Canadian Dairy Industry, Past, Present and Future

John J. Kennelly[1], Mike Southwood[2] and Bruce Beattie[3]

[1]University of Alberta, Edmonton AB T6G 2P5
[2]Alberta Milk, 1303-91 St SW, Edmonton, AB T6X 1H1
[3]R.R. 2, Sundre, Alberta T0M 1X0
Email: john.kennelly@ualberta.ca, msouthwood@albertamilk.ca, westhawk@cciwireless.ca

Take Home Messages

- Over the past 35 years, attendance at the Western Canadian Dairy Seminar (WCDS), initially known as the Alberta Dairy Seminar, has grown ten-fold from an initial attendance of 77 paid registrations to over 700 today.
- The WCDS is now recognized as one of the premier dairy conferences of its kind in the world. The WCDS has been an important contributor to maintaining the overall efficiency and productivity of the Western Canadian dairy industry by providing all stakeholders with an opportunity to keep abreast of the latest developments in research, technology, innovation and policy that influence production efficiency, environmental sustainability, milk quality, and marketing of milk and milk products.
- The past 35 years have seen many changes in the Alberta and Canadian dairy sectors. A dramatic decline in the number of producers has been accompanied by a new era of collaboration, provincially and nationally. Collaboration has strengthened our efforts in research, extension, dairy product promotion and producer sustainability.
- Pooling agreements first established in the 1980’s have provided industry sustainability, stability and predictability. Consolidation and collaboration will continue as the industry evolves over the next 35 years.
- Consumers will demand that we operate in a responsible manner that meets societal standards. Producers must continue to work together to ensure a sustainable future for dairy in Canada.
- The industry has evolved over the last 35 years and will continue to do so in the future, evident by the national ingredient strategy coming into effect February 2017.

Introduction

The year 2017 marks the 35th anniversary of the Western Canadian Dairy Seminar (WCDS). The dairy industry in Canada has experienced numerous changes since the inception of WCDS, so we decided it would be interesting to look back over the past 35 years, and forward to 2050, through the lens of the WCDS. What lessons have we learned from the past 35 years, and how do these help us envisage what the dairy industry might look like in 2050?

On the occasion of the first WCDS in 1983, Alberta had about 1,500 milk producers and 2,800 cream shippers, and MSQ was priced at $6 per kg. Pierre Trudeau was prime minister of Canada, Peter Lougheed was premier of Alberta and the world population was 4.6 billion. Fast track another 35 years from today and we are at 2052 when the world population is expected to be over 9 billion and perhaps climate change will mean that Canadians will no longer need to head south in the winter!

A Brief History of WCDS

For the benefit of a new generation of attendees, we present a brief history of WCDS here. Please see the 2007 WCDS proceedings (http://www.wcds.ca/proc/2007/Manuscripts/John.pdf) for a more detailed history. The WCDS was modelled on the very successful Banff Pork Seminar that was initiated by University of Alberta professor, Dr. Frank Aherne in 1972.

The ingredients that have led to the success of the seminar include: excellent speakers, a dedicated organizing committee representing a broad cross section of the industry, high quality conference proceedings, and excellent support from our sponsors.

The organizing committee for the first WCDS met at Alumni House at the University of Alberta in the summer of 1982 at the invitation of the University of Alberta. In attendance were representatives from the University of Alberta (Departments of Animal Science and Faculty of Extension), Alberta Milk Producers Association and Alberta Agriculture. The committee decided to adopt the two and half day format that had proven so successful for the Banff Pork Seminar. The first WCDS was held in Banff, April 3–6, 1983 with 77 fee-paying delegates in attendance.

The first seminar started with a wine and cheese on the Sunday evening followed by two full day programs on Monday and Tuesday and ending at noon on Wednesday. In 1985, the start date was moved to the current format with a wine and cheese reception on Tuesday evening followed by a two and a half day program, ending at noon on Friday. The introduction of concurrent sessions during the first decade of the conference allowed for an expansion of the conference program and thus provided greater choice in program content for attendees.

From the outset, the focus was on putting on a first-class seminar by bringing in the very best speakers from Alberta, Canada and globally. However, putting on a two and a half day program with quality speakers was expensive. Thus, the big challenge during the first 10 years of the WCDS was placing the seminar on a sound financial footing, as the attendance of 100 to 120 people was not sufficient to make the conference economically viable. Although the program was very attractive to those in attendance, the seminar lost money on an annual basis and the University of Alberta had to help bridge the gap on several occasions in those early years. Efforts to boost attendance, that included moving the seminar from Banff to Kananaskis for the 1989 and 1990 seminars, met with limited success.

The big breakthrough came in 1991 when the seminar moved to Red Deer, as the attendance immediately jumped to about 200. Each successive year saw new attendance records, reaching 350 in 1995, followed by the 500, 600 and 700 attendance records being broken over the next decade. As the attendance grew, so did our sponsorship, which has placed the seminar on a strong financial foundation today. Thus, we can look ahead to the next 35 years with confidence knowing that the excellent attendance and the support of our sponsors provide the resources to continue to put on an excellent program each year.

The seminar was initially called the Alberta Dairy Seminar, but the name was changed to Western Canadian Dairy seminar in 1989 to reflect the fact that an increasing number of attendees were from out of province. Today, the conference attracts people from across the country, and indeed internationally, and is Canada's premier dairy conference. Over the years, the organizing committee was expanded to include a broad cross section of industry stakeholders who have played a critical role in helping ensure that the seminar program covered topics that were of interest to producers as well as other industry stakeholders.

The formula that has served the WCDS so well over the past 35 years has a number of key ingredients:

- an Advisory Committee that is representative of a broad cross section of the industry to provide guidance on the annual WCDS program
- excellent speakers who are at the forefront of knowledge in the subject area, and a quality conference proceedings that serves as a reference after the conference
- program directors who dedicated the time needed to put on a quality program, and conference coordinators who ensured that all the details for

the smooth operation of the conference were taken care of so that those in attendance had a positive experience

- a recognition that a lot of the learning occurs outside the formal talks; thus, the program is designed to provide adequate opportunity for one on one dialogue and learning among producers and other industry stakeholders
- strong sponsorship support so that the seminar has the resources to put on a first class program

The WCDS Program Over the Years — Fundamentals Unchanged but New Areas Emerged

In 2007, on the 25th anniversary of WCDS, Kennelly stated, "that more than three hundred (300) different speakers, drawn from academia, government and industry, have participated in the seminar. This represents an average of 13 original speakers per year for the 25-year history of the seminar. The extraordinary breath and diversity of talent represented by this diverse group of speakers is what has made the WCDS so special over the years. Those attending the seminar could always be guaranteed a fresh viewpoint on a wide range of topics – there was always something for everyone".

Although there have been significant changes in program emphasis over the years, it is perhaps not surprising that some subjects have formed the core of the program throughout the history of WCDS. Nutrition has featured in one form or another every year, reflecting the importance of this subject to the overall success of a dairy operation. Similarly, mastitis, reproduction and herd health have been top of mind for producers on an ongoing basis. Other areas that have received a lot of attention were forage quality, feeding management, lameness, replacement heifers and genetics. The relationship between level of milk production and profitability is a subject that also continued to be popular over the years.

As time passed, there was also a growing emphasis on the human resources needed to successfully operate dairy operations that were increasing in size and complexity. Dairy policy was a subject that often generated a lively debate, especially during those years when new trade agreements were being negotiated that were a threat to supply management.

Although the above topics were a recurring theme at the seminar, new areas emerged over the years. These included a growing emphasis on the environment, starting out with manure management and progressing to greenhouse gases and the carbon footprint of dairying. Animal welfare is another area that has steadily grown in importance, driven in part by consumers who are demanding the highest standards in the humane treatment of animals. Cow comfort has also received a lot of attention ranging from the design of free stalls to the bedding material used to ensure optimal comfort.

The impact of continually increasing levels of milk production on reproductive performance and longevity has also been debated at length over the years. Interestingly, this theme has continued from the early days of the seminar when production levels were relatively low compared to those achieved today. The challenge of maintaining a healthy cow immediately post-partum has been addressed by many speakers. This has included new approaches to feeding during the peripartum period that have included differential feeding programs during the far off and close up dry periods.

One cross-cutting trend across all disciplinary areas is the increasing level of precision evident in the presentations by the various speakers over time. For example, in the nutrition area, we have moved from protein requirements to the quality of protein and the amino acids needs for milk production. Similarly, we have progressed from concentrates and forages to emphasis on particle size, impact on rumen environment and link to metabolic disorders. This trend reflects a growing understanding of the complex mechanisms underlying the biology of milk production and cow health. This understanding allows for greater precision in diet formulation to optimize both milk yield and milk composition. A relatively new trend in dairy is the emphasis on feed efficiency reflecting both increased feed costs as well as a realization that maximum milk production does not equate to maximum profitability.

There have been big shifts in emphasis on milk components over the years. These have reflected changes in demand for milk components that have ranged from minimizing milk fat to maximizing milk fat content, as market demand for milk components changed.

It is 20 years since the first talk on Johne's disease at WCDS, but it has been on the program just about every year since then reflecting its importance from both an animal health perspective as well as its potential link to human health.

Dairy producers have always been leaders in employing new technology as evidenced by the fact that technology underpins every aspect of modern dairy operation, from the use of robotic milking systems to precision feeding of dairy cattle. Times have certainly changed since Mark Varner's 1996 presentation entitled "The Information Superhighway" – Getting Your Learners License".

Finally, it is nice to know that the dairy cow continues to be an amazing metabolic factory that produces high quality human food with ever-increasing efficiency despite the rather foreboding title of a 1985 talk entitled "Is the Dairy Cow an endangered Species".

▪ The Evolution of Dairy Research and Extension in Alberta

As the mandate of the WCDS is to provide a forum for the exchange of information about recent research results, let us reflect on the evolving research and extension activities in Alberta over the last 35 years.

Producers in Alberta have a long history of commitment to supporting research. Originally, a 0.01/hL assessment was collected for the sole purpose of supporting dairy production research in Alberta. In 1992 there was support to increase this assessment to $0.02/hL and effective May 1, 2007 Alberta producers supported an increase in the assessment to $0.05/hl. Also in 2007, agreement was reached between the University of Alberta and Alberta Milk for the university to sell its quota holdings to establish an endowment fund of $1.6 million to support dairy research at the U of A. In exchange, Alberta Milk agreed to extend their commitment, originally made in 1999, to provide quota accommodating the university's production of milk to a maximum of the production capability of the equivalent of 150 cows, the maximum capacity at the U of A research facilities.

The U of A quota sale and the creation of the endowment fund was an excellent opportunity to crystallize the value of the quota held by the U of A by securing long-term support for dairy research at the U of A. Since the establishment of the endowment fund in 2007, an additional $500 thousand was added to the fund from the sale of the quota held by the Canada/Alberta Livestock Trust and used by the Lethbridge Research Centre. In May 2015, the U of A was successful in securing in excess of $933 thousand in matching funds from the government of Alberta.

A more collaborative, cooperative and coordinated approach to research was formalized through the creation of the Dairy Research and Technology Centre (DRTC) in 1999. The DRTC agreement facilitated collaboration and the sharing of resources and expertise between the U of A, Alberta Agriculture, and Alberta Milk. It also helped provide the support needed to enhance the physical facilities for dairy teaching and research at the U of A. In April 2010, a new agreement was reached, the Dairy Research and Extension Consortium of Alberta (DRECA) that added the University of Calgary, Faculty of Veterinary Medicine to the partnership. DRECA continues to be the platform for the coordination of research, extension and education activities that contribute to the sustainability and advancement of the dairy sector.

Since 1995, $5.4 million dollars in producer funding has been invested in research to increase productivity and profitability of the dairy industry. These funds have leveraged over $35.6 million in additional funds from 35 funding partners that includes the government of Alberta, the U of A, the U of C and the federal government. These funds have supported research in five key areas: dairy animal health and welfare, nutrition, reproduction, new product development and economic development. Also of significance is that the collaboration between the universities and many of the funding partners has resulted in the establishment of three NSERC Industrial Research Chairs (IRC) in Western Canada. The IRC in dairy cattle welfare at UBC; the IRC in infectious diseases at UCVM and the IRC in dairy nutrition at the U of A.

▪ Dairy Industry — Changes Over the Past 35 Years

As we pause to reflect, is there any simple way to summarize the past 35 years in the dairy industry? Maybe it can best be done through two words “consolidation and collaboration”.

Collaboration in the dairy industry was clearly demonstrated in 1983 when all provinces except Newfoundland signed the National Milk Marketing Plan (NMMP) and Memorandum of Agreement, replacing the Interim Comprehensive Milk Marketing Plan that had been in place since 1971. The agreement had three main objectives: manage the supply of industrial milk to meet the Canadian requirements, provide a basis for determining provincial shares and provide a basis for collecting fees for surplus removal. A point of contention that arose almost immediately after signing revolved around the determination of provincial shares. It took until 1989 to reach an agreement to allocate quota on a 90:10 basis (90% on historical shares and 10% on population growth); this was revised to 10:90 in 2000. Newfoundland joined the NMMP in 2001. The NMMP continues to serve the industry to collectively meet the demand for milk. These agreements were not easy to achieve, balancing the political and processing realities of the Canadian dairy industry. The withdrawal of British Columbia from the National Plan in 1982 set the stage for special status of allocation of industrial quota to BC, the “65:35” formula that ensured sufficient MSQ to meet provincial processing requirements. The Western Milk Pool Agreement ended this “special arrangement”.

In 1995, the Canadian Dairy Commission (CDC) Act was amended to allow the CDC to operate revenue sharing pools. In August of that same year, the Comprehensive Agreement on Special Class Pooling signed by all provinces except Newfoundland came into effect. Newfoundland joined in 2001. Under the special class pool, revenue from products in the special classes was shared equitably among all nine provinces. The national harmonized milk classification system allowing for end use pricing came into effect at the same time. Multiple component pricing, implemented in 1993, changed the way producers were paid for milk. It meant that producers were paid on butterfat, protein and other milk solids instead of volume (with a differential based on butterfat content).

In 1995, the Dairy Industry Advisory Committee noted that market changes dictated that expanded pools were the future in order to adapt to the challenges created by disappearing provincial borders. The All Milk Pooling Agreement involving PEI, NS, NB, QC, ON and MB (P6) came into effect in 1995. Pricing differentials on fluid milk between BC and Alberta were based upon a “gentleman’s agreement” between processors. When this broke down, the potential of a race to the bottom price war between producers became a reality. The solution was found in the Western Milk Pool (WMP) formed in 1997. The WMP pooling agreements meant the pooling of all revenues from milk sales among all producers, sharing of markets, and establishing a common price for milk components by class. Manitoba joined the WMP, operating in both pools, but withdrew from the P6 pool in 2003. The pools continue to operate to the benefit of the industry.

Through the 35-year period in which the WCDS has operated, there were also significant international trade deals that impacted the Canadian industry. Driving the formation of the pooling agreement was the loss of Article XI within the General Agreement on Tariffs and Trade during the Uruguay round of negotiations that started in 1986 and concluded in 1993. The loss of Article XI meant the exemption for supply management was lost and tariffs were introduced to protect the domestic dairy market. The World Trade Organization officially commenced on January 1, 1995 replacing the GATT. During the same time period, the Canadian government negotiated and signed the Canada-United States Trade Agreement, which in 1992 become the North America Free Trade Agreement when Mexico joined. The impact of these agreements also resulted in new rules governing export subsidies and resulted in exports to the USA being significantly impacted.

The other trade deal having a significant impact on the dairy industry is the Comprehensive Economic Trade Agreement (CETA) reached between Canada and the European Union in October 2013. When fully implemented, the CETA agreement will provide additional access of 17,700 tonnes of cheese, namely fine and specialty cheese. The full legal text was signed in October 2016 and implementation will commence in 2017. The federal government also reached an agreement with 11 other countries including Japan, the U.S., New Zealand and Australia on the Trans Pacific Partnership. The agreement was signed on February 4, 2016. The agreement must still be ratified by each of the 12 countries and with the new U.S. President opting out of the TPP; it is unlikely that the agreement will come into effect.

■ Alberta Milk

Consolidation has been a part of Alberta Milk over this period. In 1989, Alberta Milk Producers organization moved from being registered under the Cooperatives Act to the Societies Act. Alberta Milk Producers Society (AMPS) was the provincial umbrella organization for the eight local producer organizations. AMPS received a universal assessment to support policy and advocacy activities on February 1, 1996 based on support from producers. In 2000, Alberta Milk Producers started two initiatives. Producers supported the merger of two producer lead and funded organizations, the Dairy Nutrition Council of Alberta (DNCA) with AMPS. This merger was predicated on the desire to better align marketing and nutrition education messaging and activities at the consumer level and to add efficiencies in administration. The merger of the two organizations took effect August 1, 2001. At the same time, based on a request from the AMPS, the provincial government initiated a governance review of the dairy industry in October 2000. The objective of the review was to consider merging the activities of the Alberta Dairy Control Board with those of the AMPS. The result would be a new producer lead marketing board under the *Marketing of Agricultural Products* Act that had the responsibility for all aspects of the dairy industry, quota and production management, advocacy, milk quality and food safety, promotion and nutrition education. A producer plebiscite held in the fall of 2001 resulted in 91.8% of the producers in Alberta that voted endorsing the establishment of Alberta Milk as a marketing board. Alberta Milk as a marketing board came into effect August 1, 2002. In 2005, the consolidation of the control board and Alberta Milk was enhanced when the organization moved into its own office merging the offices located in Wetaskiwin and Edmonton.

Consolidation in marketing and nutrition education has been ongoing since the merger of DNCA and the marketing activities in 2001. Marketing and nutrition education activities were targeted to educate consumers, mostly targeting children up to age 18 and mothers who do most of the grocery shopping in Canadian homes. It has been a multi-pronged approach. There is advertising, nutrition education (why milk is good for you), education of the consumer about dairy farming (as the consumer is further removed from the farm), and encouraging children to drink milk on a daily basis through a school milk program.

The elementary school milk program, Club Moo, was originally pilot tested in 1985 and celebrated 30 years in 2015. Club Moo is a milk program that encourages children to develop the healthy habit of drinking milk everyday by making it fun and rewarding. The school milk program was extended to junior and senior high schools through a collaborative initiative across western Canada.

Nutrition education activities in Alberta have collaborated with Alberta Education in offering programs that fit in the Alberta school curriculum such as Power 4 Bones program within the Alberta grade 5 curriculum and Power to Play, targeted to younger children in kindergarten to grade 3, that launched in January 2008. Programs aimed at health professionals have also been a focus for nutrition education and messaging. The Alberta Milk run Nutrition

File Seminar has been hosted by Alberta Milk since 1998. Annually this event attracts over 250 participants.

Prairie Milk Marketing Partnership (PMMP) that included Manitoba, Saskatchewan and Alberta formed in 2002 with the collaborative launch of a joint fluid milk campaign - *Never Stop. Milk.* For 10 years, the PMMP ran successful TV, radio, billboard and print based campaigns across western Canada focused on white and chocolate milk and cream. Chocolate milk promotion focused on the benefits of chocolate milk as a sports recovery beverage while white milk activities spoke to the enjoyment of milk and its many benefits in a healthy diet. Further collaboration happened with the formation of Milk West and the Strategic Milk Alliance. Milk West was an extension of the PMMP when BC joined the prairie provinces in 2012. Partnering with Dairy Farmers of Canada (DFC), the Strategic Milk Alliance adopted the "*Milk Every Moment*" campaign for all of English speaking Canada. Alberta Milk has taken this collaboration one step further with the transfer of all marketing and nutrition education resources to DFC effective January 1, 2017. In an ever-increasing global environment, national collaboration only makes sense.

▪ Producers

The dairy industry is often accused of being static, and that supply management discourages change at the farm level. Let us reflect on some of the most significant changes and policy adjustments at the farm level that have occurred or been implemented over the last 35 years.

Consolidation has been no more obvious than in the number of producers. There has been a decrease in producers by 64% from 1983 to 2016, from 1,458 to 530. At the same time, production has increased by 28% (Table 1)

At the introduction of supply management, production was geared primarily to the fluid market. In the early 70's, Alberta was divided into milk sheds, where fluid producers supplied individual dairy plants. Milk in excess of table demand was directed to the "industrial" market. Creameries dotted the province, producing butter along with other "industrial" dairy products. Fluid quota was traded amongst the producers shipping to those plants and fluid milk attracted a substantial price differential. The two provincial cooperatives, Alpha and NADP, provided the "balancing wheel" for the industry, handling the often volatile demands of the fluid market, ensuring a home for all farm production. In 1975, producers voted to move to an Alberta wide quota system, in which all producers participated in the fluid and industrial quota system. Dairy farmers have continued to work together, both provincially and nationally, to develop an integrated production and transportation system that is both equitable and efficient.

Table 1. Number of producers and milk production in Alberta from 1983 to 2016.

	1983	1993	2003	2013	2016
No. Producers	1,458	1,312	775	571	530
Total Shipments, hL	5,672,000	5,430,000	6,169,963	6,626,993	7,250,436
Butterfat, %	3.52	3.68	3.60	3.93	4.01
Average Blend Price, $/hL	N/A	52.35	58.47	79.41	81.14

Source: Alberta Milk

Skim-off

In the late 1970's a processor in Alberta developed a "new" product in response to a perceived consumer demand for "low fat" products. With the introduction of 1% milk, a new source of butterfat became available to processors, one that was not covered by MSQ. As this product was adopted across Canada, producers of industrial milk soon noticed the subsequent reduction in MSQ. Especially hard hit were Quebec farmers, who held almost half of the MSQ in Canada. A skim-off levy was introduced in 1977. With the leadership of DFC, a skim-off agreement was developed and signed in 1991, demonstrating the strength of our national system and the commitment of Canadian dairy farmers to work together.

Move to Single Quota

The move to a single total production quota (that would combine the fluid and industrial quotas) was a discussion in Alberta that originally happened in 1994. Following a similar initiative in Nova Scotia, a 60% threshold was determined to be required before AMPS would recommend the change to the Dairy Control Board. Producers voted 58% in favour of the Alberta Integrated Quota in the fall of 1994, resulting in no request for change. Discussions on moving to a single quota happened again unsuccessfully in 2000. Finally, driven by the discrepancy in price between fluid and industry classes, due to increased use of special classes and given that industrial classes were not experiencing the same price increases as fluid milk, a renewed effort to move to a single quota was initiated in the spring of 2008. It was also felt that a single quota system would allow for greater policy harmonization across Canada.

