herd.

Chapter 12-81 describes parasite control in dairy cattle. The cost of parasitism is related to reduced feed intake and efficiency, which results in poor growth in calves, lower reproductive efficiency, and milk production. Deworming dairy cattle goes beyond treatment of clinical cases and should be aimed first at the prevention or elimination of the parasites. Dairy producers should work closely with their veterinarians to design an effective control program that best fits their operation and should consider an efficacious product, the correct treatment time in the production cycle of the animal, and strategic deworming practices.

Since the publication of the first revised edition of this book in 1992, major advancements have been made in disease control that have contributed to an increase in milk production per cow worldwide. Nevertheless, to maintain the economic sustainability of dairy farms and meet societal expectations for the care of food-producing animals, there is a need to develop new technologies to improve animal health. Current gaps in knowledge and future needs in health management of dairy cattle include (1) understanding how behavior, during and before illness, can be used as a diagnostic tool; (2) how precision technologies can be used to identify sick cows; (3) the development of housing and management practices that improve animal wellbeing; (4) the genetic basis for disease resistance; (5) development of more effective vaccines; (6) development of alternative for antibiotic use; (7) development of clinical case definitions that affect production and warrant treatment.

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Section 13: Business and Economic Analysis and Decision-Making

Albert De Vries

The section on business and economic analysis and decision-making includes chapters on monitoring technical and financial performance, risk management, the economic analysis of a proposed operational change, and the costs of production diseases. Common themes in these chapters are the measuring and understanding of past and current farm performance, and concepts and tools to evaluate proposed changes that result in increased economic well-being. Record analysis, monitoring, benchmarking, and marginality are recurring topics.

Benchmarking is a process to compare the performance of the farm against the farm's own past performance, against similar farms, or against industry targets. Chapter 13-82 discusses ways that dairy farm managers can use financial benchmarking to identify areas for improvement, set targets for performance, and focus on planning and managing finances. The authors describe the balance sheet and income statement as basic financial statements from which 12 key farm financial performance measures are calculated. These farm financial performance measures, often ratios, can be benchmarked. These measures show the strengths or weaknesses in liquidity, solvency, profitability, and financial efficiency. The authors give numerical examples of a balance sheet and income statement and lead the reader through the calculation of the example farm's financial performance measures. They include discussions of the interpretation of the calculated measures. Some of the financial performance measures show the farm's vulnerability to risk and may motivate action to alleviate poor performance. The chapter concludes with where to find sources of financial benchmark data.

Financial benchmarking provides information about the farm's financial health that is needed to manage risk. Risk is defined as the uncertainty and volatility in expected returns in the production of an economic good. In Chapter 13-83, the author elaborates on dairy risk management. He describes 5 types of risks and briefly describes tools and ideas to manage those risks. The chapter describes one of those types of risks, price risk, in more detail. Major price risks are evident in the price of milk sold and the price of feeds purchased, especially corn and soybean. A volatility analysis shows that farmers should pay close attention to risk management for both milk prices and feed prices. If left unmanaged, then periods with low returns (low milk prices or high feed prices or both) may lead to financial risk. The author explains how price risk can be managed by forward contracting, hedging, the Livestock Gross Margin Dairy (LGM) insurance program, or by using the Margin Protection Program for Dairy (MPP). The topic of hedging is illustrated with numerical examples of using futures and options. The MPP program is also described more extensively.

Chapter 13-84 discusses the importance of understanding marginality and marginal decision making in a financial context. The chapter starts with the realization that most successful dairy farms compete by being operationally excellent. This includes the early adoption of new technology and production processes, understanding economies of scale, cost control, efficient use of resources, and good decision-making. The chapter centers on the tools, concepts, and assumptions needed when performing an economic analysis of the evaluation of a proposed operational change. One useful tool, the partial budget, is described more extensively. A common mistake made in practice is the use of averages as inputs in a partial budget. In contrast, marginally deals with a clear understanding of costs and revenues that change with the proposed operational change, and those that do not change. Numerical examples are given for the value of marginal (a little more) milk through increased feed consumption, adding cows to the farm, and renovation of freestalls. The examples illustrate the wrong decisions that can be made when benchmark data such as average feed costs are being used. Important is also that volume of milk sold is a main driver of profitability. The chapter gives a hierarchy of profitability of additional milk made on the farm and concludes with suggestions where dairy farmers should look to improve profitability.