Producers endorsed the switch to single quota by over 80% based on a net revenue basis. As a result, Alberta Milk converted to a single quota for all producers on August 1, 2008, ensuring equitable treatment of all producers.

Milk Pricing

The change to the way fluid milk is priced at the producer level transitioned from the Alberta Utilities Commission (AUC) to Alberta Milk effective September 2009. It goes without saying that the AUC served the industry well over the last 70 years, but as the industry evolved there was a need for new approaches. Having the authority and ability to enter into national discussions and make decisions with our counterparts from across Canada, and with processors, also helped position the industry for the future with an approach that treats all producers in Canada in a similar manner. A national fluid milk pricing formula was fist implemented for the February 1, 2010 price adjustment.

Social License to Operate

The consumer demand to know how, where, and when their food is raised is ever increasing. At the same time, the consumer has less direct connection to agriculture and farming practices. As a result, the agriculture industry has responded by adopting best management practices. One of the first programs aimed at addressing these consumer demands was the Canadian Quality Milk (CQM) program. This national program was developed on behalf of farmers by farmers under the guidance of DFC. The CQM program is a HACCP based on-farm food safety program. CQM was first introduced in 2002 with 35 herds volunteering to take part in a pilot project. CQM became mandatory, as a condition of a producers license, on August 1, 2009.

However, consumers want further proof and they want to know that the products they buy are safe, are produced responsibly, and meet social standards. To further maintain and enhance processor and producer confidence in the quality and sustainability of the Canadian milk supply, DFC developed, and is implementing through the provincial organizations, the proAction initiative. proAction encompasses six key elements under one program: milk quality (the Milk Grade and Price Program), food safety (CQM), animal care, livestock traceability, biosecurity and the environment. proAction was fully endorsed by all members of DFC in July 2013. proAction is designed by farmers for farmers and is designed to allow for continuous improvement. The milk quality program in Alberta has been in place for many years. The on-farm food safety program was introduced in 2002 and animal traceability is a legal requirement in Alberta. The Animal Care module will become a requirement as of September 2017. The environmental and biosecurity modules are under development and will be fully implemented by 2023.

Modernizing the Industry

At the 2007 WCDS, Pierre Doyle, Director Dairy Programs with Agriculture and Agri-Food Canada, presented a paper on Dairy Protein Ingredients in Canada: A Perspective. The take away message was that new ways to use dairy ingredients, namely protein, was changing the industry at a rapid pace. The need for better utilization of solids non-fat (SNF) has been an industry challenge for more than 20 years. Structural surplus grew from a low of 15,000 MT around the year 2000, gradually increased to 50,000 MT, and had climbed to 70,000 MT by 2014.

On December 1, 2004, a number of producer policies were put into effect to help deal with the amount of structural surplus in the system. The first was a minimum butterfat policy of 3.25 kg/hl. This meant that all milk delivered will continue to be paid for the actual butterfat content, but for producers with butterfat tests lower than 3.25, their quota will be calculated as if they had shipped 3.25% milk. The objective of this policy is to ensure producers are shipping milk that contains at least 3.25% butterfat. It targets producers with very low butterfat levels, who are contributing the most to the structural surplus. The second policy was a pricing policy. The price paid to producers for protein was reduced by $3/kg and this amount was shifted to the price paid for butterfat. The third policy was the introduction of a SNF/BF ratio. Just as each province must contribute to reach the national target ratio, each producer was asked to do their part.

Nationally, each province accepted responsibility to fill at least 97% of its quota allocation in the first six months of the dairy year. The 97% calculation is based on all milk shipped, both fluid and industrial. If a province does not achieve this mid-year accountability, the cumulative under production was not carried forward into the last six months of the dairy year. Simply, each province had to ship 97% of its total allocated quota in the first six months or lose the ability to ship to that differential (the amount under 97%). Should the above occur, the producers who are under 97% were held accountable and had their quota adjusted accordingly.

However, the fixed year-end and mid-year accountability had its own challenges. Producers were pushing to get production in the fall and often needed to slow down in July for year-end. A continuous system would allow provinces to make more gradual quota adjustments, easier to manage provincial quotas and more flexible at the national level. A national continuous quota system at the provincial level was adopted for August 1, 2008. Each province had flexibilities limits of +0.5% and a lower limit of -1.5%. The following year (August 1 2009) there was agreement to adopt continuous quota at the producer level. In Alberta, producers were provided with flexibility limits of +10 days and -30 days.

Concentrated efforts to find new ways to use domestic SNF were first initiated in 2006, when the federal government established the Dairy Industry Working Group, led by Agriculture and Agri-Food Canada, involving producers and processors. A second attempt at finding a way to deal with structural surplus and modernize the industry was the 2012 Dairy Industry Producer Processor Dialogue, also facilitated by the federal government. Neither process reached a conclusion.

Dairy Farmers of Canada initiated its own process in 2007, known as the Montebello Working Group. This group explored the opportunities to use dairy ingredients. While the Montebello process did not lead to any new initiatives, DFC continued to pursue a new environment for the Canadian dairy industry. In May 2014, producers presented a proposal to processors and governments that had three main elements: stabilize producer income that had been eroded over the two years, deal with the surplus removal that would greatly reduce or eliminate the mountain of skim milk powder, and provide market growth for both producers and processors. In January 2015, processors presented a response with their own proposal. A negotiation process started in August 2015 and concluded in July 2016 with the announcement that a Memorandum of Understanding had been reached. The new strategy will be implemented starting February 1, 2017.

Consolidation and collaboration has been the focus of the dairy industry in all aspects — from research to marketing and promotion. Consolidation will continue and could very well lead to the industry being governed at a regional level - Western Milk Pool Board governing the industry in Western Canada – in the next 35 years.

GMOs – Food Supply Saviour or the Devil in Disguise?

Margaret Smith

Professor, Plant Breeding and Genetics, Cornell University, G42 Emerson Hall, Ithaca NY 14853, USA
Email: mes25@cornell.edu

■ Take Home Messages

- Human intervention in crop genetics through selection and conventional breeding goes back thousands of years.
- Genetically engineered (GE) crop varieties (or GMOs) result from a new tool that humans use to genetically improve crops.
- Currently, there are commercially-sold GE varieties of soybean, corn (both field corn and sweet corn), cotton, canola, sugar beet, alfalfa, papaya, and summer squash in the U.S. GE potatoes and apples were approved in the U.S. recently, but there are no commercial plantings of these GE crops yet.
- Adoption of GE herbicide tolerant crop varieties in the U.S. has been accompanied by increased herbicide use per acre. However, there also was a shift to more use of a herbicide with low environmental impact quotient, and reduced use of more damaging herbicides. GE herbicide tolerant varieties facilitated reduced tillage, which has environmental benefits.
- Adoption of GE insect resistant varieties of cotton and corn in the U.S. has been accompanied by reduced insecticide use per acre.
- Four multinational companies hold 79% of the U.S. approvals for commercialization of GE crop varieties. This could go as high as 84% if Bayer's proposed purchase of Monsanto moves ahead.
- Ingredients derived from GE crop varieties are found in an estimated 60% to 70% of packaged, processed foods in the U.S.
    - Most (but not all) are present as highly refined ingredients that no longer contain any of the GE genetic material or its protein product.

  - Highly refined ingredients from a GE variety and from a non-GE variety are chemically indistinguishable.
- To date, there is no scientifically-confirmed evidence of food or feed safety concerns with GE crop varieties commercialized in the U.S.

▪ Introduction

Genetically engineered organisms (what many call GMOs – genetically modified organisms) are increasingly showing up in newspaper headlines and on web sites, blogs, and emails. There have been media splashes about new genetically engineered (GE) crop types, contentious debates about labeling legislation, and even shocking photos claiming to show animals harmed by consuming GE crop products. After noting possible reasons why genetic engineering has stirred up so much controversy, this article will describe GE crops, their prevalence, and evidence about the impacts of GE crop adoption in the U.S. The aim is not to tell anybody what to think about GE technology, but rather to explain what is known about GE crops and thus help all of us arrive at better-informed personal perspectives on GE crops and their roles in our agricultural and food systems.

▪ Why the Controversy?

It is not often that plant breeding-related topics make it onto newspaper covers or are the subject of activists' protests. Why now? Shortly after the first GE crops were commercialized in 1996, Hallman et al. (2001) did a survey of the general public to assess their understanding of traditional crop breeding and genetic engineering (which was newly entering the market at that time). After a simple explanation of traditional cross breeding, respondents were asked, "Have you ever eaten a fruit or vegetable created using these methods?" Only 28% correctly answered "yes", while 61% said "no" and 11% were not sure (Figure 1). In reality, North Americans have eaten little but traditionally cross-bred crops for at least the last hundred years. Responses were very similar when people were asked a question about whether they had ever eaten a GE fruit or vegetable (Figure 1), even though almost no GE crops were available in the market at the time.

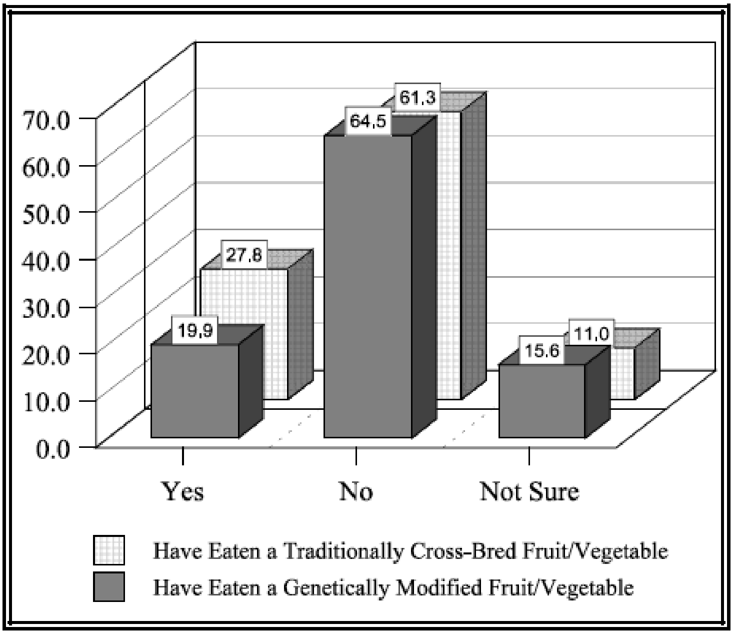

Figure 1: Reported consumption of traditionally crossbred and "genetically modified" (GE) fruits and vegetables. Source: Hallman et al. (2001).

Clearly, the general public has limited understanding of past or present human crop breeding activities. Along with that confusion, we have introduced a new genetic technique that is being applied to ingredients in the food we eat every day. Mix that with the perception that any new technology probably brings with it some inherent risks, and it is no surprise that controversy resulted.

▪ What Are Genetically Engineered Crop Varieties?

Genetics of Crop Domestication and Improvement

GE crops cannot be fully understood without first considering the history of our domesticated crops. Virtually all of them had their origins thousands of years ago, with wild species that early hunter-gatherers found useful as sources of food. For corn, that wild ancestor was teosinte, a grass with heads containing about 10 small seeds that fell on the ground when they were mature and were indigestible unless they were cracked or ground to break open the seed coat (Figure 2). As for all living organisms, the traits of wild crop ancestors were determined by the genetic code contained in their DNA. That code provides the instructions for the traits an organism possesses and how it grows. The DNA code varies from plant to plant of the same species, allowing for individuals to differ one from another. Since the entire DNA code must be copied every time a cell divides (to provide copies for the two daughter cells), copying mistakes (called mutations) happen regularly. These mistakes, or mutations, are the source of differences among individuals of the same species.

Figure 2: Left photo: Modern corn (left) and its wild ancestor, teosinte (right). Right photo: Seeds of teosinte (lower left), typical commercial yellow dent corn (upper left), and Andean flour corn (right) with penny for comparison.

As the early gatherers found naturally-occurring mutant types that happened to be useful to them, they collected and saved them. For example, they would have chosen and saved seed from teosinte plants that had larger seeds, and seeds that stuck to the central stem (now the cob) when they were mature rather than falling on the ground, and seeds lacking the hard indigestible seed coat. Gradually, those genetic changes (resulting from natural mutations) that were favored by farmers' selection of seeds from the most useful and productive plants created a new domesticated crop, corn, from what had been a wild plant. Similarly profound changes took place in all our domesticated species — a long-term process of genetic modification brought about by human selection. Since the time of domestication, human breeding and selection of crops and livestock have continued and intensified as our knowledge of genetics and performance measurement has improved. In reality, our domesticated crops are no longer "natural." Most would never survive in nature (that is, without a partnership with farmers who cultivate them) because they have been so profoundly genetically changed from their wild ancestors and even from their earlier domesticated predecessors (Figure 3).

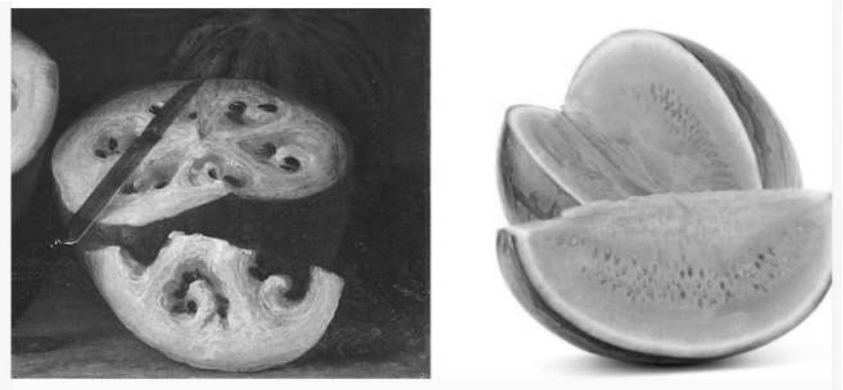

Figure 3: Watermelon from a still life painting done by Giovanni Stanchi in the mid-1600s (left) and current day watermelon improved by traditional plant breeding (right). Credit: James Nienhuis, University of Wisconsin.

Genetic Engineering: A New Tool for Crop Genetic Improvement

Although it is being applied to crops that resulted from this extensive process of human genetic improvement, genetic engineering is, indeed, a new tool that changes the genetic code in ways that were not previously possible. Our increased scientific understanding of the genes that control inheritance has allowed us to identify the genetic material of an organism that enables it to make particular compounds. For example, the bacterium *Bacillus thuringiensis*, long sold as a natural, organic, bacterial insecticide, can infect and kill certain caterpillar- and beetle-type insects. Researchers identified the gene in this bacterium that codes for the protein that is chemically converted to a toxin inside a caterpillar's or beetle's alkaline gut. They then inserted this bacterial gene (called the Bt gene) into crops like corn and cotton to create insect resistant versions of these plants: so-called Bt corn and Bt cotton. For each insect, a slightly different variant of the Bt gene from the bacterium is used because those genes differ in how effective they are against different insect species. In corn, for example, there are several different Bt-corn borer genes that also all differ slightly from the Bt-corn rootworm genes. Several of these genes are built into many commercially-available GE corn varieties.

A similar process was used to create GE plants that are able to tolerate being sprayed with herbicides that are normally toxic to plants. These include the glyphosate (Roundup) resistance genes and the glufosinate (Liberty) resistance gene, both originally found in naturally-occurring soil bacteria. Herbicide resistance from these genes (especially the "Roundup Ready" glyphosate resistance trait) has been built into many GE crops, including soybean, corn, cotton, canola, alfalfa, and sugar beet.

GE insect resistant (Bt) and herbicide tolerant (HT) crop varieties (including many with both traits together) are planted on the majority of U.S. soybean, field corn, and cotton acres (Figure 4). Survey data indicate that GE canola, sugar beet, and papaya varieties occupy the majority of acreage for these crops, while GE alfalfa was planted on 13% of U.S. alfalfa acres in 2013 (Gonsalves, 2014; Fernandez-Cornejo et al., 2016,). Reliable data for acreage of GE varieties of sweet corn and summer squash are lacking. Clearly many GE varieties have been widely adopted by farmers.

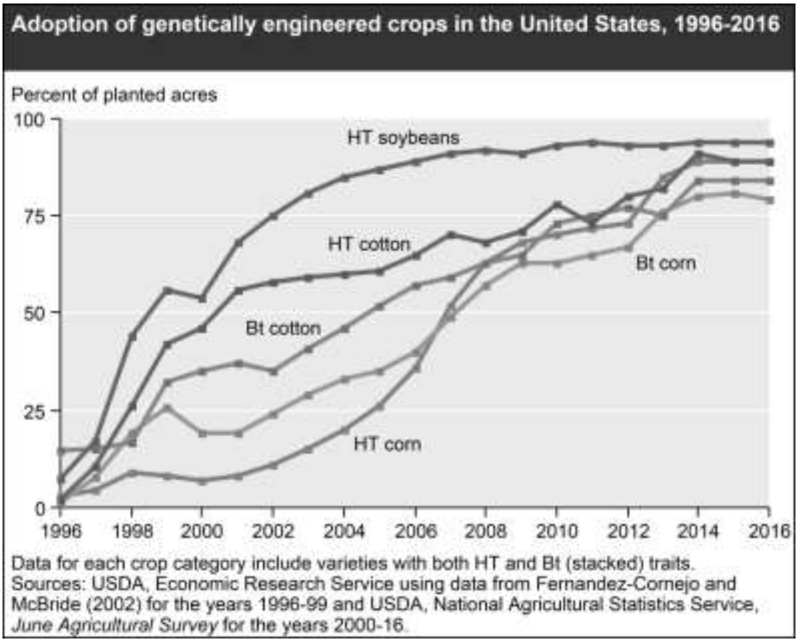

Figure 4. Adoption of GE crops in the U.S., 1996-2016. HT = herbicide tolerant. Bt = insect resistant. Source: USDA ERS (2016).

Similarities and Differences: GE vs. Traditional Plant Breeding

So how does genetic engineering differ from “traditional” plant breeding? (“Traditional” plant breeding means the kind of selection and breeding practiced by early farmers and by plant breeders for over a hundred years – cross pollinating different parents and searching among the offspring to find genetically superior types that better meet human needs). The GE crop varieties in the marketplace now were created by moving individual genes between organisms that cannot naturally cross breed with each other (like a soybean and a bacterium). For many years, plant breeders have made crosses between crops and their wild and weedy relatives to transfer genes for traits like pest resistance to the domesticated crops, so this process is not entirely new. However, traditional plant breeders are limited to moving genes between organisms that are so closely related to each other that they can be sexually crossed. Consequently, the range of genes that can be introduced into a GE variety is broader than what traditional plant breeding has access to, because genetic engineers can reach beyond the boundary of sexual cross-compatibility. Second, when making sexual crosses (i.e., traditional plant breeding), the offspring receive a relatively random mix of the genes from both of their parents, including both desired genes and any others that come along with them. Genetic engineering, on the other hand, inserts only one or a few genes into an existing crop variety, so the GE variety differs by only one or a few genes from its parent. This is why genetic engineering is described by some as more precise than traditional cross breeding. Lastly, the ability to identify and manipulate individual genes has led to the legal right to patent genes, so most (if not all) GE traits are patented and their use is legally constrained by the patent holder.

There are also similarities between traditional plant breeding and genetic engineering. Both depend on changes in the genetic code to create crops that are agriculturally superior. Both approaches aim to modify crops to better meet human needs, just as was done by the earliest farmers who domesticated our crops. Finally, it is not new that private companies seek a return on their investments in plant breeding. With traditional plant breeding, they were able to do that through plant variety protection laws and through marketing hybrid varieties for which seed must be bought each year. With genetic engineering, the option of patenting genes has provided a different avenue for private companies to seek a return on their investment. Thus, although genetic engineering is a distinct new tool for plant breeding, it shares some fundamental elements with traditional plant breeding: genetic variation is the basis, improving crops to better meet human needs is the goal, and private companies all seek a return on their research investment, whatever the nature of that research.

▪ Issues and Concerns Regarding GE Crops

The issues and concerns being raised regarding GE crops include some that can be informed by science (e.g., economics of production and use, environmental risks, food and feed safety) and others that are societal value questions (e.g., should GE crop products be labeled in the market? Is there too much concentration in the industry that controls and profits from GE traits? Is genetic engineering ethically wrong?). This section will cover the primary areas of concern about GE crops and describe data and research results that shed light on these concerns.

Economic Costs and Benefits

From a farmer's point of view, the farm-level economics of growing a GE vs. a non-GE variety are a major concern. The U.S. National Academy of Sciences' recent assessment concluded that many farmers had generally benefited economically from adopting GE soybean, cotton, and field corn, but that individual farm benefits are highly variable (National Academies of Sciences, Engineering, and Medicine, 2016). Seed of GE varieties is typically more costly because of the "technology fees" for the GE traits, and it is sold with technology use agreements that prohibit saving seed (even for your own on-farm use). There are also some domestic and international markets with limited acceptance of GE varieties. All of these factors can make production costs higher for a GE variety. On the positive side, however, GE varieties may achieve better yields, reduce labor and production costs, allow greater flexibility in management, and provide increased convenience for producers. In the future, there may be GE crops whose products have value-added benefits for consumers or processors, and thus they will receive price premiums, but these types of varieties are a tiny fraction of the commercial GE crop market at present. What should be clear from this brief list is that economic costs and benefits are very case specific, depending on the individual farm operation, the GE crop and trait being considered, and the marketing environment.

Environmental Impacts

Both farmers and consumers wonder about environmental impacts of GE crops. The National Academies of Sciences, Engineering and Medicine (2016) study found that adoption of GE varieties resulted in positive environmental impacts from reduced insecticide use and from less need for tillage (resulting in reduced erosion potential). There has been a pronounced reduction in insecticide use in field corn and cotton that has occurred with increased adoption of Bt varieties (Figure 5).

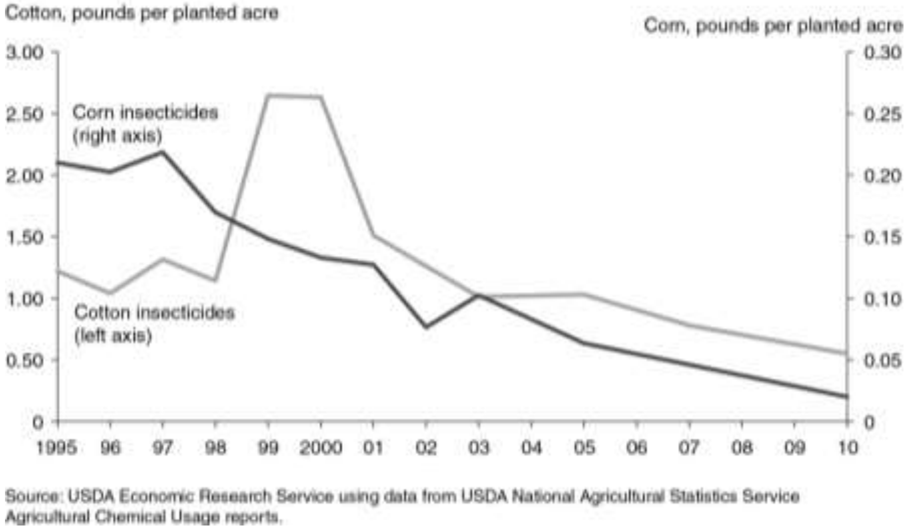

Figure 5: Insecticide use in field corn and cotton production in the U.S., 1995-2010 (field corn darker line and right axis, cotton lighter line and left axis). Source: Fernandez-Cornejo et al. (2014).

The results regarding herbicide use were less clear: overall herbicide use increased with adoption of GE crop varieties, but there was more use of a herbicide generally considered to be less toxic (glyphosate) and reduced use of some of the more environmentally undesirable herbicides. Figure 6 shows herbicide data for cotton, where the increase in total herbicide use can be most easily seen, and for soybean, where the shift in types of herbicides used is very pronounced (NAS-NRC, 2010). This combination of changes makes debate regarding herbicide use particularly complicated: opponents of GE crops can point to data showing that increased GE crop adoption was accompanied by increased herbicide use, and advocates of GE crops can point to data showing that use of environmentally-undesirable herbicides has declined and reduced tillage (with its environmental benefits) has been promoted. Both points are correct, but neither provides the full picture.

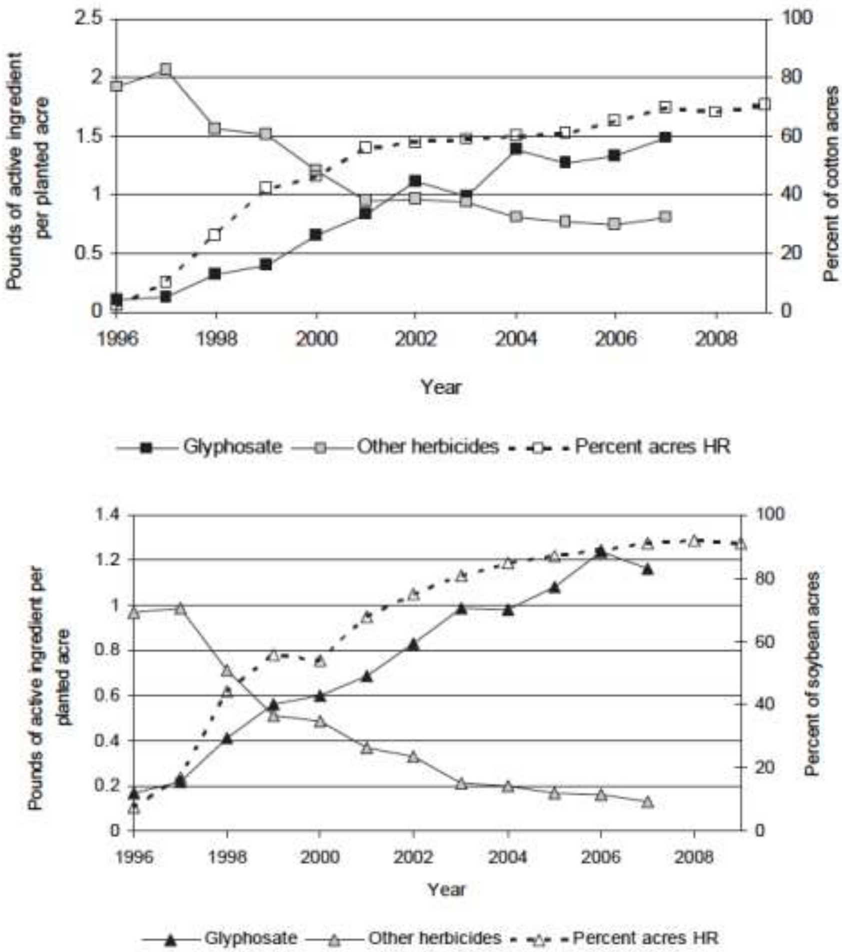

Figure 6. Herbicide use on cotton (top) and soybean (bottom) in the U.S. from 1996 to 2007. Solid black line: glyphosate use, solid gray line: other herbicide use, dashed line: percentage of U.S. acres planted to GE herbicide tolerant varieties. NOTE: The strong correlation between increased acreage of herbicide tolerant varieties and changes in herbicide use suggests, but does not confirm causation between these variables. Source: NAS NRC (2010).

The NAS NRC (2010) study noted the risk from pest evolution to overcome GE resistance. This is a risk for any pest control method, including traditionally bred resistance, chemical pesticides, and even some cultural control methods. Evolution of pest resistance to a control measure happens most readily when a single control approach is used repeatedly and over a large acreage. That is exactly what is happening with glyphosate resistant crops, and farmers are now seeing weeds that are resistant to glyphosate (Heap, 2016). There is evidence of the same problem with corn carrying the Bt-corn rootworm trait, and a few well-documented examples of control failures have occurred in recent years (Tabashnik et al., 2013). Both GE crop types have been very popular and provided very good pest control. Their effectiveness may have led farmers and the seed industry to rely too heavily on these single control measures. As with any pest control measure, over-use favors pest evolution towards more resistance. The importance of rotating or alternating pest control methods is a principle we learned long ago and have promoted through integrated pest management programs (National Academies of Sciences, 2016). It seems we need to re-learn it with respect to GE pest resistance tools!

Safety as Food and Feed

From a consumer's point of view, the logical concerns are whether GE crop varieties are found in foods, whether they are safe as food and feed, and whether GE approaches have or could introduce allergens into common foods.

A body of over 700 studies (including over 200 independently-funded studies) has not revealed evidence of any food or feed safety concerns with commercialized GE crop varieties (NIcolia et al. 2013; Haro von Mogel and Bodnar, 2015). Those few studies that have purported to show problems from feeding GE crops to animals have been widely discredited by scientists for their poor design, inappropriate analysis, and other scientific problems. There are also many peer-reviewed, published studies conducted by the private sector that show no evidence of food or feed safety concerns. Some people regard these studies as open to question, since most were carried out by the same companies that have a vested interest in marketing GE crop seed. That is true, but two points should be taken into account. First, many of these studies have had to meet the standards of scientific scrutiny that the peer-reviewed publication process demands, which provides some assurance (though not a guarantee) of scientific integrity. Secondly, it is not clear what mechanism exists to fund extensive safety testing done by the public sector (on the contrary, public funding for research has long been on the decline). In the absence of increased public sector funding, testing will continue to be done largely by those who can hope to recoup their research investment — the private sector companies who plan to market GE seed.

Concern about novel and unanticipated allergens is also important for consumers, as there is the chance that genes from organisms we don't normally consume as food might produce proteins with allergenic potential. Testing for allergens has relied on scientific understanding of the general nature of allergenic compounds, and on evaluating how fast the new proteins produced by GE varieties break down in human digestive enzymes.

Transgene protein products that are anything like known allergens are more thoroughly tested. Any new protein that breaks down more slowly than others when exposed to digestive enzymes also is more thoroughly tested (the longer something stays in your stomach without breaking down, the more time it has to cause an allergic reaction). Although this approach to monitoring for allergens has not proven very reassuring to concerned consumers, it is not clear that a better approach exists.

Concerns That Are Not Scientific in Nature

Areas of concern about GE crops that are not scientific in nature include the debate about labeling GE-derived foods, concerns revolving around consolidation of seed industries and profits from GE crops, and opposition to genetic engineering that is ethically or religiously based. As noted at the beginning of this section, there is a limited contribution that science can make to these debates. However, the following paragraphs provide some data upon which to ground discussions of these concerns.

Labeling of GE-derived Food Products

Recent years have seen extensive political and media debate about whether foods derived from GE crop varieties should be labeled. Various groups have estimated that 60% to 70% of packaged foods in a typical North American grocery store contain one or more ingredients from a GE crop variety. This level is not too surprising given the prevalence of ingredients derived from corn, soybean, canola, and even cotton in our processed foods, and the fact that the vast majority of North American acreage of these crops is planted to GE varieties.

Most food labeling in the U.S. is product based; it tells something about the content of the food in the package (how much protein, fat, oil, fiber, vitamins, etc. is in a serving). Most ingredients from GE varieties of corn, soybean, canola, and cotton found in processed food are highly refined ingredients, like corn starch, oils, corn syrup, soy lecithin, and many more. These ingredients are purified in the refining process and do not contain DNA or proteins. In such highly refined ingredients, there will be no detectable difference between a version derived from a GE variety and a version of that same ingredient derived from a non-GE variety. For example, corn syrup is chemically just sugar and water, so corn syrup from a GE corn and corn syrup from a non-GE corn will be chemically indistinguishable. This complicates labeling, because packaged foods that contain these highly refined ingredients from GE varieties would show no measurable difference from those made with ingredients from non-GE varieties, raising the question of what the label tells us. It also highlights the dilemma of label verification: for such products, there is no means for verifying the label accuracy by testing the product on the shelf.

A consumer survey that asked “Should GM food be required to be labeled?” found that 73% of respondents said “yes” (Hallman et al., 2013). That same survey asked “What information would you like to see on food labels that is not already there?” and only 7% of respondents brought up GE crop content. As always, the answer you get regarding the importance of labeling depends on how you ask the question. Proponents and opponents of labeling will use different parts of this same study to make their case — clearly an over-simplification of what the data tells us. There is no doubt that labeling will imply a cost (primarily due to keeping GE and non-GE crops and their products segregated from planting all the way to the grocery store shelf, and tracking them to ensure label accuracy). It is not clear that labeling will increase consumer choice, since there are already non-GE options available in stores including both certified organic products, which cannot be produced with varieties that were genetically engineered, and products voluntarily labeled as “Non-GMO Verified” (Non-GMO Project, 2015).

In 2016, the U.S. government approved a law regarding GE crop content labeling. It gives the U.S. Department of Agriculture two years to write regulations for a “national mandatory bioengineered food disclosure standard.” The standard will specify text, a symbol, or an electronic/digital link to provide this information on food packages. Restaurant foods and food derived from animals that simply consumed GE feed (but were not themselves genetically engineered) are exempted. Reactions to this law varied, but at a minimum it will prevent the confusion that would result from a patchwork of state-level laws.

Industry Consolidation and GE Crop Varieties

There is some concern that GE crops contribute to the overall trend toward consolidation, globalization, and industrialization in agriculture. The ability to patent genes appears to vest control over the raw material of agriculture — the genetics of our crops and livestock — in large private sector corporations. Developing and bringing a GE crop variety to market is a costly prospect, so it is beyond the reach of many smaller seed and crop breeding enterprises. Recovering the research and development investment for GE varieties has led some seed companies to seek as many outlets for their varieties as possible, adding additional push to what was an on-going trend toward consolidation in the seed industry. This can be seen by examining which companies have received approvals to commercialize GE varieties, and who now owns those companies. Of the 96 approvals for GE variety commercialization that have been granted in the U.S. to date, the original applicants included 30 different entities (private companies, universities, government agencies; Figure 7, top). With industry consolidation that has taken place since approvals were granted, these now represent only 17 independent entities, and 76 of the 96 GE variety approvals are held by only four companies (Figure 7, bottom). If the proposed Bayer purchase of

Monsanto moves forward, four companies will hold 81 of the 96 GE crop approvals. Whether this degree of concentration in ownership of GE crop technology is cause for concern is a societal value judgment, not a question that can be answered by scientific research.

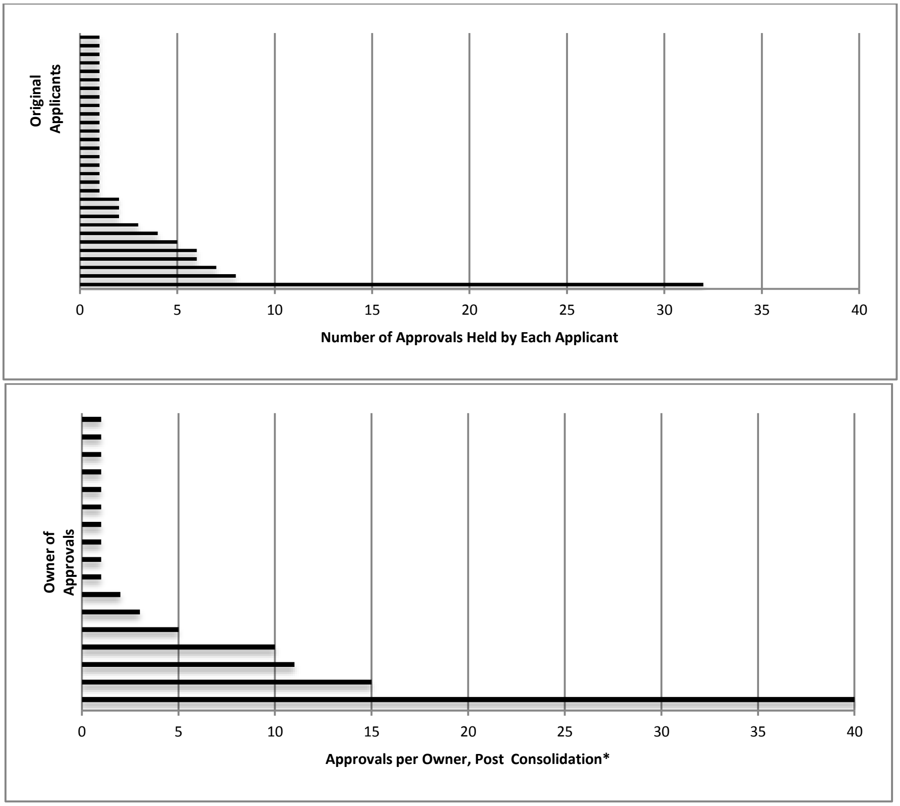

Figure 7: Original applicants for approvals to commercialize GE crop varieties (top) and owners of approvals after seed industry consolidation (bottom). Data source: ISB (2015). *Consolidation does <u>not</u> include potential Bayer purchase of Monsanto; if approved, the largest owner would hold a total of 45 approvals.

Ethical and Other Concerns

Some oppose GE technology based on ethical or religious beliefs. These too are concerns that cannot be answered by scientific studies. They will have to be addressed through public and political debate, policy-making, and regulation, which are the approaches we use to implement societal value judgments.

Summary

So what's the bottom line? GE crop varieties have their basis in genetic variation and creating new genetic combinations — phenomena that we have used for centuries to improve our crops for human use. However, genetic engineering is a new and different tool for crop improvement. The resulting varieties need to be monitored for their effectiveness, safety, and environmental impacts just like any other new technology. The outcomes of such evaluations will vary depending on the particular crop and trait, so evaluations must be made on a case-by-case basis. The currently commercialized GE varieties, which are primarily (but not exclusively) corn, soybean, cotton, canola, sugar beet, alfalfa, and papaya varieties, have proven themselves attractive to farmers and have not revealed any negative effects as food/feed. They have reminded us what we should have learned well a long time ago — it is unwise to repeatedly use the same pest control methods over large areas, because the pests tend to evolve to overcome those control methods. So we all need to remember that GE varieties, just like any other technology, are not a silver bullet for pest control. They must be used wisely. Finally, a robust body of scientific study has addressed questions of food and feed safety, and no convincing scientific evidence of problems with commercialized GE varieties has been revealed to date. On-going evaluation and monitoring will be needed to ensure the continued safety of GE varieties and their products in the future.

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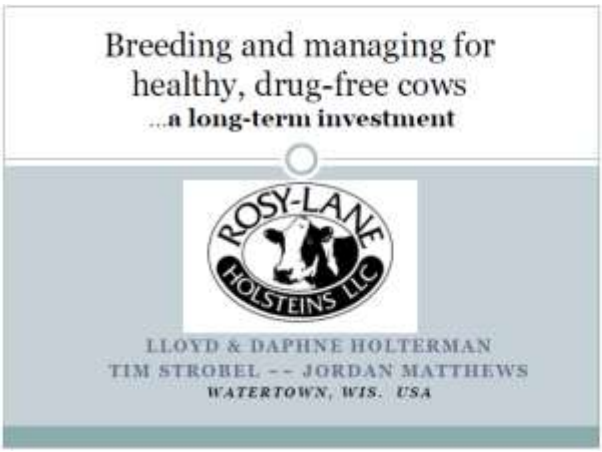
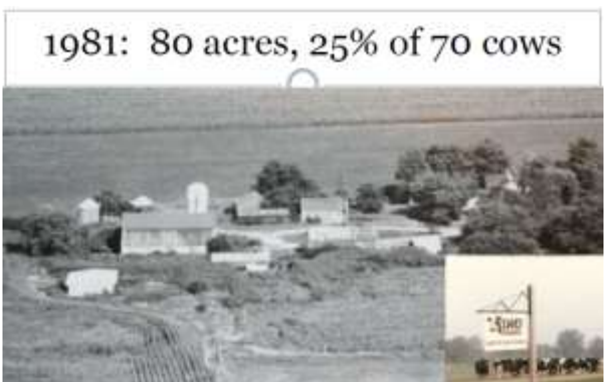
Breeding and Managing for Healthy, Drug-Free Cows… a Long-Term Investment

Lloyd Holterman

Rosy-Lane Holsteins, W3757 Ebenezer Drive, Watertown, WI, USA
Email: daphne@rosylane.com





2016

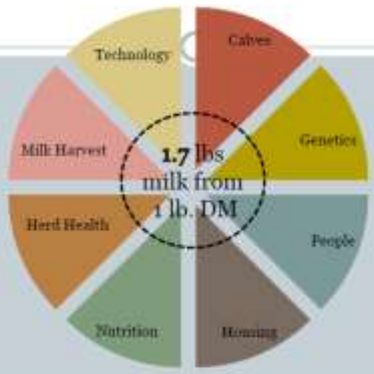
Four partners

Farm Overview

- Lloyd: finances, genetics
- Daphne: accounting, Human Resources, public relations, safety
- Tim: crops/machinery, environmental compliance, safety
- Jordan: cows, milking staff, reproduction

Overall Goal

1.7 lbs. of milk per lb. dry matter TMR (total mixed ration) fed to cows



$$ Income $$

92% milk
5% cull cows and bull calves
Less than 1% genetic sales
2% misc., government payments, etc.

Cow Goals

2016 actual	Goal
3.7% death loss	< 3%
0% treated with antibiotics	<0.5%
154 DIM	< 170
2.0 services / conception	<2.0
$1220 profit /cow/year 3 ave.	>$800

2016 Calf Results

- 570 raised
- 1.7 lbs./ head / day average daily gain
- Goal: double birth weight, ranges 40-80%
- 4.1 % DOA rate
- 6.0 % culls & deaths
- Healthy lungs, healthy stomachs


Ventilation tubes


• Clean water
• Fresh air
• Clean, fluffy, DRY bedding every day


Heifer barn

Pre-fresh

- 94% cows:stall ratio
- Big stalls, add fresh sand 2x week
- Don't move cows
- Top quality feed
- Fresh water (clean 2x week minimum)
- Excellent ventilation

Calving

- "Just in time" calving
- Move to freestall close-up group:
  - 14 days heifers, 21 days cows
- Checked every hour 24/7 when each group is moved to milking parlor
  - Move to straw pack during calving
  - Do NOT assist unless absolutely necessary

Calving

- Bovikalc at calving
- Milk cows within 30 minutes
- Feed calf within same 30 minutes
- Add lots fresh straw after each calving

Fresh group, continued

- 58 stalls
- 56 or less cows (48 is best)
- 2-year olds and cows together
- Move out healthiest cows at 15-21 days
- Dry hay top-dressed 2 lbs / cow / day
- Ketosis prevention:
  - Low energy pre-fresh diet
  - Feed always available

Fresh cow performance

- O.5% DA's (displaced abomasum)
- 0% Ketosis
- 0% Milk fever

Lactating cows

- Fresh group is 0 to 21 days post calving
- Monitor performance on Afi Milk
  - Daily milk weights
  - Check only poor performers, RP cows

Repro: leading reason for culling

Short term:
- Afi Milk real-time
- Double Ovsynch

Long term:
- Genetics!

Breeding

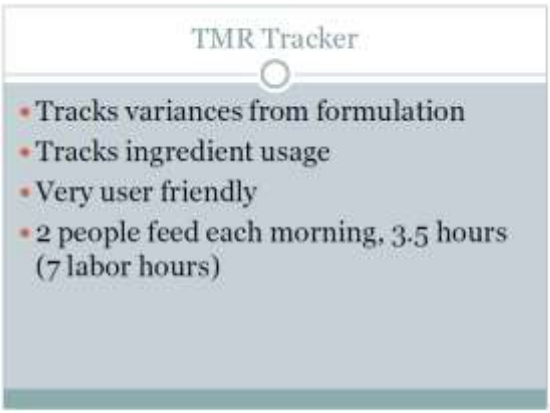
- Repro - No. 1 issue in our herd
- Pregnancy check ultra sound 32 days
- Re-check at 90 days & dry-off
- Pregnancy loss 8.6% cows, 5% heifers

Mastitis control – market 100% milk

- Alternating J-Vac and Endovac
- Add fresh sand 2X week; Scrape cow alleys 3X day
- Don't overcrowd groups:
  - <10% in two-row barn
  - <5 % in three-row

Mastitis control – market 100% milk

- Full prep
- Test clinicals on tri-plate incubator
- Enterobacter / E coli – treat
- Klebsiella and Pseudomonas – not treated
- Zero antibiotics used for 44 months!