One area where the marginally concept of dairy decision-making is also important is in the prevention and treatment of production diseases, as described in Chapter 13-85. The authors make the distinction between failure costs—the costs that result from a production disease—and preventive costs—the costs to prevent the disease from occurring. They give a literature review of the failure costs of mastitis, lameness, and ketosis. Many estimates are available. Failure costs are farm-specific and often underestimated by farmers.

Preventive costs are much less known but can be as large as failure costs. Increases in preventive costs generally reduce failure costs. The marginality principle then says that the optimal level of prevention is at the point where an additional amount of money spent on prevention is equal to the amount of money saved from reduced disease. The authors give a list of steps to take to estimate the optimal level of prevention at the farm level. A partial budget is useful in this analysis.

In this section, several authors have given guidelines about how to improve monitoring and benchmarking on dairy farms. Part of this improvement relates to implementing existing concepts and methods as illustrated in the chapters. Another part relates to better showing the value of monitoring and benchmarking to dairy farmers because this value may be underestimated. Future needs include quantification of the importance of such data collection and analysis. The marginally concept further requires a clear understanding of which costs and revenues change with a proposed operational change. Dairy farmers need to be reminded about this principle because mistakes are commonly made. Another need is quantification of preventive costs of production diseases. Only then can economically optimal levels of prevention be determined such that the total cost of production diseases is minimized.

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Section 14: Effective Management of Farm Employees

Phillip T. Durst and Stanley J. Moore

As owners of large dairies, you determine the course for your dairy, but employees drive it. Good managers see employees as members of their team to move the farm forward. They see employees as an integral part of their farming operation rather than as a cost or a necessary evil. Unless employers can move to this mindset, they will be limited in their labor productivity, efficiency, and quality.

Labor is in a seller's market as the supply of employees for dairy farms has decreased. Whereas it was once the case that employees were easily replaceable and there was always another body to take the place of one who left, that is no longer the situation in many areas. There are several reasons for this shift: population changes, immigration changes, and changes in what people are willing to do for work.

The current trends portray a future that will make keeping and developing employees more important. Employee turnover is becoming increasingly expensive, and it is getting harder to find good replacements, even as the required skills to use technology on farms increase.

In addition, the productivity of labor is being recognized as one of the greatest differences in the cost of milk production, separating high-profitability farms from lower-profitability farms. For example, at Michigan State University, farm financial data of the dairy farms in the top 25% (sorted by rate of return on investment) showed a 76% higher value of farm production per hour of labor than the farms in the low 25%.

It is not just a matter of productivity; it is a question of the quality of labor and the quality of the care of the animals. Animal care standards are increasing in most areas of the world, as consumers demand that dairy cattle be cared for humanely, with dignity, and with reduced stress. However, when we fail to provide those same measures for employees (humanity, dignity, and reduced stress), they may not, in turn, provide that for the animals in their care.

Human dignity is certainly a greater issue than that of farm animals. Yet, it has not been routinely or evenly applied to dairy employees. Respect for the dignity of individual humans and the meeting of their needs for connection with people and meaningful work is sometimes lost in the drive to produce more, grow bigger, and respond to decreasing profit margins.

That is not true on many farms where employers and managers have made employee management a cornerstone of the business. Those businesses are an example to others. However, where good employee management is not the priority, it has opened the door for worker advocacy movements and regulation.

We believe that all dairy employees, no matter where they are in the world, no matter their ethnic background, economic situation, or personal ability level, are worthy of being treated with respect and that when we do that, the business will grow as a result. That is the common thread that runs through all the chapters in this section.

In his chapter (Chapter 14-86: Leadership for the farm business), Bob Milligan sets the stage with his challenge to employers on what it means to have a healthy organization.

In Melissa O'Rourke's chapter (Chapter 14-87: Building the team: Continuous recruitment, selection and onboarding), the need for finding and hiring good people and bringing them into the organization effectively has at its heart the need to treat employees with worth as humans.

Compensating employees fairly with a structure that recognizes their need to know what to expect is the foundation of Chapter 14-88: Compensation, bonuses, and benefits: Key start to building a committed, productive workforce by Felix Soriano.

Phil Durst and Stan Moore write of valuing the minds of employees and helping them to apply their minds for the benefit of the business in Chapter 14-89: Building a culture of learning and contribution by employees.

Chapter 14-90 (Setting goals and using performance feedback effectively) by Jorge Estrada tells how to provide what employees need on a regular basis in order to improve their performance and become more valuable to the business.