TMR Tracker
• Tracks variances from formulation
• Tracks ingredient usage
• Very user friendly
• 2 people feed each morning, 3.5 hours (7 labor hours)

Lameness prevention

- Scrape alleys every day in all groups
- Dry alleys best for foot health
- Scrape lactating groups at every milking
- Copper sulfate footbath 1x week
- Soap/chlorine footbath 2x week

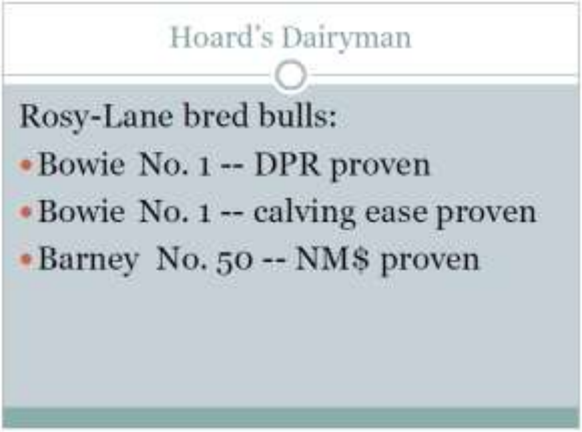
Lameness prevention

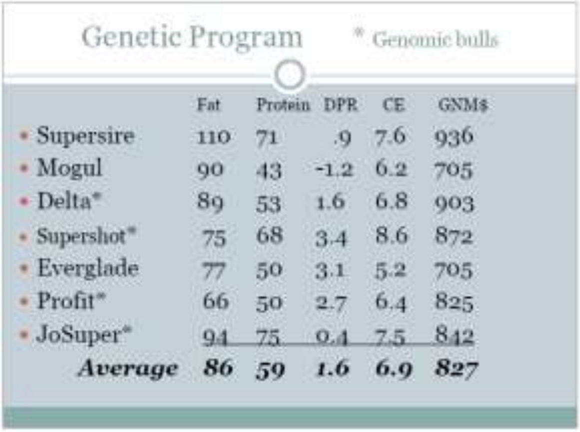
- Long term solution is genetics
- University of Wisconsin School of Veterinary Medicine research shows you should select for:
  - Moderate heel depth (select 0 to .5 linear)
  - Slightly spread toe

Research footnote

- Journal of Dairy Science 96:3713-3722
- American Dairy Science Association 2013
- Sire predicted transmitting ability for conformation and yield traits and previous lactation incidence of foot lesions as risk factors for the incidence of foot lesions in Holstein cows
- G. Oikonomou (Cornell University), NB Cook and RC Bacalho (Univ. of Wisconsin-Madison)


8-row cross ventilated barn
500 cows

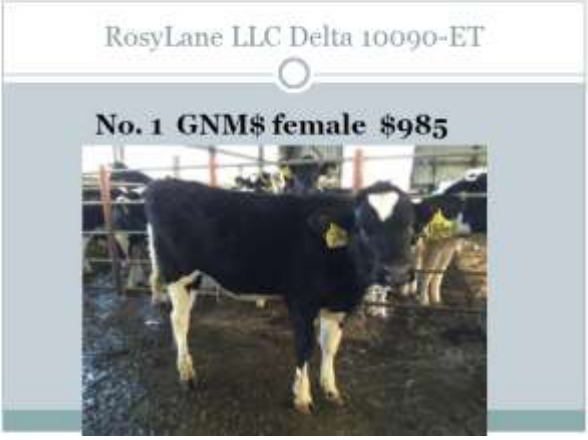




	Fat	Protein	DPR	CE	GNM$
Supersire	110	71	.9	7.6	936
Mogul	90	43	-1.2	6.2	705
Delta*	89	53	1.6	6.8	903
Supershot*	75	68	3.4	8.6	872
Everglade	77	50	3.1	5.2	705
Profit*	66	50	2.7	6.4	825
JoSuper*	94	75	0.4	7.5	842
Average	***86***	***59***	***1.6***	***6.9***	***827***

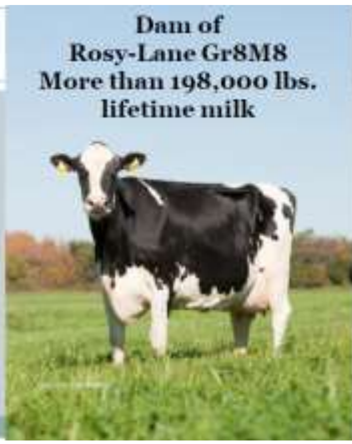

Dam of Jerald
RosyLane-LLC Jives 5611 $17,000


$176,000
Rosy-Lane-LLC
Oak 7276


RosyLane LLC Delta 10090-ET
No. 1 GNM$ female $985

10090

- $1143 DWP$
- 11.0PL
- 53 Protein, 73 Fat
- 4.4 DPR
- 6.9 Sire Calving Ease
- 3.8Daughter Stillbirths
- Delta x Supersire x Yano x Shottle x Oman



9 years progress at Rosy-Lane

	2007	2016
Cows	695	970
Milk	28,498 lbs.	30,030 lbs.
Fat & Protein	1905 lbs.	2255 lbs.
Vet cost/cwt. milk	$96	$32
Services/conception	3.1	2.0
DOA	8.6%	4.1%
% Milking treated	0.9%	0%
Lbs milk/ lbs. feed	1.62	1.69


Summary
A total management program needs to create wealth
One practice must integrate & complement other practices
It's a puzzle in progress!


Where are you headed on your journey for healthier cows?
S
N

Farm Safety: Keeping Everyone Safe on the Farm

Glen Blahey

Canadian Agricultural Safety Association, 3325 – C Pembina Highway, Winnipeg, MB R3V 0A2. Email: gblahey@casa-acsa.ca

■ Take Home Messages

- Ensuring the health and well-being of everyone that lives, works, visits and plays on your farm is both a moral and business-management obligation.
- Developmentally, children and youth do not have the same cognitive and physical abilities most adults possess. Caregivers have an obligation to protect the wellbeing of children in their care.
- Developing a health and safety plan or strategy (that will be compliant with general occupational health and safety standards) for a farming operation is something that any farm owner/manager can easily accomplish with a bit of thought and a guidance document like the Canada FarmSafe Plan.
- Safety is good business risk management. Decision makers, in cooperation with all farming members (including family and workers) have to have a mind-set of prevention. Instead of assuming that accidents and injuries cannot happen to them, they need to ask themselves and each other "what can go wrong?" and "what can we do about it?"

■ Introduction

Agriculture work-related incidents result in fatalities, critical injuries, permanent disabilities, illnesses and injuries of varying severity. These incidents involve the full spectrum of individuals that live and work on farms. Canadian Agricultural Injury Reporting (CAIR), looks at agricultural fatalities between 1990 – 2012. During that time, the agricultural fatality rate was 11.7 per 100,000 farm population (including non-workers). 2,324 people were killed in agriculture-related injury events. Of those killed in agriculture-related injuries, 47% were farm owner/operators, 11.7% (272) were children and youth under 15 years of age, and 38.2% were adults over 60 years of age. The top causes of fatal injuries are shown in Figures 1 and 2.

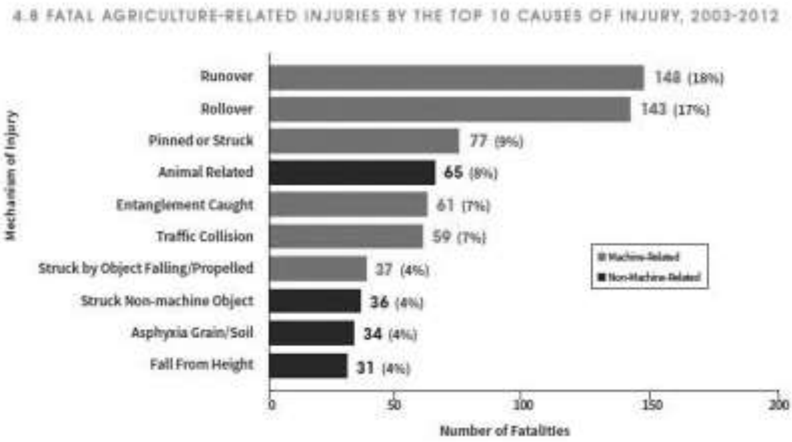


Figure 1: The top causes of fatal injuries in Canada from 2003-2012. (Canadian Agricultural Injury Reporting (CAIR) 1990-2012)

Figure 2: Agricultural Fatalities in Canada. Prepared by The Injury Prevention Centre, University of Alberta based on CAIR data, 2003-2012.

While recent hospitalization / non-fatal injury data are currently unavailable, historical data and experiential data from other occupational sectors suggest that there is a relationship between fatalities, critical injuries, minor injuries and close calls. In 2009, SMARTRISK conducted an Economic Burden of Injury Within the Agricultural Population in Canada. The analysis found that in 2004 there were:

- 184 deaths
- almost 4000 hospitalized
- over 1,000 permanently disabled
- over 72,000 emergency room visits
- $373 million in total economic costs

(SMARTRISK 2009)

For every fatality, there were approximately 22 hospitalizations; for each of those hospitalizations, there were 18 emergency room visits. The direct costs of agricultural injury in 2002 amounted to $208 million. The indirect costs were $165 million (SMARTRISK 2009).

Impact of Agriculture-Related Fatalities

In 2004, researchers at Queens University in Ontario began research in establishing economic impact of agriculture-related injuries on an individual farm's economy. By looking at agriculture-related fatality data, costs of production, health care costs and available workers' compensation data from other industrial sectors, the Queen's University team were able to create a substantial profile.

The researchers estimated that the average cost to a farm's economy was approximately $700 for a non-hospitalized injury, $10,000 for a hospitalized injury; $143,000 for a permanent disability and approximately $275,000 for a fatality (Locker et al., 2003).

What is not measurable is the family and community impact of an agriculture-related fatality. It is impossible to measure the social impact of losing a community member. These agriculture-related fatalities may mean the loss of a community leader, an important volunteer, a classmate; in families, the loss of a parent, a spouse, or a child. The emotional and social impact reverberates across all spectrums of close-knit rural communities.

Other impacts of a traumatic agriculture-related farm injury or fatality include disruptions like hospital stays, a shift in farm management responsibility, disruptions or changes in off-farm employment to accommodate for the injury or death, and personal relationship challenges. Impact on the mental wellbeing of affected community members and family members can range from regret to survivor's guilt. These social impacts are also vital in understanding the issue of agriculture-related injuries and fatalities.

▪ Who is at Risk

Unlike any other industrial sector workplace, agriculture has the notoriety of impacting everyone from toddlers to nonagenarians being seriously injured or killed in agriculture-work-related incidents. CAIR data indicate that between 2003 and 2012, 30 children aged one to four were killed in an agriculture-related incident, and 68 individuals over the age of 80 were killed (Canadian Agricultural Injury Reporting (CAIR) 1990-2012). A challenge of preventing these agriculture-related fatalities is to address the culture. Often there is rationalization regarding the "way of life" or the description of the agriculture-related fatality as a "freak accident." There is often language that works to justify the loss of both the very young and the very old in agriculture-related incidents.

Through injury surveillance systems like CAIR, it is clear who is dying on Canadian farms and how. However, the agricultural industry is slow to react and adjust to the research. (Agri)Culturally, there is emphasis placed on preparing young farm children to be stewards of the land. The question is how are these children being taught, and what are the costs?

In 2008, a 14-year-old died when he lost control of the ATV he was operating and it crashed over an embankment. His obituary read like that of a farmer that had been farming for 20 years. In 2014, two brothers, 16 and 10, died when the tractor they were riding on with a baler in tow, careened down a hill and crashed, killing both boys. They were remembered for their love of farming. Their mother spoke about them by saying "keeping her kids from farm work wasn't an option". These three boys were brothers. (The Canadian Press 2014).

There is seemingly great parental pride in children operating machinery or caring for livestock at a young age. There also appears to be a perception that children doing adult work creates a good work ethic.

▪ Beyond Emotional Loss, Safety is Business Risk Management

Along with the personal and emotional impacts associated with agriculture work-related injuries, there are serious business losses to consider. Agricultural workplace managers manage their operations to maximize productivity and efficiency while minimizing losses. The economic burden of injuries and illnesses are significant.

The strategy for controlling the losses related to workplace injuries and illnesses can be easily integrated into existing risk management programs such as On-Farm Food Safety or supplier required protocols, which are already in place on most farms. The only difference is that most risk management programs look only at the product or process to produce or maintain the commodity. It is imperative to include the necessary details to ensure that farmers and farm workers are as protected as the commodity is.

There are four key steps to making farms safer places.

1. A commitment, or a policy statement, is the first step in creating a safe farm. This should be shared with all people who live, work and visit the farm.

2. The second essential step is to recognize and understand the factors that can impede the success of creating a safe farm. Hazards need to be identified and acknowledged.

3. Once hazards have been identified and acknowledged, control strategies have to be discussed and implemented. The control strategy will vary by hazard and will depend upon the hazard. Multiple control strategies may have to be engaged to be effective in addressing the hazard.

4. Lastly, it is essential that everyone who lives, works and visits a farm understands that the safety of everyone is not just one person's responsibility. Safety is a shared responsibility and will only succeed if there is a clear delineation of responsibilities and effective communication between everyone that lives on, works on and visits your farm.

▪ Policy Statements

The best way to counter the oft-used excuse, 'I didn't know, no one ever told me', is to put the information in writing; make it visible for all to see and make it required reading. There are two types of policy statements that should be used. The first is a general statement that proclaims the farm's commitment to everyone's health and wellbeing and charges others with the responsibility to comply with the policy and fulfill their personal responsibilities to protect themselves and anyone who may be impacted by their actions.

The second type of policy statement is an operational policy statement that sets out how farm owners/operators expect a particular activity or practice to be carried out. This meshes with the Standard Operational Procedures required by programs such as On-Farm Food Safety.

Whether a farm owner/operator is concerned about driving practices or the use of personal protective equipment, operational policies can establish the core expectations and limitations. These expectations and limitations can then be supplemented by specific work practices for the hazardous jobs.

■ Hazard Recognition

Identifying hazards, while not a difficult task, is a conscious objective analysis of the work environment that answers basic questions such as: Does that object, animal, chemical, machine, tool, etc., have the potential to cause harm to someone or cause an interruption of the work process?

Hazards can be biological, chemical, ergonomic, physical and lifestyle (smoking, stress, diet, etc.). During a hazard assessment, it is essential to maintain a neutral attitude. It is unhelpful to assume that injuries or problems won't happen.

■ Control Strategies

Once hazards have been isolated and identified, it's essential to create control strategies to address the issue. Control strategies can be grouped into five categories.

1. **Personal wellness assessments**: These encourage farm owner/operators, farm workers and farm families to recognize that maintaining optimum health brings dividends including lower stress levels and safer behaviour.

2. **Integrated safety Standard Operating Procedures (isSOP)**: isSOPs put (safe) work expectations into writing. Not only do isSOPs document safety expectations, they also act as training tools, employee performance evaluation tools, and operational performance evaluation tools. In the event that an incident should occur, an isSOP will demonstrate due diligence, showing hazards were considered and procedures were instituted to control the hazards.

3. **Emergency Response Plan:** This plan considers potential emergencies that might occur, and the actions needed in response. Fast, coordinated responses in emergency situations can lessen the impact of an injury and may even save lives. Additionally, bringing attention to such a hazardous situation may provide motivation to not have that hazard cause an incident.

4. **Training**: Training is the foundation of prevention. If the people preforming the task have been trained, they have been informed of the expected procedures as well as expected outcomes. Permitting someone to learn by trial and error is a gamble, and negates expectations of quality work.

5. **Investigation**: Although investigations sound ominous, they are exceedingly valuable. Taking the time to analyze what when wrong when an incident occurs determines why there was a system failure and what can be done to prevent its reoccurrence and minimize future losses.

▪ Communicating Responsibilities

Safety and health can be enhanced by clarifying responsibilities during routine work and during emergency situations. Everyone on the farm must be able to rely on each other to do their jobs responsibly and to protect the health and safety of every other person on the farm.

Communication is bi-directional, as safe work practices are only effective when there is ongoing dialogue between everyone involved in the farming operation.

▪ Benefits

Safety and health planning is (farm) business risk management. A 2012 White Paper by the Occupational Safety and Health Administration (OSHA) from the U.S. Department of Labor titled “Injury and Illness Prevention Programs” looks at various research on the ‘bottom line’ of effective programming.

“Based on its review of the literature on the effectiveness of these programs and on the experience of the states that have implemented injury and illness prevention program requirements, OSHA estimates that implementation of injury and illness prevention programs will reduce injuries by 15 percent to 35 percent for employers who do not now have safety and health programs.” (Occupational Safety and Health Administration (OSHA) 2012)

▪ Resources and Support

There are various templates for developing occupational health and safety programs. Canada FarmSafe, developed by the Canadian Agricultural Safety Association (CASA), is one of the very few that was specifically developed for a primary agricultural workplace.

The Canada FarmSafe Plan has been adapted for use in Nova Scotia, Quebec, Ontario, Saskatchewan and Alberta. CASA has associates across Canada to assist individual producers in enhancing their health and safety practices.

Additionally, CASA has an extensive collection of resources, including training aids (http://casa-acsa.ca/teaching-kits), age appropriate tasks for children (http://casa-acsa.ca/search/node/child%20safety), online and in-person training (http://casa-acsa.ca/training), and direct member consultations (info@casa-acsa.ca).

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Employee Management to Improve Milk Quality

Ronald Erskine

Michigan State University, Large Animal Clinical Sciences, 736 Wilson Road, East Lansing, MI 48837, USA
Email: Erskine@msu.edu

Take Home Messages

- Employee training needs to be consistent.
- Employees need to how, what and WHY.
- Let the cows evaluate the protocols……. and training.
- If the cows like the protocols, you will like your milk cheque.

The North American dairy industry is rapidly intensifying; in the U.S., farms with fewer than 100 cows accounted for 49% of the country's 9.7 million milk cows in 1992, but just 17% of the 9.2 million milk cows in 2012. In contrast, farms with at least 1,000 cows accounted for 49% of all cows in 2012, an increase from just 10% in 1992 (MacDonald and Newton, 2014). Additionally, 63% of the milk supply is produced by herds with more than 500 cows (von Keyserlingk et al., 2013). However, the percentage of herds with less than 100 cows only decreased marginally, from 83% to 77% (USDA:NAHMS, 2007).

Dairy farms are also becoming more diverse in terms of employment practices and organization (Jackson-Smith and Barham, 2001). Increasing numbers of Latino workers are being employed on many farms that had previously hired relatively few foreign-born laborers (Jenkins et al., 2009). Recent reports have estimated that about half of U.S. dairy farms depend on Spanish-speaking foreign labor and 62% of milk is produced from farms employing immigrant labor (Baker and Chappelle, 2012; von Keyserlingk et al., 2013). As the role of immigrant labor increases in the U.S. dairy industry, cultural and communication barriers complicate management–employee relationships as Spanish-speaking workers are increasingly seen in jobs traditionally held by individuals whose first language is English (Cross, 2006; Stack et al., 2006; Jenkins et al., 2009).

To address this potential cultural and language barrier, education, training and translation tools have been developed by land grant universities, consultants and agricultural agencies (Fuhrmann, 2002; Chase et al., 2006, Stack et al., 2006; Jenkins et al., 2009). However, these programs were developed from a management-directed perspective with minimal input from employees and the effectiveness of employee training, or education programs, relative to farm protocols and productivity, has not been evaluated for short or long term success. Additionally, many dairy managers have limited human resource knowledge and experience, this often leads to frustration with protocol drift and a sense that employees are not motivated to engage in the success of the farm beyond prescribed instructions. These and other workplace conditions can contribute to employee turnover, which has been attributed to relationships with management and co-workers (Billikopf and Gonzalez, 2012). Taken together, these gaps in the nation's dairy farms constitute a form of cultural lag. That is, there is a gap between the human resource needs arising within the industry's labor force and the capacity of producers and managers to address them.

Although somatic cell counts (SCC) continue to decrease among U.S. dairy herds (USDA:NAHMS, 2013), poor protocol compliance may contribute to variability in mastitis control among herds (Fuhrmann, 2002; Brasier et al., 2006). We contend that ineffective training of employees and ensuing protocol drift may prevent some herds from attaining their milk quality goals. This is particularly relevant for mastitis control protocols as Latino laborers are heavily concentrated in entry level positions on dairy farms that include milking, maintenance of housing and administration of therapies such as intramammary infusions of antimicrobial drugs (Valentine, 2005; Stack et al., 2006). A recent survey of 628 herd owners and managers from Florida, Michigan, and Pennsylvania revealed that herds that offered quality incentives for employees, or ensured strict compliance of milking protocols had lower bulk tank somatic cell counts (BTSCC) than herds that did incorporate these management practices. Conversely, herds that responded that mastitis was a problem in their herd, or had difficulty with compliance of milking or treatment protocols, were more likely to have higher BTSCC (Schewe et al., 2015). Thus, issues of employee management and training, as well as producer values and attitudes regarding mastitis, are related to BTSCC.

In an attempt to enhance engagement on the part of dairy employees, we are developing an on-farm evaluation, the Quality Milk Alliance (QMA) that incorporates a unique aspect of assessing milk quality opportunities on a dairy farm, the management culture. Beyond identifying traditional opportunities for improving milk quality (e.g., improved bedding quality), the QMA evaluation can also serve as a platform for employee training and teaching.

▪ What Do Employees Tell Us?

While there is a considerable body of research that links dairy producer beliefs and attitudes with the prevalence of mastitis and antimicrobial drug use (Barkema et al., 1999; Vaarst et al., 2002; Wenz et al., 2007; Sato et al., 2008; Jansen et al., 2009), employee knowledge and attitudes as they relate to quality milk are not well documented (Stup et al., 2006). In a study of 14 farms from four states, employees received a paper copy of a 29 question survey (bi-lingual) and then were instructed to call a bi-lingual interviewer who asked the employees to respond to each question (Durst and Moore, unpublished). The responses were anonymous and a total of 174 employees participated. Owners and managers were also surveyed to determine how they thought their employees would respond. Employees overwhelmingly want to go beyond their current level of knowledge; rating their interest in learning as 4.73 on a scale of 1 to 5 where they were told that “1” corresponded with “I already know enough to do my job” and “5” corresponded to “I am interested in dairy and I want to keep learning”. This is an opportunity to be seized by dairy owners (who ranked employee interest in learning as 3.27), rather than squandered.

In a pilot study in 12 Michigan dairies, when herd owners or managers were asked, “Who trains new employees how to milk cows?”, 11 of the 12 management teams responded that they perform the training. However, when the employees were asked the same question, only 29% stated they learned how to milk from the managers or owners; 71% said they learned from other employees, or they just “learned on the job”. Employee responses examined by language (Spanish-speaking and English-speaking) showed that only 14% of Latino workers said they learned the milking protocols from managers or owners, which was lower than English-speaking workers (42%; Erskine et al.,2015).

As part of a field trial to develop the QMA evaluation, we have started to gather more extensive information about employee training and communication that will ultimately have over 120 participating herds from Michigan, Pennsylvania, and Florida. Preliminary results suggest that communication and training barriers are similar to those found in our pilot study; on average about half or the employees on farms know the SCC goals for the herd, and a majority rely on training from someone other than a herd manager, or state that team meetings among farm personnel only occur if there is a problem, or not at all (Table 1). Likewise, about half of employees in each herd believe the lag time between teat stimulation and unit attachment should be about a minute, with a variety of responses accounting for the remainder of respondents. Perhaps most intriguingly, when the proportion of employees within each herd was correlated to the percent of employees that were aware of herd SCC goals, there was virtually no association (Figure 2; coefficient of variation = 0.0337). This suggests that herds that offer incentives for milk quality don't have a greater proportion of employees who are aware of herd goals than herds that do not pay an incentive. Proper preparation of udders and teats before milking improves milk quality by 1) ensuring good hygiene, 2) detecting cows with clinical mastitis, and 3) harvesting milk efficiently. Productivity of a dairy operation increases when milking is done as efficiently as possible, without sacrificing milk quality and harvest. Also, cow health improves when the time standing in holding pens and parlors, or having units attached, decreases.

Table 1: Mean percent of employees within herds (n=37 herds) that responded to questions regarding training and herd goals. Responses were attained anonymously from 194 employees (mean of 5.3 employees per herd) with remote response technology. Range of responses among herds was 0 to 100% for all questions.

Do you know the somatic cell count goals for this dairy farm?	Yes	No
	51	49
Who trains you to milk the cows?	Owners/Managers	Other Employees or Self-taught
	23	77
How often do you have team meetings with other employees and managers?	At least once per year	Only when there is a problem or never
	28	72

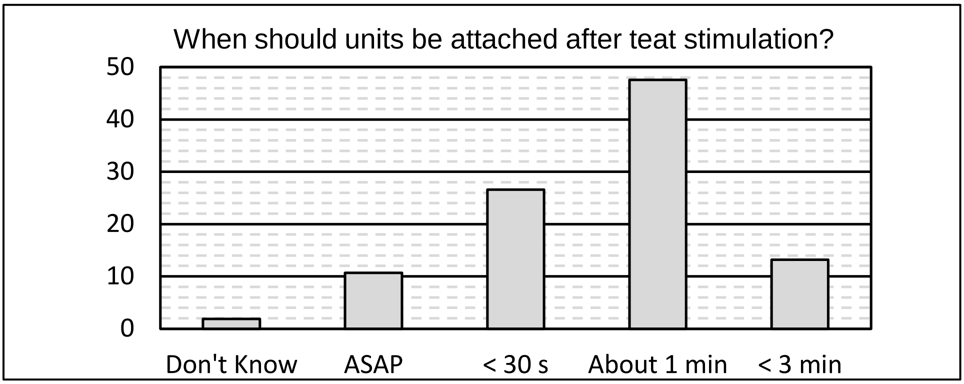


Figure 1: Mean percent of employees within herds (n=37 herds) that responded to the question "When should units be attached after teat stimulation"? Responses were attained anonymously from 194 employees (mean of 5.3 employees per herd) with remote response technology.

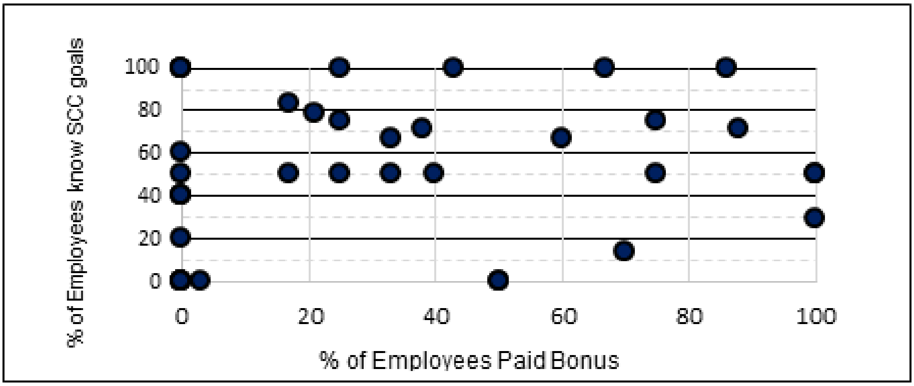


Figure 2: Relationship between the percent of employees that knew herd somatic cell count goals and percent of employees receiving a milk quality incentive within 37 herds.

▪ What Do The Cows Tell Us About Employee Training?

Given the effort spent on most dairies to insure proper milking protocols, how do we know if they are being done correctly? Let the cows answer this question, they know best! VaDia® units (Biocontrol NA) digitally record vacuum at the teat end (inside the liner) and cluster, letting the cows tell us if they're ready to milk, or if they're milked too long (overmilked). VaDia units don't measure milk flow directly, but a simple way to interpret VaDia results relative to milk flow is:

High Milk Flow = Low vacuum in the liner

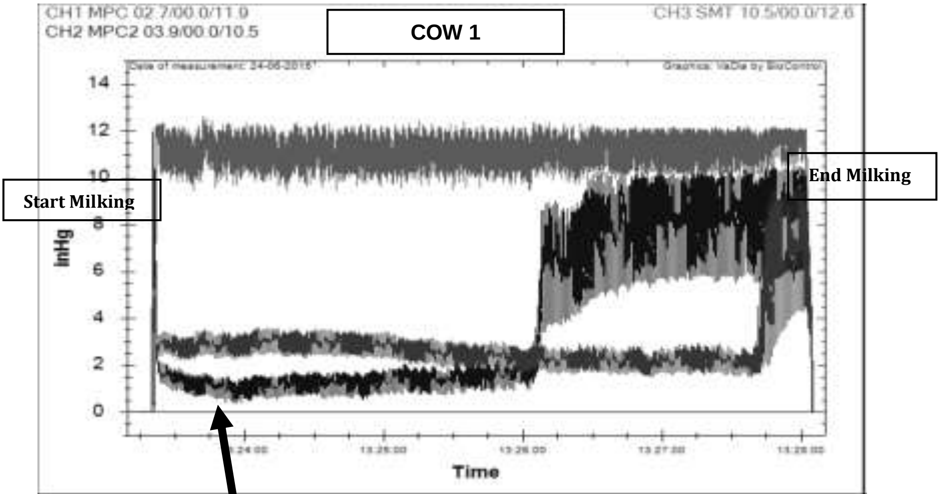
Low Milk Flow = High vacuum in the liner

VaDia units can measure vacuum levels at four different places on the cluster simultaneously. Generally, we measure vacuum in the mouthpiece chamber of a front and rear liner (near the teat ends), near the cluster and in a short pulsation tube.

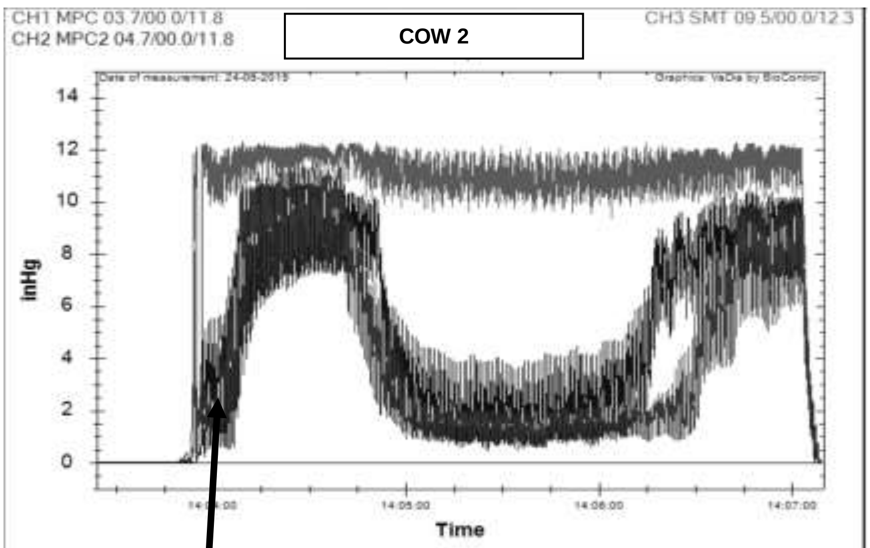
Below are VaDia analyses from two cows during milking.

Cow 1 was ready to milk; the mouthpiece vacuum near the teat ends dropped quickly (less than 15 seconds after the unit was attached) and remained low until each teat was finished milking.

What about Cow 2? Teat end and cluster vacuum (top line) decreased, but then increased to near maximum levels, and finally decreased again. This cow was not ready to milk, milk flow was low for more than a minute after the milking unit was attached, signifying delayed milk letdown. This increases milking time, and may reduce her milk output as well as increase the risk of mastitis.



Mouthpiece vacuum (rear teat ; front teat) near teat ends drops to low level immediately after unit is attached- Cow was ready to milk!!!



Vacuum decreases, increases and then decreases again…
Bi-modal milking from poor milk letdown

VaDia analysis "Lets the cows score the milking protocols" and results can be used for employee training and teaching, as well as follow evaluations after training.

■ Discussion

Taken together, there are misperceptions among many herd owners and managers as to the effectiveness of employee training efforts. This may be exacerbated on farms that lack prescribed communication opportunities among personnel, for example, the high proportion of employees that responded that there was a lack of regular team meetings, or only met when there was a problem, could be perceived as a punitive management style among employees. Especially considering that on many farms, employee turnover is considered a problem (Erskine, personal observation), the need for effective and consistent communication, training, and education is critical for the prevention and control of mastitis.

To date, our studies suggest that employees lag behind the understanding of mastitis prevention and control, even though they are performing a greater role in the critical work of milking, cleaning barns, observing the health of cows, etc. From an extension education standpoint, we have possibly lagged behind the cultural changes brought about by the demographic changes in the labor force in the dairy industry. In a separate question from the pilot study, 36/74 (49%) of the employees stated that they receive no education regarding mastitis control and management, and only 12/74 (16%) stated they receive education (videos, consultant or veterinary visits, workshops, etc.) on a regular basis. Thus, a new approach for enhancing the education for dairy employees may be needed to augment extension education models by enlisting and facilitating “education amplifiers”, who spend considerable time on individual dairy farms, develop professional relationships with employees, and apply their expertise in employee training and education.

During the course of our pilot project, we developed learning resources (lessons, learning objectives, metrics of farm goals) for use by veterinarians on each of the 12 farms. The learning resources varied by farm depending on the particular observations and deficiencies that were determined during the course of the milk quality evaluation. Additionally, we provided visual aids in the form of a “Quality Milk Corner” that included a poster board for employees to serve as a focal point for learning about herd goals, metrics, and educational materials. In effect, we tested the ability of veterinarians to serve as “on-farm science teachers” for the employees to help promote better understanding of the protocols on the farm, and ultimately to attain more consistent and sustained practice of mastitis control protocols.

During focus group discussions at the completion of the demonstration project, employees strongly expressed their appreciation for the education program, which helped them better understand why they do their tasks and the importance of those tasks. The education program also instilled a sense of respect, to which one employee added, “Without understanding why we do things, it’s like being told as a kid ‘Not to touch the hot stove’ but never being told why you shouldn't do it." Dairy producers also noted the positive attitude of employees brought about by veterinarian-initiated education activities and cited several examples of improved interest and team effort on the part of the employees in the work they performed. Additionally, producers expressed interest in continuing this program and believed it held economic value for their operation. One of the critical comments brought forth by veterinarians was the need for support in educating Latino employees, both for interpretation and comprehension of learning materials, and to help navigate cultural differences (e.g., ensuring employees believe that the veterinarian is there to build a relationship with them and not to report back to the owner and get them in trouble).

We believe that engaged employees take the initiative and work to get the desired result for the dairy operation, beyond just "doing the job." Engaged employees understand the goals of the farm, how things must get done to achieve those goals, and why they should follow protocols to attain those goals. We further believe that in order to close the gap between employee knowledge and dairy farm production, extension personnel should build capacity to support "on-farm education" and facilitate "science teachers," be they veterinarians, herd managers, or other professionals who can make a more durable impact on employee engagement and thereby improve productivity on dairy operations in the context of the major changes in the industry. Employees who work long hours may not be fully receptive to learning after travelling to attend structured education programs such as a three-hour-long workshop. Additionally, literacy and education levels can be problematic for some employees, and the application of what has been learned on farm sites generally relies on the herd owners or managers, many of whom are not trained or inclined to serve in the role of educator. Our preliminary results indicate that there are considerable training and communication barriers between herd owners and managers and their employees, especially Spanish-speaking employees. These barriers provide opportunities for further research and implementation.

Acknowledgements

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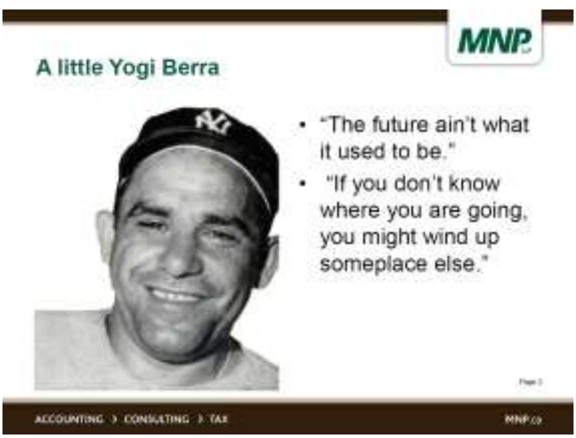
Creating an Effective Farm Business Strategy

Jeff Orchard

MNP LLP, 1500, 640 – 5th Avenue S.W., Calgary, AB T2P 3G4
Email: jeff.orchard@mnp.ca




Thriving in Interesting Times
TIME
Change
• Agriculture is changing, has to change more.
• Competition is worldwide
• "Old thinking" is risky
• Need "plans of attack" (strategy)
• Execution is also critical.
• History provides great examples including:
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CREATIVE EXECUTION
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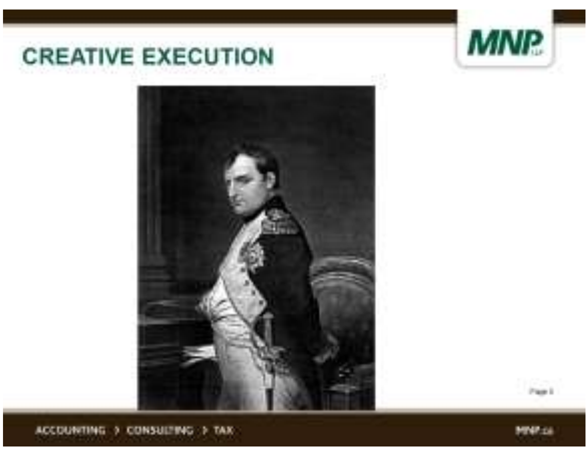
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CREATIVE EXECUTION
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• 1805 Europe lies within Napoleon Bonaparte's grasp
• Only England stands in his way
• 200,000 crack troops in France
• Admiral Villeneuve joins forces with the Spanish Armada to secure the Straits of Dover
• "Let us be masters of the Straits for six hours and we shall be masters of the world."
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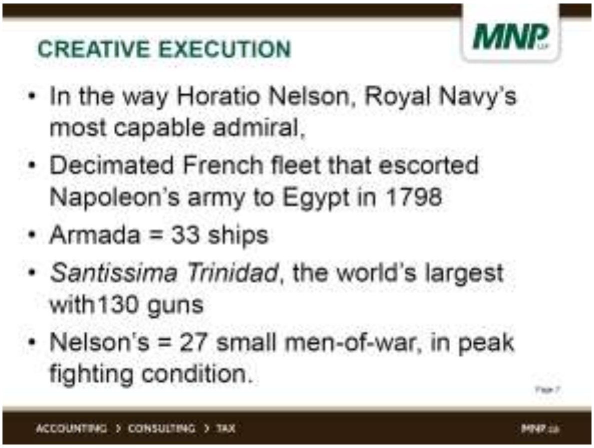
CREATIVE EXECUTION
MNP
• In the way Horatio Nelson, Royal Navy's most capable admiral,
• Decimated French fleet that escorted Napoleon's army to Egypt in 1798
• Armada = 33 ships
• *Santissima Trinidad*, the world's largest with130 guns
• Nelson's = 27 small men-of-war, in peak fighting condition.
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CREATIVE EXECUTION
MNP
• Nelson surprises Villeneuve off Cape Trafalgar
• The English sink or capture18 French ships
• 14,000+ French and Spanish killed in action, 10X more than the English
• Villeneuve commits suicide
• Napoleon's dreams of a French Europe shattered
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Nelson's touch

- Ability to **execute a strategy**
  - almost **guaranteed** a successful outcome.
- **Crush** not just defeat
- No **traditional "parallel lines"** pounding from a distance
- Attack at **90-degrees**
- Attack individual ships from **close quarters (size matters!)**

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Nelson's touch

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Nelson's touch

- Strategy:
  - Plan - Speed versus power
  - Practice - Load and fire twice as fast
  - Sink or disable enemy ships from short range
  - Shoot, turn and reload, fire
  - Forgot one thing – Duck!

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What About You?

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- Aren't you the little guy?
- Business is like war
- Your "battle plan"?
- You invincible Napoleon?
- Aren't most of us just like the British navy?
  - Nimble versus slow, fit versus huge
- **But what's is YOUR plan?**

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7 Essential Elements of Effective Strategy

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1. Competitive Advantage
   - Differentiate, be better in a way or ways that matter
2. Thorough and deep analysis
   - External environment and the internal capabilities
   - Leverage strengths, shore up areas of weakness
   - Seize opportunities, minimize threats
3. Be flexible, ready and willing to adapt
   - To changing circumstances
   - Napoleon's soldiers carried own provisions vs supply train

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7 Essential Elements of Effective Strategy

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4. Deeply understood direction, shared by the organization
   - Genghis Khan's Mongols defeated far larger armies without direct supervision
5. Invite varied input from a diverse group of thinkers
   - Lincoln surrounded himself with his political rivals
   - No group think
6. Never Stop Communicating
   - Change does not occur without ample communication
   - Repetition is expected and needed
7. Monitor, Measure and Report results
   - Facts verify the strategy and provide early warning signals
   - Use a scoreboard

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5 Things every leader needs to know about strategy:
1. Compete to be unique, not to be the best
– Many ways to win
– Young Farmers of Saskatchewan
– Uber, Air B and B
2. Compete for profit
– Farm business is not about being the largest or growing fast. It's about being profitable in a sustainable manner
3. Know your industry and your place
– A farm is not an island – it's part of a larger ecosystem, an industry
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5 Things every leader needs to know about strategy:
4. Strategy means Choice
– WHO are you are going to serve and a clearly HOW you are going to serve them
– Connect the outside world – demand side – with your farm – the supply side
5. Don't ever stand still
– customers' needs and behaviors change, technology evolves, competition moves
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LONG TERM SUCCESS REQUIRES PLANNING
Today you must be a business architect.
Anything built in today's business environment must have a step-by-step blueprint or plan on how to achieve success.
~Worth
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LONG TERM SUCCESS REQUIRES PLANNING
If you do not know where you are going…you will not know:
1. How to get there
2. The progress toward your destination
3. When you have arrived
ENTERING THE MIDDLE
Well this is just going from bad to worse
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STEPS TO SUCCESS
1. Plan
2. Critical success factors
3. Metrics - KPIs
4. Implement, Measure and Manage always
5. Evaluate
6. Improve
7. Continue forever
SUCCESS
1 2 3 4 5
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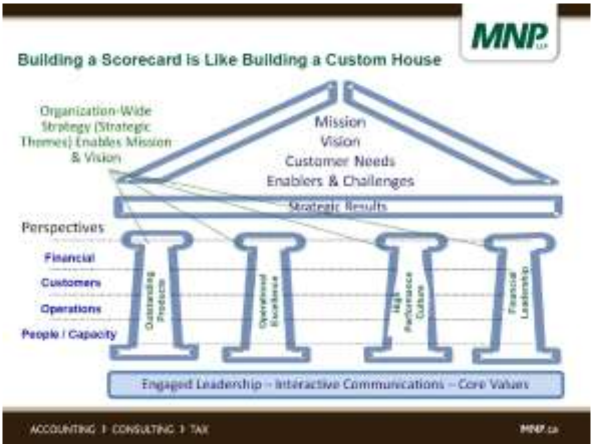

Financial	How do we create value?	•Financial Performance •Perception of Value
Customer	How well are we meeting their needs?	•Attraction •Satisfaction •Retention
Operations	How can we improve internal processes to deliver, products & services better, faster and cheaper?	•Efficiency •Quality
People	How can we support the internal processes through improved knowledge & skills abilities, tools & technology, leadership and other capacities?	•Human Capital •Tools •Innovation •Infrastructure •Culture


Balanced Scorecard
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Vision
Customers
• Attract sufficient customers (that we want)
• Delight (retain) good customers
Operations
• Be sufficiently productive (efficient output)
• Consistently turn out high quality (products and/or services)
People
• A skilled team that is constantly getting better
• A highly motivated team that wants to be part of a successful organization
Financial
• Sales (Marketing)
• Gross Margin (Input costs)
• Expenses (Overhead)
• Net
• Cash Flow
Exit
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Balanced Scorecard –
In our Neighbourhood
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Vision
Customers
• Go Get 'em
• Keep'em Happy
Operations
• Get it done!
• Do it right
People
• Willing
• Able
Finance
• Sell Lots
• Maintain Margins
• Manage Expenses
• Manage Working Capital
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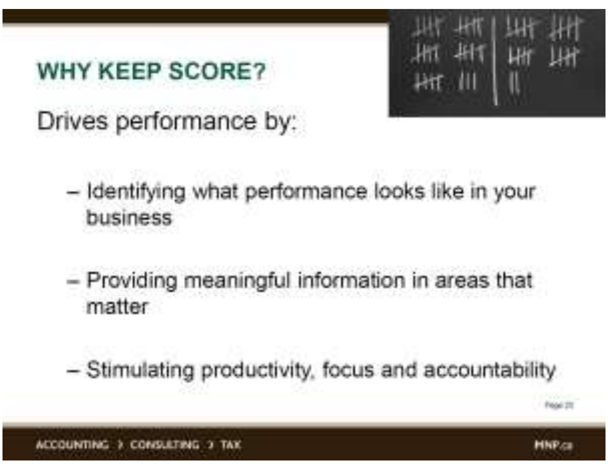
WHY KEEP SCORE?
Drives performance by:
– Identifying what performance looks like in your business
– Providing meaningful information in areas that matter
– Stimulating productivity, focus and accountability
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KNOWING THE SCORE, ALLOWS YOU TO PLAY MORE EFFECTIVELY

Armed with the right information (metrics)

BUSINESS OWNERS are able to make real-time adjustments TO MEET THEIR SHORT and LONG TERM GOALS.