In Chapter 14-91 (Overcoming challenges and building team cohesion), Barb Dartt presents the case that it is about bringing together a group of diverse individuals into one team while not losing sight of the individuals that make up the team.

In the final chapter of this section (Chapter 14-92: Effective and efficient operations management for farm staff), Kay Carson writes about using the principles of Lean Management to increase farm profits. In that sense, it pulls together every other chapter, as she writes of employees and management working together to move the business forward.

While good leadership and management of people take an investment of time and resources, it may be the best investment on a dairy farm. In the end, this is about business and the success of that business. However, achieving the highest level of success with cows and budget sheets depends on the success of the people employed.

Owners and managers have the responsibility to engender a workplace environment that is supportive as well as efficient, that is about developing people as much as about developing cattle, and that is about accountability on all levels, more than just about accounting.

The difference between a good dairy farm operation and a great dairy farm operation is the difference in leadership and management of employees. You cannot have a great farm and not be a great leader of people. While you may get by with it for a short period, in the long term, the deficiencies in working with people will limit the ability of the operation to respond to changes and to increase productivity and profitability.

Leadership attitudes and skills for improved management of people can be developed by dairy owners and managers who have the desire, and the humbleness, to learn. We commend you for taking the initiative to do just that with this section on Effective Management of Farm Employees.

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Section 15: Precision Management Technologies

Jeffrey Bewley

Technologies are changing the shape of the dairy industry across the globe. These technologies will continue to change the way that dairy animals are managed. This technological shift provides reasons for optimism for improvements in both cow and farmer well-being moving forward. Precision dairy farming technologies provide tremendous opportunities for improvements in individual animal management on dairy farms (Chapter 15-93). These technologies are changing how dairy producers manage reproduction and health.

Automated estrus detection systems have been developed to help dairy managers identify and inseminate cows in estrus (Chapter 15-94). Most systems use sensors attached to the cow to monitor physical activity alone or in combination with other behavioral or physiological parameters altered during estrus events in cattle. Alerts for estrus are generated based on the relative change of the parameters monitored. In the future, technological advancements and improvements will help refine existing and develop novel methods and devices for automated estrus detection thereby favoring adoption by dairy farms.

Precision dairy technologies can support producers by identifying animals that may require treatment, through exception reporting of deviating health-related parameters based on production, physiology, or cow behavior (Chapter 15-95). The data generalized from these systems can enable early detection of disease and more timely and informed decision making that requires minimal labor. Commercially available monitoring technologies exist for most animal health and wellbeing conditions, yet in almost all situations, issues remain regarding system performance and value to producers. However, technology is advancing at a rapid rate with new sensor measurement techniques being developed and the potential to improve existing technology performance by combining multi-sensor sources and non-sensor data.

Despite advantages that precision dairy technologies can offer, adoption is still limited. This is explained by the lack of information on added economic value when these technologies are used on farm (Chapter 15-96). To determine the economic value of technologies, the straightforward partial budget can be used. This economic tool allows one to estimate extra costs and benefits that result from using a technology. Because technologies concern long-term investments, an investment analysis can be used to retrieve a more precise estimation of the economic value. The driver of farmers investing in precision dairy technologies may not be the economic value, but farmers' preferences and social impact may be as important as or even more important than potential economic benefits.

Milk weight plus the milk composition data can be used to monitor component production and detect when a ration change may be negatively affecting milk composition (Chapter 15-97). The potential exists to extract more information from mid-infrared spectra of milk for use in management of feed efficiency, health, and reproduction of individual dairy cows. Application of more frequent mid-infrared fatty testing to milk from individual cows, coupled with the fat, protein, lactose, and milk urea nitrogen and milk weight adds value to support precision management decision making.

Although technology provides opportunities to monitor cow health, comfort, and welfare, a producer must still practice good husbandry techniques. These technologies can only enhance a well-managed system, due to the increase in available information. How the data provided by these technologies are turned into actionable solutions is critical. Wearable technologies dominate the market now, and new sensor systems will be introduced into the market in the years to come. These systems will likely transition from primarily wearable technologies to more imaging and milk-based systems. Investment decisions should include a thorough, formal evaluation of profitability. The human factors related to successful technology adoption cannot be overlooked. Excitement about technical capabilities must be balanced with consideration of implementation challenges and economic realities.

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