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WHAT IS A METRIC?

- MEASURES
- METRIC

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MEASURE VS. METRIC

- MEASURE : Butterfat produced
- METRIC: Fat % =Total butterfat produced /Total volume

- MEASURE: $ spent on feed
- METRIC: Feed cost per litre = $ spent on feed/ # of litres produced

- MEASURE: Vet spend ($)
- METRIC: Average vet cost per head= Vet spend/ Size of herd

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GOOD PERFORMANCE METRICS:
1. Are Financial or non financial
2. Add meaning to measures
3. Show results not process
4. Use easily accessible Data
5. Get Measured and Reported at regular intervals
6. Are Tracked over time to show a trend
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CRITICAL SUCCESS FACTORS
Success
Your company's profitability depends on how well you and your people consistently perform specific activities.
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THE RIGHT METRICS: KPI's
• Show progress to goals
• Developed from Critical Success Factors
• Aligned with strategy
• Used to track, monitor and evaluate progress
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METRICS MUST BE SMART
• Specific
• Measurable
• Attainable
• Results focused
• Time Based
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WHAT IS THE RIGHT NUMBER OF METRICS?
• The simpler the business, the fewer the metrics.
• Don't get overwhelmed by too many things
• Focus on WHAT MATTERS MOST
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HOW OFTEN TO MEASURE?
• What activities drive that measure?
• Evaluating short intervals is better than waiting too long and missing out
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Five keys to Creative Execution
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1. A Unique Strategy understood and accepted by everyone.
2. Candid Dialogue.
3. Clear Roles and Accountabilities.
4. Bold Action
5. Visible Leadership
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The Creative Execution Loop
MNP
Candid Dialogue
Engagement
Excitement
Clear Roles & Accountabilities
Visible Leadership
Unique Strategy
Commitment
Momentum
Bold Action
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4 Disciplines of Execution
- McChesney, Covey and Huling
MNP
1. Focus on the Wildly Important (Results)
2. Act on the lead Measures (Activities)
3. Keep a Compelling Scoreboard
4. Create a Cadence of Accountability
The 4 Disciplines of Execution
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Making It Work For You
MNP
• Evaluate / Create strategy. (Have one?)
– What will you become?
– How will you compete?
– Why should you win?
• Encourage bold thinking
– How engaged are the minds?
• Lead from the Front
– Anyone can KITA!
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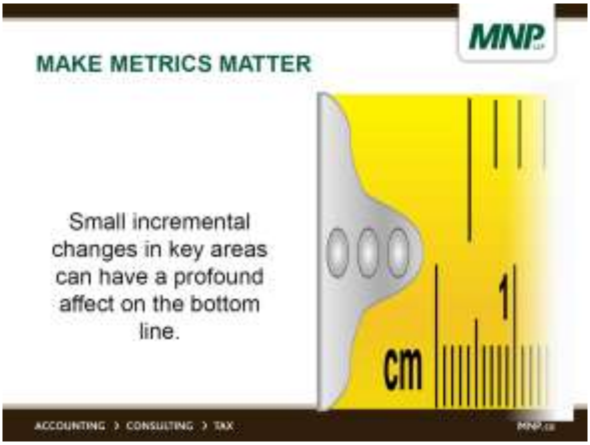
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MAKE METRICS MATTER
Small incremental changes in key areas can have a profound affect on the bottom line.
cm
1
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How to Start

- Look out
- Look in the mirror
- Be honest
- Chart your course
- Lead from the front
- Keep score
- Play to win

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Where to start?

- Your trusted business advisor
- Two heads are better than one
- Allies are great in a time of war
- Pick your battles
- Victory by design

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Have you ever been to sea, Billy?

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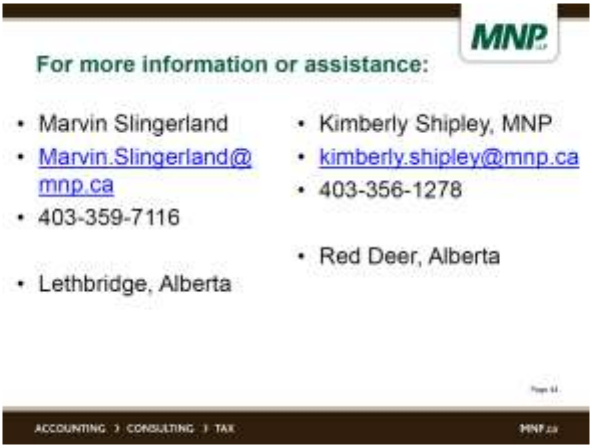
MNP LLP
For more information or assistance:
Marvin Slingerland
Marvin.Slingerland@mnp.ca
403-359-7116
Lethbridge, Alberta
Kimberly Shipley, MNP
kimberly.shipley@mnp.ca
403-356-1278
Red Deer, Alberta
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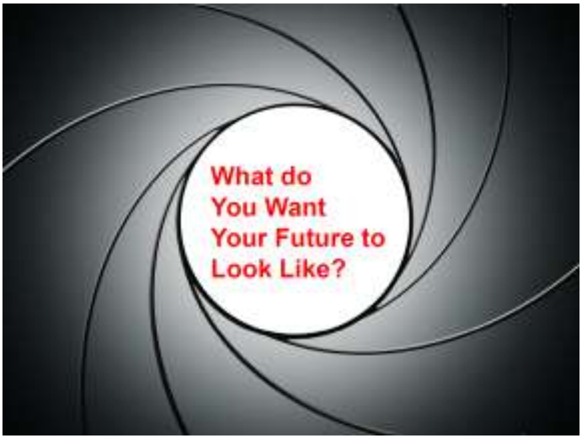
What do
You Want
Your Future to
Look Like?

The True Value of Feeding Canola Meal

Timothy Mutsvangwa

Department of Animal and Poultry Science, University of Saskatchewan, 51 Campus Drive, Saskatoon, S7N 5A8, SK
E-mail: tim.mutsvan@usask.ca

Take Home Messages

- Canola meal (CM) is a highly palatable feed ingredient for dairy cows, and it can be included in dairy cow diets up to 20% of dietary dry matter.
- Cows fed CM as a protein source produce, on average, 1.4 kg/day more milk compared with cows fed other protein sources, and 0.7 kg/d more milk compared with cows fed soybean meal (SBM).
- Newer research shows that CM has a greater content of ruminally-undegradable protein (RUP; bypass protein) than has been previously reported, and CM RUP is at least equal to, if not greater, than that of SBM.
- Compared to other protein sources like SBM, CM is an excellent source of essential amino acids like methionine and histidine.
- Although CM contains greater amounts of fibre compared with other protein sources, recent research shows that the energy value of CM is higher than previously thought because the fibre is more digestible and can provide more energy for milk production.

Introduction

In lactating dairy cows, nitrogen (N) in the form of crude protein (CP) is an important feed nutrient for use in maintenance and productive functions such as milk protein synthesis, and numerous studies have focused on strategies to optimize milk N efficiency (MNE: the quantity of N secreted in milk expressed as a proportion of feed N intake). It is well-established that the type, amount and quality (e.g., true protein vs. non-protein nitrogen) of protein supplements that are included in dairy cow diets are among some of the key factors that can influence MNE, primarily through their effects on ruminal fermentation and the flow of microbial protein to the small intestine (Clark et al., 1992; NRC, 2001; Ipharraguerre and Clark, 2005). Also, protein is one of the most expensive components of dairy cow diets, so poor MNE can be economically costly through higher feed costs. In addition, poor MNE can also result in excessive losses of N into the environment, thus contributing to environmental pollution. Therefore, when formulating dairy cow diets, the choice of protein supplement(s) is an important decision that dairy nutritionists have to make. In western Canada and parts of the U.S., dairy cow diets typically contain canola meal (CM) as the principal source of protein because it is readily available and is a high quality protein supplement (Hickling, 2008; Mulrooney et al., 2009). In most regions of Canada and the U.S., however, soybean meal (SBM) is the principal source of protein in dairy cow diets (Huhtanen et al., 2011; Martineau et al., 2013). Recently, a rapid expansion of the ethanol industry in North America has resulted in large quantities of dried distillers grains with solubles (DDGS) becoming available for feeding dairy cows, with corn DDGS (C-DDGS) and wheat DDGS (W-DDGS; primarily in western Canada) being the major forms of DDGS (Mulroney et al., 2009; Chibisa et al., 2012). There are major differences primarily in CP content, essential amino acid profile, and ruminal degradability of CM, SBM, C-DDGS, and W-DDGS (NRC, 2001; Huhtanen et al., 2011; Maxin et al., 2013a) that might influence the responses of dairy cows when these ingredients are fed as the major sources of protein; thus, many experiments have been conducted to compare lactational performances of dairy cows when CM, SBM, C-DDGS and W-DDGS were fed as the major protein supplements. In meta-analytical studies involving 122 (Huhtanen et al., 2011) and 49 (Martineau et al., 2013) experiments, it was concluded that cows fed CM as the principal source of protein yielded 1.3 to 1.4 kg/d more milk compared to cows fed the other protein sources. These studies suggest that CM might be a superior source of protein for dairy cows compared with SBM, C-DDGS and W-DDGS.

▪ What is Canola Meal (CM)?

The Canola Meal Feeding Guide (2015), published by the Canola Council of Canada, contains excellent information on the origins of canola, solvent-extraction of canola seed to produce edible oil and CM, and the chemical composition of CM, so the reader is referred to that publication for more detailed information. Canola is improved rapeseed that was developed by Canadian researchers in the 1970s from two varieties of rapeseed (*Brassica napus* and *B. campestris*) (Bell, 1984; Canola Meal Feeding Guide, 2015). Original varieties of rapeseed contained high levels of erucic acid, which made rapeseed oil undesirable for human consumption due to the toxic effects of erucic acid. Also, original rapeseed varieties contained high levels of glucosinolates, which made CM unpalatable to livestock and could also result in negative effects on animal health. Canola is also known as “double-zero” or “double-low” rapeseed. Solvent-extraction of canola seed produces edible oil that contains <2% erucic acid, together with CM as a byproduct that contains <30 μmol/g glucosinolates (Canola Meal Feeding Guide, 2015).

Because of its low levels of erucic acid and glucosinolates, canola is now a very important source of food for humans and feed for livestock, and there has been a tremendous increase in the production of canola around the world. In Canada, approximately 20 million acres (or 8 million hectares) are devoted to canola production every year, with the production of canola expanding rapidly from 12,789,000 in 2010/2011 to 17,960,000 metric tonnes in 2013/2014 (Canola Feeding Guide, 2015). During the same period, the production of CM increased from 3,568,000 to 4,034,000 metric tonnes, with approximately 15% of that being used locally in Canada and the remainder being exported, primarily to the U.S. (>95% of exports; Canola Meal Feeding Guide, 2015).

▪ The Nutrient Composition of CM and Other Major Protein Sources

For the proper utilization of different protein supplements in dairy cow diets, it is important to have detailed and reliable information on their nutrient composition that can be used in diet formulation. Various publications and databases (e.g., NRC, 2001) are available that contain detailed information on the nutrient composition of various protein supplements, and perusal of those sources of information indicate that the nutrient composition of protein supplements can be quite variable. This variability can be caused by many factors, including differences in cultivar, growing conditions of the crop (e.g., soil type and level of rainfall), and processing conditions of the seed and meal (Canola Meal Feed Guide, 2015). The nutrient composition of CM, SBM, C-DDGS and W-DDGS are presented in Table 1. For comparative purposes only, it was decided to obtain these data mainly from a single study (Maxin et al., 2013a) that used similar analytical methods to determine the chemical composition of these protein supplements. It should be noted that for some nutrients, data were not reported by Maxin et al. (2013a), so the data for those nutrients were obtained from other sources as indicated in Table 1.

Of the 4 protein supplements, SBM contains the highest CP level, whereas CM, C-DDGS and W-DDGS are similar (Table 1). The CP contents that are reported by Maxin et al. (2013a) are in agreement with values that have been published by others (NRC, 2001; Canola Meal Feed Guide, 2015). According to the Canola Meal Feeding Guide (2015), the CP content of CM can range from 36 to 39%, with the variability being attributed to yearly variation in growing conditions of canola. For soluble CP content (expressed as a % of CP), CM, SBM and W-DDGS are comparable (mean = 28.6%), whereas C-DDGS has a much lower soluble CP content compared with the other 3 protein sources (Table 1).

Table 1. Nutrient composition of common protein supplements fed to cows[1]

	Protein supplement[2]			
Item[3]	CM	SBM	C-DDGS	W-DDGS
CP, % of DM	40.1	53.6	40.3	37.2
Soluble CP, % of CP	25.3	31.0	12.0	29.5
NDICP, % of CP	16.7	4.0	8.8	9.1
ADICP, % of CP	7.7	1.5	10.1	8.8
RUP, % of CP				
NDF, % of DM	31.9	9.5	26.2	27.9
ADF, % of DM	22.5	6.4	13.5	14.6
Ether extract, % of DM	3.6	1.5	4.0	5.6
Starch, % of DM	1.6	1.5	7.0	3.4
Ash, % of DM	8.0	6.9	3.5	6.2
Calcium, % of DM	0.65	0.40	0.22	0.10
Phosphorus, % of DM	0.99	0.71	0.83	0.96
Essential AA, % of CP				
Arginine	6.62	7.32	4.06	1.48
Histidine	2.54	2.55	2.53	2.21
Isoleucine	3.72	3.89	3.77	3.61
Leucine	6.78	7.52	12.83	7.27
Lysine	4.88	5.91	2.72	2.53
Methionine	2.32	1.55	2.26	2.10
Cysteine	2.29	1.50	1.86	0.34
Phenylalanine	3.95	5.02	5.17	4.77
Threonine	4.40	4.07	3.81	3.37
Tryptophan	1.33	1.26	0.87	0.40
Valine	4.35	3.76	4.26	4.07
Total essential AA	43.2	44.4	44.1	32.2

[1]Data on nutrient composition were obtained from Maxin et al. (2013). Nutrient composition data for C-DDGS are for high-protein C-DDGS. For Ca, P, arginine, cysteine, and tryptophan, data for CM were obtained from the Canola Meal Feeding Guide (2015), those for SBM and C-DDGS were obtained from NRC (2001), and those for W-DDGS were obtained from the Wheat DDGS Feed Guide (2013).
[2]CM = canola meal; SBM = soybean meal; C-DDGS corn-based distillers grains with solubles; and W-DDGS = wheat-based distillers grains with solubles.
[3]CP = crude protein; DM = dry matter; NDICP = neutral detergent insoluble crude protein; ADICP = acid detergent insoluble crude protein; NDF = neutral detergent fibre; ADF = acid detergent fibre; and AA = amino acids.

Neutral detergent insoluble crude protein (NDICP) is the component of the CP that is associated with the residue remaining after performing neutral detergent fibre (NDF) analysis, and it estimates the portion of the ruminally-undegradable protein (RUP; which is commonly referred to as bypass protein and represents that portion of dietary protein that escapes degradation in the rumen) that is potentially available to the animal (NRC, 2001). In the study by Maxin et al. (2013a), the NDICP (% of CP) for the 4 protein supplements was quite variable (Table 1), with SBM having the lowest value (4.0%) and CM having the highest value (16.7%). These data suggest that CM potentially has a greater RUP fraction than the other 3 protein sources. The implications of these differences in RUP fractions will be discussed elsewhere in this paper. Feed contents of acid detergent insoluble crude protein (ADICP) varied from 1.5% for SBM to 10.1% for C-DDGS, with CM having an intermediate value (7.7%). The ADICP is the CP fraction of feedstuffs that is bound to the acid detergent fibre (ADF) fraction, and it represents protein that has been heat-damaged. Heat damage makes the protein largely indigestible in the rumen and post-ruminally; thus, it is unavailable to the animal and is recovered in the feces (NRC, 2001). The NDF (31.9%) and ADF (22.5%) values for CM that were reported by Maxin et al. (2013a; Table 1) were greater than those reported for the other protein sources. Based on a larger number of samples that were analyzed over 3 years, the Canola Meal Feeding Guide (2015) reported NDF and ADF values of 25.4 and 16.2%, respectively. For the ether extract (EE) fraction, values ranged from 1.5% for SBM to 5.6% for W-DDGS (Maxin et al., 2013a; Table 1). According to the Canola Meal Feeding Guide (2015), the EE content of Canadian CM is typically 3.5%, which is greater than the 1 to 2% EE that is contained in CM and rapeseed meals that are produced in other parts of the world. The greater EE content of locally-produced CM can be attributed to the canola gums (that contain variable amounts of glycolipids, phospholipids, triacylgycerols, fatty acids etc.) that are added to CM at inclusion levels of 1 to 2% during the production process of CM (Canola Meal Feeding Guide, 2015).

Maximizing the intestinal supply of metabolizable protein is important for high-producing dairy cows as this will dictate the extent of milk protein synthesis (NRC, 2001; Ipharraguerre and Clark, 2005). Metabolizable protein is composed of microbial protein and RUP. Although ruminally-synthesized microbial protein is the major component of metabolizable protein, the contribution of RUP to the intestinal supply of essential amino acids (EAA) is also important in meeting animal requirements (NRC, 2001). Of the EAA, lysine and methionine are considered the two most limiting for milk and milk protein synthesis on a wide variety of diets that are typically fed to dairy cows in North America (Schwab et al., 1992), so the major challenge when feeding dairy cows is to ensure that sufficient amounts of these EAA are provided for intestinal absorption. Both SBM (5.91% of CP) and CM (4.88%) had greater contents of lysine compared with C-DDGS (2.72%) and W-DDGS (2.53%; Table 1). It should be noted that the lysine content for CM reported by Maxin et al. (2013a) is lower (5.95% of CP) than that reported in the Canola Meal Feeding Guide (2015). For methionine, SBM (1.55%) had the lowest content, with the other 3 protein sources being comparable (mean = 2.23%; Maxin et al., 2013a). For cows fed grass silage-based diets, Kim et al. (1999) and Vanhatalo et al. (1999) postulated that histidine was the most limiting EAA for milk production. Recently, Lee et al. (2012) postulated that, for cows fed corn silage- and alfalfa haylage-based diets, histidine might be the most limiting EAA. Based on the study by Maxin et al. (2013a), CM, SBM and C-DDGS contained similar amounts of histidine (mean = 2.54% of CP) and this was greater than for W-DDGS (2.21%). It should be noted, however, that the histidine content for CM (2.54%) reported by Maxin et al. (2013a) is lower than that (3.39%) reported in the Canola Meal Feed Guide (2015). Some of these differences in EAA content among protein sources could partly account for the observed differences in milk and milk protein production in dairy cows fed these feedstuffs as the major source of protein.

▪ Responses in Milk Production to Dietary Inclusion of Canola Meal

Canola meal is a common ingredient in dairy cow diets that are typically fed in western Canada and parts of the USA, primarily because CM is readily available and is considered to be a high quality protein supplement (Hickling, 2008; Mulrooney et al., 2009). When included in the diet, CM is a highly palatable feed ingredient for dairy cows, and the available research indicates that dietary inclusion levels for CM can be as high as 20%, while maintaining (or even increasing) feed intake (Canola Meal Feeding Guide, 2015). As indicated below, the dietary inclusion of CM as a replacement for other protein sources like SBM can actually promote greater feed intakes (Huhtanen et al., 2011; Martineau et al., 2013; Broderick et al., 2015). Based on numerous feeding experiments that have evaluated the feeding value of various protein sources, it appears that cows fed CM produce more milk compared with those fed other protein sources (Brito and Broderick, 2007; Huhtanen et al., 2011; Martineau et al., 2013; Broderick et al., 2015; Mutsvangwa et al., 2016).

Brito and Broderick (2007) examined the effects of feeding supplemental protein as urea, SBM, cottonseed meal (CSM), or CM on milk production and nutrient utilization. The choice of SBM, CSM, and CM was based on the fact that these protein supplements differ markedly in their RUP and EAA contents. Feed intakes and levels of milk production were greater when true protein supplements (SBM, CSM, and CM) replaced urea, but there were no differences in feed intake, milk yield, and fat-corrected milk yield (FCM) among cows receiving true supplemental protein sources; however, cows fed CM produced numerically more milk (+1.7 to +2.1 kg/day) compared with cows fed SBM and CSM. In a follow-up study, Broderick et al. (2015) compared CM and SBM at 15 and 17% total dietary CP to determine animal responses to incremental dietary CP levels with the 2 protein sources. Cows fed CM had a greater feed intake (+0.4 kg/day) and produced more milk (+1.0 kg/day) and energy-corrected milk (ECM; +1.0 kg/day) compared with cows fed SBM (Table 2).

Table 2. Production responses to the substitution of canola meal (CM) for other protein sources in dairy cow diets

	Protein source			
Item[1]	CM	Other	Response	*P* value
Broderick et al. (2015)[2]				
DMI, kg/d	25.2	24.8	+0.4	0.05
Milk yield, kg/d	40.3	39.3	+1.0	<0.01
ECM yield, kg/d	39.5	38.5	+1.0	0.04
True protein (TP), %	3.06	3.04	+0.02	0.51
TP yield, kg/d	1.22	1.19	+0.03	0.02
MUN, mg/dL	10.3	11.5	-1.2	<0.01
Moore and Kalscheur (2016)[2]				
DMI, kg/d	25.8	25.0	+0.8	0.09
Milk yield, kg/d	55.7	51.2	+4.5	<0.01
ECM yield, kg/d	57.6	53.6	+4.0	<0.01
MUN, mg/dL	10.9	11.4	-0.5	0.10
Mutsvangwa et al. (2016)[3]				
DMI, kg/d	31.1	31.6	-0.5	0.23
Milk yield, kg/d	43.7	42.6	+1.1	0.35
3.5% FCM yield, kg/d	43.4	42.4	+1.0	0.28
Protein, %	3.24	3.24	-	0.97
Protein yield, kg/d	1.41	1.38	+0.03	0.42
MUN, mg/dL	17.5	17.1	+0.4	0.46

[1]DMI = dry matter intake; ECM = energy-corrected milk; MUN = milk urea-nitrogen; FCM = fact-corrected milk.
[2]For these studies, canola meal was compared with soybean meal (SBM).
[3]For this study, canola meal was compared with wheat-based dried distillers grains with solubles (W-DDGS).

A recently-completed study at the University of Wisconsin-Madison (Moore and Kalscheur et al., 2016) compared CM and SBM as major protein sources in diets fed to early-lactating cows at 15.4 and 17.6% dietary CP (Table 2). Cows fed CM tended to have greater feed intake (+0.8 kg/day) than those fed SBM; what was more dramatic were the responses in milk yield, as cows fed

CM had greater actual milk yield (+4.5 kg/day) and energy-corrected milk yield (+4.0 kg/day) compared with those fed SBM (Moore and Kalscheur, 2016).

In western Canada, major growth of the ethanol industry has resulted in large quantities of W-DDGS being available as an alternative protein supplement for dairy cows. Because W-DDGS is usually cheaper than CM (Mutsvangwa et al., 2016), dairy nutritionists have become interested in the relative feeding values of CM and W-DDGS as protein sources. For this reason, my research group at the University of Saskatchewan has conducted experiments with dairy cows to compare production and metabolic responses in dairy cows fed CM or W-DDGS as the major protein sources (Chibisa et al., 2012; Mutsvangwa et al., 2015). In one study (Mutsvangwa et al., 2016) to determine animal responses to incremental dietary CP levels, we evaluated CM and W-DDGS at 15 and 17% dietary CP. Our results (Table 2) indicated that feed intake was unaffected by the source of dietary protein. Although milk production was not statistically different when CM or W-DDGS were fed as protein sources, it was noteworthy that cows fed CM produced numerically more milk (+1.1 kg/day) compared with those fed W-DDGS.

In an effort to obtain a better understanding of how cows respond in terms of milk production and other parameters when CM substitutes for other protein sources, various research groups (Huhtanen et al., 2011; Martineau et al., 2013) have recently conducted meta-analytical studies. With this meta-analysis approach, statistical procedures are used to combine the results of multiple feeding experiments in which supplemental protein sources have been compared. A major benefit of meta-analysis is the aggregation of information from multiple studies into a large dataset, thus leading to a higher statistical power and more robust conclusions than can be obtained from any single study. Huhtanen et al. (2011) combined data from 122 studies that compared CM and SBM as protein sources, and concluded that milk yield increased by 3.4 kg/day for every 1 kg/day increase in CP intake when CM was the source of dietary protein, whereas the increase in milk yield with SBM was only 2.1 kg/day. Martineau et al. (2013) combined information from 49 experiments that compared CM with other protein sources, with dietary inclusion levels for CM ranging from 1 to 4 kg/day (mean = 2.3 kg/day). Overall, that meta-analysis demonstrated that cows fed CM produced 1.4 kg/day more milk compared with cows fed other protein sources; however, the response in milk yield when CM was compared with SBM was smaller at +0.7 kg/day (Martineau et al., 2013). These studies clearly indicate a production advantage when CM replaces other protein sources in dairy cow diets, so the question is, what mechanisms are responsible for this response?

▪ How Does Canola Meal Increase Milk Production When It substitutes for Other Protein Sources in Dairy Cow Diets?

Greater Feed Intake with Canola Meal

It appears that the positive responses in milk production when CM replaces other protein sources in dairy cow diets can be partly attributed to greater feed intakes with CM. Various studies (Vanhatalo et al., 2003; Brito and Broderick, 2007; Broderick et al., 2015) reported greater feed intakes when CM replaced other protein sources, including SBM. Based on a meta-analysis of numerous published studies, Huhtanen et al. (2011) and Martineau et al. (2013) concluded that CM stimulated greater feed intake compared with other commonly-used protein sources. In general, milk yield is positively correlated to DM intake (NRC, 2001), so the greater feed intake in cows fed CM is partly the mechanism that is responsible for the improved milk yields.

Greater RUP and Amino Acid Supply with Canola Meal

The substitution of CM for other protein sources in dairy cow diets has improved milk production, and milk protein content and yield (Huhtanen et al., 2011; Martineau et al., 2013). Huhtanen et al. (2011) suggested that these positive responses could be partly attributed to a greater supply of EAA at the small intestine or the supply of metabolizable protein that has an EAA profile that closely matches that of milk. The contribution of CM to RUP flow and its EAA profile is an area that has received research attention in recent years. For a variety of reasons, protein sources vary in their rates and extents of ruminal degradation; consequently, the RUP content of protein sources will vary. Most models that are based on data from older studies (e.g., NRC, 2001) assign a lower RUP value to CM compared with other protein sources like SBM. Part of the reason for this is that CM has a high soluble protein fraction (designated fraction A in these models) compared with other protein sources, and the soluble protein fraction was assumed to be completely degraded in the rumen with rates of degradation ranging from 100 to 500%/hr. However, Hedqvist and Udén (2006) demonstrated that, for various proteinaceous feedstuffs, the in vitro degradability of the A (soluble) fraction varied tremendously, and that as much as 56% of CM fraction A can escape ruminal degradation and contribute to RUP reaching the small intestine. Using in vitro methodologies, 56% (Hedqvist and Udén, 2006), 63% (Bach et al., 2008), and 57% (Stefanski et al., 2013) of the soluble fraction of CM was demonstrated to escape ruminal degradation. Using the newer in vitro methodologies (rather than the in situ technique) to determine the RUP values of CM and SBM, more recent experiments have provided evidence that the RUP value of CM was greater or at least comparable to that SBM. In an in vivo study (Brito et al., 2007) that compared urea, SBM, CSM and CM as protein sources for cows, RUP values for SBM, CM and CSM were estimated to be 29, 34, and 51%, respectively, with no statistical difference between CM and SBM.

Another major factor that might influence animal responses to source of dietary protein is the profile of EAA flowing to the duodenum. It is well-established that the profile of EAA reaching the duodenum should closely match that of milk protein in order to positively influence milk production in dairy cows (NRC, 2001). Protein sources like CM and SBM differ in their EAA content, so these differences could influence the EAA profile of RUP fraction that escapes ruminal degradation. Although not statistically different, omasal flows of lysine, methionine, and histidine (which are EAA that are often referred to as limiting for milk protein synthesis in dairy cows) were numerically greater in cows fed CM compared with those fed SBM (Brito et al., 2007). At the University of Saskatchewan, we compared CM and W-DDGS as protein sources (Mutsvangwa et al., 2016) and observed that omasal flows of EAA such as lysine (+20 g/d), histidine (+13 g/d), threonine (+24 g/d), and tryptophan (+5 g/d) were greater in cows fed CM compared with those fed W-DDGS. Maxin et al. (2013b) showed that cows fed CM exhibited the greatest plasma concentrations of most EAA compared with cows fed SBM or DDGS, suggesting that the post-ruminal supply of EAA in digestible RUP was greatest with CM. The greater post-ruminal flow of EAA with CM could supply more substrate for milk protein synthesis and, overall, milk production.

Greater Fibre Digestibility with Canola Meal

The true value of CM might also be underestimated in terms of its NE_L value for dairy cows. This underestimation arises from unreliable estimates of the digestibility of NDF from CM that are then used to calculate the energy value of CM by older models such as the NRC (2001) and CNCPS (Tylutki et al., 2008). Canola meal contains relatively high amounts of NDF (25.4 to 31.9%; Maxin et al., 2013a; Canola Meal Feeding Guide, 2015), with a lignin content of 5.8 to 6.6% (Canola Meal Feeding Guide, 2015). Generally, lignin content is negatively associated with NDF digestibility; as a result, older models like NRC (2001) estimated the indigestible NDF (iNDF) content of feedstuffs using the lignin content as acid-detergent lignin (ADL) x 2.4/NDF (NRC, 2001). The suitability of this approach for calculating iNDF in non-forage fibre and/or by-product feeds has been questioned (Cotanch et al., 2014). Recently, the Cornell group and others have determined iNDF contents in non-forage fibre and/or by-product feeds using a modified in vitro Tilley and Terry system (Raffrenato and Van Amburgh, 2010) that requires up to 240 h of incubation (Cotanch et al., 2014). Using this newer approach, Cotanch et al. (2014) determined that the iNDF content of CM was 42% (as a % of total NDF), whereas it was 81% when using the ADL x 2.4/NDF equation, thus suggesting that the older method of estimating iNDF grossly overestimated the iNDF content of CM. With greater NDF digestibility of CM based on the newer methods, it appears that the energy value of CM is greater than what would be predicted by older models like NRC (2001), which could partly explain the greater milk production of cows fed CM compared with other protein sources.

■ Summary

A preponderance of the available research indicates that CM can be included in dairy cow diets up to 20% of dietary dry matter as a replacement for other protein sources like SBM without any negative effects on feed intake and milk production. In fact, a meta-analysis of available research indicates that cows fed CM consume more feed and produce more milk compared with cows fed other protein sources. Besides the greater feed intake, the positive response in milk production can be attributed to a greater RUP value for CM, a more balanced EAA profile of the RUP fraction, and a greater energy value for CM than was previously thought.

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Fatty Acid Digestibility and Dairy Cow Performance

Kevin Harvatine

Penn State University, 301 Henning Building, University Park, PA 16802 USA
Email: kharvatine@psu.edu

Take Home Messages

- Fat supplementation can increase dietary energy density without increasing diet fermentability, but also has other physiological effects.
- Nearly all dietary ingredients contribute some fat to the diet. Ingredients with a low fat content are commonly overlooked, but some are fed at high rates and contribute greatly to fat intake.
- Feeding high fat byproducts, and the development of plant varieties selected for a specific fatty acid profile complicate ration balancing.
- The bioactivity of lipids, and their use as an energy source and as a substrate for cellular membrane synthesis and for signaling factor synthesis make determination of requirements difficult.
- Digestibility of hydrogenated triglycerides is low, but research summaries report little difference between digestibilities of individual fatty acids.
- Increasing fat supplementation is expected to decrease total fatty acid digestibility.
- Important aspects of fat supplements are their digestibility, their effect on intake and milk production, and their ability to modify physiology.
- Enriched palmitic acid increases milk fat more than other long-chain fatty acids.
- Selection of fat supplements should consider the basal diet, rumen available fat sources, and the goal of using the fat supplement.

Introduction

Dietary fatty acids (FA) are the nutritionally important component of lipids and serve a number of functions in animal nutrition. Fatty acids are a concentrated source of energy, but also serve as integral structural components of cellular membranes and regulatory molecules. Over the past 25 years, we have come to appreciate that some FA are bioactive compounds that modify physiology and metabolism. The dairy cow experiences very different metabolic demands and physiological conditions across lactation, and it is reasonable to expect that the role of FA differ during these states. It is impossible to make a one-size-fits-all recommendation for dietary fat feeding or expectation on the response to dietary fat. However, current knowledge of fat supplements can direct their use to modify a number of important production parameters.

Palmquist and Jenkins (1980) reviewed the history of fat research in dairy cows starting from a 1907 review of the effect of fat on milk and milk fat yield. It is interesting that over 100 years later we still are asking some of the same questions, but in the context of a cow with much higher metabolic demands. Interest in fat supplementation has traditionally centered around increasing dietary energy density without increasing dietary fermentability to support energy requirements of high producing cows. More recently, interest in fat supplementation has broadened to increasing milk or milk fat yield, increasing reproductive efficiency, and modifying the FA profile of milk. The field of ruminant FA metabolism underwent tremendous growth with the Biohydrogenation Theory of milk fat depression (MFD) and the identification of bioactive conjugated linoleic acid (CLA) isomers. Most recently, availability of enriched palmitic acid supplements provides additional options for fat feeding.

■ Fat Digestion and Metabolism

Fatty acids are not broken down in the rumen, and normally, duodenal flow of FA is similar to intake. Rumen microbes synthesize some FA, resulting in ruminal outflow of odd and branch-chain FA. There is growing interest in the positive human health attributes of these FA, and ruminant meat and milk are the predominant source in the human diet. Ruminal synthesis of FA is increased when feeding low fat diets because the microbes require FA for synthesis of their cellular membranes. The majority of FA in forage and grain feedstuffs are unsaturated, and the rumen microbes will biohydrogenate these unsaturated FA forming *trans-FA* intermediates. Complete biohydrogenation results in saturated FA, but biohydrogenation is commonly incomplete. Rumen microbes biohydrogenate unsaturated FA because these FA are toxic, and the microbes prefer saturated and *trans-FA* for their cellular membranes. The pathways of biohydrogenation are dynamic and responsive to nutritional factors and rumen environment. Specific *trans-FA* formed in alternate biohydrogenation pathways can cause diet-induced MFD, and limit the amount of unsaturated FA that can be fed to dairy cows [see Harvatine et al. (2009)]. Biohydrogenation also severely limits absorption of the essential polyunsaturated FA by the cow.

Rumen Availability of Fatty Acids

Increasing the amount of unsaturated FA in the diet increases the toxic effect on rumen microbial populations and also increases the substrate required for biohydrogenation. Dr. Tom Jenkins developed the concept of Rumen Unsaturated Fatty Acid Load (RUFAL), which is the sum of unsaturated FA in the diet, and provides insight into the risk of altering fermentation. The rates of FA availability must also be considered, but little research has been directed towards understanding the rate of FA availability. The rate of rumen availability is drastically different between some feeds. For example, unsaturated FA in distiller's grains with solubles is rapidly available and has a large impact in the rumen compared to whole cottonseed that is slowly released. Increased grinding of oilseeds increases the risk of diet-induced MFD. Dr. Jenkins recently presented the initial development of a laboratory method to estimate FA availability, and future analytical progress in this area is expected.

Calcium salts of FA were developed to reduce the inhibitory effects of unsaturated FA on fibre digestion because they are insoluble salts that block FA metabolism by microbes (Palmquist and Jenkins, 1980). A main mechanism of calcium salts is slowing rumen availability, rather than true protection, as bypass rates of unsaturated FA fed as calcium salts are rather low. The dissociation of the calcium salt in the rumen is dependent on the dissociation constant of the FA and rumen pH, and increasing unsaturation decreases the strength of the calcium salt. However, calcium salts are far less disruptive to rumen fermentation than are free oils.

Digestibility of Fatty Acids

Intestinal absorption of FA is quite different in the ruminant compared with the non-ruminant, as duodenal flow is predominantly saturated free FA. Non-ruminants depend on monoglycerides and unsaturated FA for formation of micelles, while in the ruminant lysolecithin is a very potent emulsifier and aids formation of micelles. In the ruminant, there is a large decrease in total tract FA digestibility when feeding hydrogenated saturated triglycerides (TG) because they are more resistant to ruminal and intestinal lipolysis than are unsaturated TG (e.g. Elliott et al., 1999). Hydrogenated TG may have a digestibility below 40%. Research studies report significant variation in total tract digestibility that reflects both variation between diets and the technical challenges of digestion studies. Total tract FA absorption is roughly 70 and 80% in dairy cows. Differences in digestibility of individual FA is controversial and is difficult to investigate because of rumen and hindgut biohydrogenation. Meta-analysis studies using different approaches have observed little difference in digestibility between FA, although FA digestibility decreases with increasing fat intake (Glasser et al., 2008, Schmidely et al., 2008, Boerman et al., 2015). The decrease in digestibility with increased intake has important implications as it represents diminishing returns. More attention should be paid to FA digestibility, but this will require a dedicated effort to conduct well-controlled experiments.

Metabolic Fate of Fatty Acids

Fatty acids can be oxidized to provide energy for maintenance and production and provide 2.5 times more energy than carbohydrate. Fatty acids can also be used for body storage and milk fat production; these are energetically efficient processes as FA can be directly deposited and do not have any energy loss. The metabolic fate of absorbed FA depends on the physiological state of the cow and the FA. During peak lactation, FA are directed towards meeting energy requirements for milk production. In some cases, fat supplementation increases milk fat yield and the response appears to be dependent on FA profile. Kadegowda et al. (2008) observed a 243 g/d increase in milk fat yield with abomasal infusion of 400 g/d of butter oil and the increase was predominantly short and medium chain FA. More recently, milk fat responses have been commonly reported when feeding enriched palmitic acid (C16:0), but also have been observed with oilseeds and other FA supplements. After peak lactation, dietary FA will be increasingly partitioned toward body reserves. Importantly, oxidization of FA spares other nutrients from oxidation, which creates a complicated discussion of the metabolic impact of dietary FA. The milk production responses to fat supplements are variable, normally of small magnitudes, and are expected to depend on the interactions discussed above.

Essential Fatty Acids

Fatty acids can be categorized as essential or nonessential based on the animal's capacity to synthesize or conserve the required amounts. Linoleic (C18:2 n-6) and linolenic (C18:3 n-3) acid are traditionally considered the 2 essential FA. Some consider the very long chain omega-3 FA (e.g. eicosapentaeonic acid (EPA**)** and docosahexaenoic (DHA)) to be conditionally essential as they can be synthesized by elongation and desaturation, but the capacity of their synthesis is highly limited in most production animals. There is overlap in the ability to utilize omega-3 and omega-6 FA as substrate in some pathways; however, signaling molecules originating from omega-3 are more anti-inflammatory and omega-6 FA are more pro-inflammatory. Competition for elongation and desaturation has led to the concept of omega-3 to omega-6 ratios, although the importance of these measures is still uncertain.

The requirement for essential FA is different based on the amount needed for maintenance and sustained production vs. the amount that may stimulate maximum production through changing physiology and metabolism. The first definition is easier to define based on metabolic use, but the second demands an understanding of the physiological and metabolic effects of individual FA, including their effect on hard to research processes such as immunology and reproduction. Absorption of essential FA is very limited in ruminants, but there are no reports of classical FA deficiency in adult ruminants. Mattos and Palmquist (1977) determined that linoleic acid was available to the cow at twice the requirement for female weanling rats on a metabolic body weight basis. In addition, ruminants may be adapted to conserving essential FA as they are less available for oxidation. It appears that essential FA are normally available in adequate concentrations based on production requirements; however, there may be benefits of FA supplementation to health including improving reproductive efficiency and immunology.

Effect on Intake

A main goal of fat supplementation is to increase energy intake, but depression of dry matter intake (DMI) can limit the benefits of fat supplements. Intake is highly regulated by animal nutrient requirements and metabolic state, and also by the type and temporal pattern of fuels absorbed. Fat source, form, and FA profile are significant predictors of intake response. In a meta-analysis, Allen (2000) reported a linear decrease in intake with calcium salts of palm distillate, while saturated FA had no effect on intake. Benson et al. (2001) summarized 11 infusion studies and observed a negative relationship between infused C18:1 and C18:2 FA concentration and intake, with C18:2 creating greater intake depression. Some studies with enriched palmitic acid supplements have shown decreased intake compared with no fat controls (Lock et al., 2013, Rico et al., 2014), although the overall decrease in DMI was not significant, and energy intake was increased in a recent meta-analysis (deSouza et al., 2016).

▪ Important Consideration in Fat Sources

It is best to think about diet FA starting with the base diet through to high fat feeds and fat supplements. Feeds vary in type and FA profile and have different effects in the rumen. Forages and cereal grains have a low concentration of fat, but their high feeding rates make them a major dietary source of FA. Oilseeds, high fat byproduct feeds, and liquid fats are economical sources of FA, but care must be taken to not disrupt rumen fermentation. Lastly, dry fats are convenient to add on farm and provide the opportunity to customize absorbed FA profile, but are expensive and differ greatly in FA profile, risks, and benefits.

Forages

Lipids in forages are predominantly in the plant leaf in the form of glycolipids. Total FA concentration in forages is only around 50% of the ether extract value because of the large non-FA content of glycolipids. Fatty acids in forages are highly unsaturated and normally contain more than 50% α-linolenic acid (C18:3). Forages would be a great source of essential FA, but these FA are readily available in the rumen and extensively biohydrogenated. Grasses contain higher levels of FA in the early growth stages (can exceed 5%) and are a common culprit in diet-induced MFD with intensive grazing. Lastly, wilting and drying before harvest decreases the availability of unsaturated FA in forages because of the formation of indigestible resins.

Cereal Grains

Corn, wheat, barley, and oats all have similar FA profiles and contain approximately 55% linoleic acid (C18:2 n-6) and less than 1% omega-3 FA. Corn grain is higher in total fat than small grains. In a recent characterization of test plots of 36 commercial hybrids we observed a range of 3.3 to 3.9% total FA (10^{th} to 90^{th} percentile) and 55.7 to 60.0% linoleic acid. In corn, the majority of the FA is in the germ and processing methods that increase rate of digestion will likely increase the rate of rumen availability of the unsaturated FA.

Corn Silage

Corn silage is a mixture of grain and forage and thus has a combination of the forage and grain attributes discussed above. We recently found that 80% of the total fat and over 90% of the oleic (C18:1 n-9) and linoleic (C18:2 n-6) acid was found in the kernel and over 70% of the α-linolenic acid (18:3 n-3) was in the leaves. Therefore, grain concentration is going to impact the FA concentration and profile. Additionally, we expect that unsaturated FA in the kernel are rapidly available in well processed and ensiled silage. We also observed moderate variation in FA concentrations and profiles of corn silage test plots with C18:2 ranging from 0.94 and 1.60% of DM (10^{th} and 90^{th} percentile). Fatty acid profile of corn silage is going to be highly dependent on genetics. Routine analysis is probably not needed, but it is advisable to determine each crop's profile or when trouble-shooting diet-induced MFD.

Oilseeds

Feeding oilseeds is commonly an economical and convenient method to increase FA intake. The FA are highly unsaturated and are mostly found in triglycerides in the fruit contained inside the seed coat. The seed coat and processing method dictate the rate of rumen availability, which has a large impact on the associative effect of the FA on the rumen. Although the release rate of FA in the rumen can be decreased by less aggressive processing, oilseed unsaturated FA are normally extensively biohydrogenated and it is difficult to bypass unsaturated FA in oilseeds.

Expeller oilseed meals are normally higher in fat (~9%) than solvent extracted meals (<3%), but this depends on the seed, processing plant, and batch. Some facilities may also add phospholipids and free recovered oil back to the meal, which may change rumen availability and risk for oxidative rancidity.

Oilseed FA profile has and continues to undergo strong genetic selection to modify FA profile for human health and processing characteristic. The recent development of high-oleic acid soybeans (>70% C18:1) is expected to have an impact on animal feeds. These specialty oilseeds are commonly processed in specific facilities allowing identification, but as the market grows they may become mixed within the commodity market.

Byproducts

Many high fat byproduct feeds are available at a reasonable cost and vary considerably in amount and profile of FA. The FA in many of these byproducts is rapidly available. Arguably, many of the issues with diet-induced MFD when distiller's grains with solubles is fed may be due to the rapid availability of the unsaturated FA and may not be the amount of unsaturated FA. Many ethanol plants are now recovering some of the lipid to be sold as oil, which has decreased fat concentration. The key element to any byproduct feed is managing the variation to take maximal advantage of its value.

Liquid Fats

Liquid fats can be an economical source of FA. They adhere to feed particles and are expected to be rapidly available in the rumen. Liquid fats vary in their FA profile depending on their source, and changes in oilseed FA profile also impact vegetable oil streams. Quality can be an issue in liquid fats as unsaturated FA are more susceptible to oxidation once extracted and some processing streams include heating. Antioxidants are commonly added to liquid fats, especially when they are highly unsaturated. Measuring unsaponifiable matter can also provide some indication of quality.

Dry Fat Supplements

Dry fat supplements are convenient because they are concentrated sources of FA that are easy to handle on farm. They differ greatly in their source, FA profile, and metabolic effects. Some dry fat supplements may melt in extreme temperature conditions.

Prilled Saturated Fats

Saturated FA are naturally ruminal inert as they are not toxic to microbes and do not require biohydrogenation. The first major difference in prilled fats is their free FA concentration. Hydrogenated (saturated) TG are poorly digested as they are not hydrolyzed in the rumen and the cow has poor lipase activity in the intestine. Most prilled supplements on the market are high free FA products (80 to 99%) and decreased digestibility may occur in products that are higher in TG. The second major difference is FA profile. Traditionally, prilled products were a mixture of palmitic and stearic with a lower concentration of oleic. More recently, enriched palmitic acid (> 80% C16:0) products have become available as a byproduct of palm oil manufacturing. Additional differences exist in FA source and manufacturing. For example, saturated FA can be enriched by separation from unsaturated FA or unsaturated oils or made by partial or full hydrogenation of unsaturated FA. Partial hydrogenation adds the risk of presence of bioactive *trans*-FA. Also, some plant-based sources have an increased risk for contamination of residues including dioxins. Prill size can also differ between manufacturing processes and the impact on digestibility has not been extensively investigated, but appears to be minor.

Prilled free FA blends of palmitic and stearic acid have the longest history in the literature and generally do not decrease DMI and are well digested. Enriched palmitic acid products (80 to 90% C16:0) have been extensively investigated in the past 6 years, and generally result in a small increase in milk fat (~0.2-unit increase when fed at 1.5 to 2% of diet) and are also well digested. Limited research has been done with highly enriched palmitic and stearic acid products (> 95%). The highly enriched product used in these experiments decreased diet FA digestibility considerably, although it is unclear if this is attributed to specific attributes of the product fed, such as prill size, or the high enrichment.

Calcium Salts of Fatty Acids

Calcium salts of palm FA were developed in the 1980’s to allow feeding unsaturated FA without negative effects on fibre digestion. Traditionally, calcium salts were made from palm oil distillate, but specialty blends that include n-6 and n-3 FA are now available. More recently, there has been interest in using calcium salts to protect unsaturated FA in the rumen and increase essential FA absorption. Using calcium salts is the only method currently available to increase rumen bypass of unsaturated FA; however, the effectiveness of calcium salts is limited. The release of highly unsaturated FA in the rumen increases the risk of diet-induced MFD when feeding calcium salts enriched in polyunsaturated FA compared to feeding a prilled saturated FA supplement.

■ Conclusions

Fat supplementation continues to evolve with changes in oilseed FA profile through selection and new dry fat supplements available from palm oil processing. Fatty acids have been appreciated as bioactive FA for some time with great interest in CLA-induced MFD and essential FA, but there also appears to be differences between saturated FA. We will continue to move toward balancing for specific FA as our knowledge of ruminal biohydrogenation, specific roles of individual FA, and strategies to protect unsaturated FA improves.

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Leaky Gut's Contribution to Inefficient Nutrient Utilization

S.K. Kvidera[1], E.A. Horst[1], M. Al-Qaisi[1], M.J. Dickson[1], R.P. Rhoads[2], A.F. Keating[1], and L.H. Baumgard[1]

[1]Iowa State University Department of Animal Science
[2]Virginia Tech Department of Animal Science
Corresponding author: baumgard@iastate.edu

Take Home Messages

- Ketosis and heat stress are two hurdles to profitable dairying.
- Both ketosis and heat stress are characterized by increased inflammation.
- Evidence suggests endotoxin originating from the gut as the underlying cause for both disorders.
- Immune system activation has important metabolic consequences that negatively affect production.

Introduction

There are a variety of situations in an animal's life when nutrient utilization is reprioritized from productive towards agriculturally unproductive purposes. Two well-known examples that markedly reduce production are heat stress and ketosis. Decreased feed intake, experienced during both disorders, is unable to fully explain production losses. Additionally, both disorders are characterized by negative energy balance, body weight loss, inflammation, and liver fat accumulation. While the metabolism of ketosis and heat stress has been thoroughly studied for the last 40 years, the initial insult in the cascade of events ultimately reducing productivity in both heat-stressed and ketotic cows has not been identified. To that end, we have generated preliminary data strongly implicating a metabolic disruptor, endotoxin, as the underlying cause in each case.

Heat Stress

Heat stress (HS) negatively impacts a variety of production parameters and is a significant financial burden (~$900 million/year for dairy in the U.S. alone;

St. Pierre et al., 2003). Heat stress affects productivity indirectly by reducing feed intake; however, direct mechanisms also contribute, as we have shown reduced feed intake only explains approximately 50% of the decreased milk yield during HS (Baumgard et al., 2012, 2013). Direct mechanisms contributing to milk yield losses during HS involve an altered endocrine profile, including reciprocal changes in circulating anabolic and catabolic hormones (Baumgard and Rhoads, 2012, 2013). Such changes are characterized by increased circulating insulin concentration and lack of adipose tissue (i.e. backfat) mobilization. Liver and skeletal muscle cellular bioenergetics also exhibit clear differences in carbohydrate production and use, respectively, due to HS. Thus, the HS response markedly alters carbohydrate, fat, and protein metabolism through coordinated changes in fuel supply and utilization across tissues in a manner distinct from commonly recognizable changes that occur in animals on a reduced plane of nutrition (Baumgard and Rhoads, 2013). The result of HS is underachievement of an animal's full genetic potential.

Ketosis

The transition period is associated with substantial metabolic changes involving normal metabolic adaptations to support milk production. Unfortunately, a disproportionate amount of herd culling occurs before cows reach 60 days in milk. Ketosis is arbitrarily defined as an excess of circulating ketone bodies (β-hydroxybutyrate [BHBA] and/or acetoacetate), and is characterized by decreases in feed intake and milk production, and increased risk of developing other transition-period diseases (Chapinal et al., 2012). About 20% of transitioning dairy cows clinically experience ketosis (BHBA > 3.0 mM; Gillund et al., 2001) while the incidence of subclinical ketosis (>1.2 mM BHBA) is thought to be much higher (> 40%; McArt et al., 2012). Ketosis is a costly disorder (estimated at ~$300 per case; McArt et al., 2015) and thus it represents a major hurdle to farm profitability. Traditionally, ketosis is thought to result from excessive fat mobilization (Baird, 1982), which in turn contributes to fatty liver and excessive ketone body synthesis.

Heat Stress Etiology

Mechanisms responsible for altered nutrient partitioning during HS are not clear; however, they might be mediated by HS effects on gastrointestinal health because HS compromises intestinal barrier function (Pearce et al., 2013; Sanz-Fernandez et al., 2014). During HS, blood flow is diverted from the internal organs to the skin in an attempt to dissipate heat, leading to reduced oxygen flow to the intestine (Baumgard and Rhoads, 2013). Unfortunately, for a variety of reasons, intestinal cells are very sensitive to reduced blood flow and their "barrier function" is quickly compromised. As a result, HS increases the infiltration of potentially harmful intestinal molecules into circulation (Pearce et al., 2013).

Endotoxin, also known as lipopolysaccharide (LPS), is a glycolipid embedded in the outer membrane of Gram-negative bacteria, which are abundant and prolific in luminal content, and is a well-characterized potent immune stimulator in multiple species (Berczi et al., 1966). Immune system activation occurs when LPS binding protein (LBP) binds LPS for removal and detoxification; thus, LBP is frequently used as a biomarker for LPS infiltration (Ceciliani et al., 2012). For a detailed description of how livestock and other species detoxify LPS see our review (Mani et al., 2012). Endotoxin infiltration during HS into the bloodstream is common among heat stroke patients (Leon, 2007) and is thought to play a central role in heat stroke pathophysiology, because survival increases when intestinal bacterial load is reduced or when plasma LPS is neutralized (Bynum et al., 1979). It is remarkable how animals suffering from heat stroke or severe endotoxemia share many physiological and metabolic similarities to HS, such as an increase in circulating insulin (Lim et al., 2007). Infusing LPS into the mammary gland increased (~2 fold) circulating insulin in lactating cows (Waldron et al., 2006). In addition, we intravenously infused LPS into growing calves and pigs and demonstrated >10-fold increase in circulating insulin (Stoakes et al., 2015a; Kvidera et al., 2016). Interestingly, increased insulin occurs before increased inflammation and the temporal pattern agrees with our previous *in vivo* data and a recent *in vitro* report (Bhat et al., 2014) suggesting LPS stimulates insulin secretion, either directly or via other endocrine mediators (Kahles et al., 2014). The possibility that LPS increases insulin secretion likely explains the hyperinsulinemia we have repeatedly reported in a variety of heat-stressed animal models (Baumgard and Rhoads, 2013). Again, the increase in insulin is energetically difficult to explain as feed intake is severely depressed during both HS and endotoxemia.

■ Transition Period Inflammation

Recently, the concept that LPS impacts normal nutrient partitioning and potentially contributes to metabolic maladaptation to lactation has started to receive attention. Although LPS itself has not been the primary causative focus, general inflammation has been the topic of investigations. Increased inflammatory markers following parturition have been reported in cows (Bertoni et al., 2008). Presumably, the inflammatory state following calving disrupts normal nutrient partitioning and is detrimental to productivity (Bertoni et al., 2008). This assumption was recently reinforced when infusion of an inflammatory cytokine decreased productivity (albeit without overt changes in metabolism; Martel et al., 2014). Additionally, in late-lactation cows, injecting the same inflammatory cytokine increased (>100%) liver lipid content without a change in circulating non-esterified fatty acids (NEFA; Bradford et al., 2009). Our recent data demonstrate increased inflammatory markers in cows diagnosed with ketosis only and no other health disorders. In comparison with healthy controls, ketotic cows had increased circulating LPS prior to calving and post-partum acute phase proteins such as LPS-binding protein, serum amyloid A, and haptoglobin were also increased (Figure 1; Abuajamieh et al., 2016). Endotoxin can originate from a variety of locations, and obvious sources in transitioning dairy cows include the uterus (metritis), mammary gland (mastitis) and the gastrointestinal tract (Mani et al., 2012). However, we believe intestinal permeability may be responsible for inflammation observed in the transition dairy cow. A transitioning dairy cow undergoes a post-calving diet shift from a mainly forage-based ration to a high concentrate ration. This has the potential to induce rumen acidosis, which can compromise the gastrointestinal tract barrier (Khafipour et al., 2009).

In order to further investigate the effects of intestinal permeability on production and inflammation, we intentionally induced intestinal permeability in mid-lactation dairy cows using a gamma secretase inhibitor (GSI), a compound that causes “leaky gut” (van Es et al., 2005). We anticipated feed intake of GSI-administered cows would decrease, so we pair-fed controls in order to eliminate the confounding effect of feed intake. Administering GSI decreased feed intake and altered jejunum structure consistently with characteristics of leaky gut (shortened crypt depth, decreased villus height, decreased villus height to crypt depth ratio). Circulating insulin and LBP were increased in GSI cows relative to controls. Interestingly in our GSI model, the acute phase proteins––serum amyloid A and haptoglobin—increased for both treatments over time, indicating inflammation was occurring in pair-fed controls as well (Stoakes et al., 2014). This is not surprising, as pair-fed controls were receiving only ~20% (an 80% reduction in feed intake) of their ad libitum intake and decreased feed intake has been shown to increase intestinal permeability in feed restricted rodents and humans (Rodriguez et al., 1996) and pigs (Pearce et al., 2013; Sanz-Fernandez et al., 2014). Recently, we confirmed the detrimental effects of feed restriction in mid-lactation cows by demonstrating a linear increase in circulating acute phase proteins and endotoxin with increasing severity of feed restriction. Furthermore, cows fed 40% of ad libitum intake had shortened ileum villus height and crypt depth, indicating reduced intestinal health (Stoakes et al., 2015b). In summary, inflammation is present during the transition period and likely contributes to changes in whole-animal energetics.

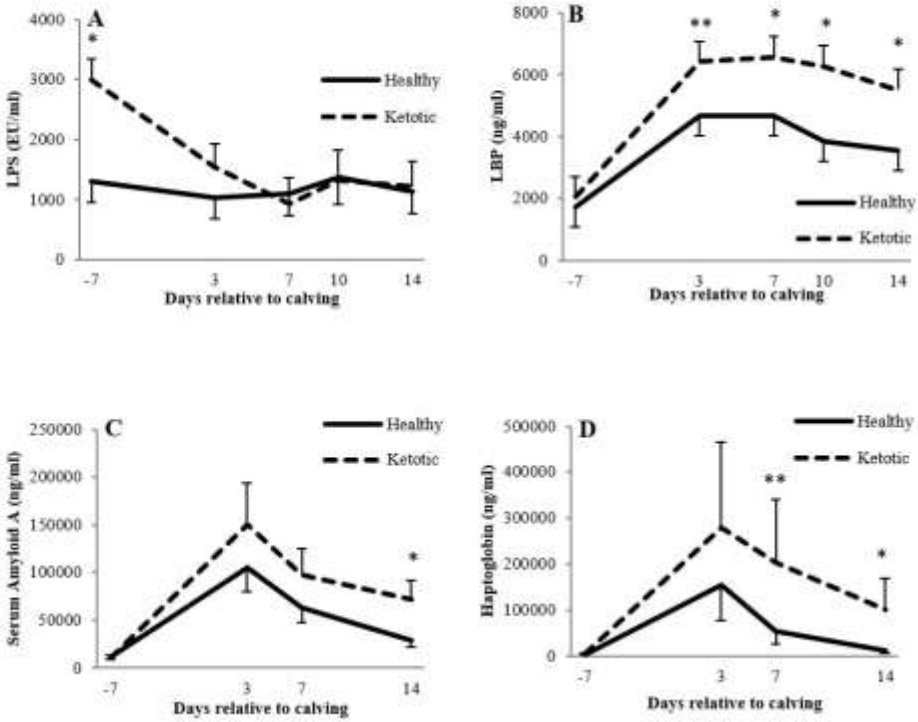

Figure 1. Markers of inflammation in healthy (solid line) and ketotic (dashed line) transition cows.

■ Metabolism of Inflammation

LPS-induced inflammation has an energetic cost, which redirects nutrients away from anabolic processes that support milk and muscle synthesis (see review by Johnson, 1997) and thus compromises productivity and efficiency. Interestingly, immune cells become more insulin sensitive and consume large amounts of glucose upon activation in order to support rapid proliferation and biosynthetic processes (Calder et al., 2007). In contrast, inflammation induces an insulin resistant state in skeletal muscle and adipose tissue (Liang et al., 2013). Recent data has also demonstrated a decrease in ketone oxidation during LPS infiltration (Suagee et al., 2011), which we believe may partly explain increased ketone body concentrations during the transition period.

Endotoxin has previously been recognized to be involved with metabolic dysfunction. In humans, both obesity and high fat diets are linked to endotoxemia (Cani et al., 2007). Furthermore, LPS is involved with the development of fatty liver (Ilan, 2012), and cytokines are linked to lipid accumulation and cholesterol retention (Ma et al., 2008). Experimentally-induced endotoxemia in dairy cattle has been linked to several metabolic and endocrine disturbances including decreased circulating glucose, termination of pregnancy, leukopenia, disruption of ruminal metabolism, and altered calcium homeostasis (Griel et al., 1975; Waldron et al., 2003). The aforementioned pathological conditions are likely mediated by LPS-induced inflammation and the subsequent changes in nutrient partitioning caused by immune system activation.

Energetic Cost of Immune Activation

An activated immune system requires a large amount of energy and the literature suggests that glucose homeostasis is markedly disrupted during an endotoxin challenge. Upon immune system activation, immune cells switch their metabolism from oxidative phosphorylation to aerobic glycolysis, causing them to become obligate glucose utilizers (Vander Hiden et al., 2009). Our group recently quantified the energetic cost of an activated immune system by infusing exogenous glucose to maintain normal blood glucose levels during LPS-induced hypoglycemia (i.e., LPS-euglycemic clamp). Using this model, we estimated approximately 1 kg of glucose is used by the immune system during a 12-hour period in lactating dairy cows. Interestingly, on a metabolic body weight basis the amount of glucose utilized by LPS-activated immune system in lactating cows, growing steers and growing pigs were 0.64, 1.0, and 1.1 g glucose/kg $BW^{0.75}$/h, respectively; Stoakes et al., 2015a,c; Kvidera et al., 2016). Increased immune system glucose utilization occurs simultaneously with infection-induced decreased feed intake. This decreases the amount of nutrients available for the synthesis of valuable products (milk, meat, fetus, wool). We and others have now demonstrated that both heat-stressed and ketotic animals have increased circulating markers of endotoxin and inflammation. We believe the circulating LPS in both maladies originates from the intestine and thus both likely have an activated immune system. This activated systemic immune response reprioritizes the hierarchy of glucose utilization, and milk synthesis is consequently deemphasized.

▪ Conclusion

Ketosis and heat stress are two of the most economically important pathologies that severely jeopardize the competitiveness of animal agriculture. Heat stress and ketosis affect herds of all sizes and every dairy region in the country. The biology of ketosis and heat stress has been studied for almost a half century, but the negative impacts of both are as severe today as they were 30 years ago. We suggest, based upon the literature and on our supporting evidence, that LPS is the common culprit for both metabolic disorders. Taken together, our data and the literature suggest that LPS markedly alters nutrient partitioning and is a causative agent in metabolic disruption during heat stress and ketosis.

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Evaluating the Cost Effectiveness of Feed Additives

David Galligan

University of Pennsylvania, School of Veterinary Medicine, 382 West Street Road, Kennett Square PA 19348, USA
Email: Galligan@vet.upenn.edu

■ Take Home Messages

- Economic evaluation must be done on a marginal basis.
- Management must understand all the dimensions of production affected.
- Improved feed efficiency (digestion) and/or the dilution of animal nutrient maintenance requirements.
- Management must understand all the direct and indirect costs.
- Management must understand the risk attributes (type I and II error, real options).

■ Overview

Feed additives are a critical input technology for the successful management of the modern dairy operation. Feed additive products are continually evolving, and can impact the dairy operation in a number of dimensions. Feed additives are part of the wealth creation activities of a successful dairy. While feed additives may differ in their impacts, they share common economic attributes, which will be the main focus of this manuscript. Dairy managers should continually evaluate available products in terms of their potential impact on the economic efficiency of their operations.

■ Background

Feed additive products are often initially explored through well designed research trials to determine their production attributes. Successful additives are embraced by the industry at large, and often become part of the new “norm” of dairy management. Listings of products and their production impacts can be found at the DeLaval web site:

www.milkproduction.com/Library/Scientific-articles/Nutrition/Feed-additives, and in the proceedings paper presented by Dr. Hutchens at the 2014 Penn State Nutrition conference (Hutjens, 2014). This paper will focus on the major underlying economic principles that are relevant to most feed additive products.

A critical issue in determining if a feed additive is to be used is what are the relative costs and benefits associated with the product. The most common and major impact of a feed additive is the effect it has on milk yield, composition of milk, and feed efficiency. Impacts in these dimensions directly affect the revenue stream value associated with the product, and must be accounted for in the economic assessment. There are other possible benefits beyond milk yield, which include reduced disease prevalence and/or severity, improved feed efficiency, improved reproduction efficiency, and potentially improved longevity. The potential economic value of these dimensions often require the use of specifically designed economic models that can account for the correlation of impacts or the use of general summary estimates (disease costs/case, cost/day open etc.). These broader potential impacts of feed additives will not be explored in this paper.

The cost associated with the use of a product is more complicated and can have a number of important nuances. First, the direct cost of the product must be adjusted in terms of the number of animals that are offered the product versus those animals in which the benefits are likely to be accrued. For example, a feed additive to reduce the incidence of milk fever will accrue costs for all animals fed within a pen (1st and > 1 lactation animals), while the benefit, a reduction in milk fever prevalence, will be realized primarily by the older lactation groups. Management can alter the cost associated by using these types of products targeting specific high risk groups (separate feeding pens); however, there may be additional costs associated with those actions.

One of the most important costs associated with the use of a feed additive product is the consequential impact it may have on dry matter intake. Feed intakes may be increased resulting in an increase in milk yield; however, the feed consumed may be digested at an altered efficiency (increase, decrease, or no change) and thus have different associated costs. Feed additives can vary in terms of their mean responses as well as their variation of responses. Additives that have greater variation in response will carry greater risk (expected value of failure) than products with lower response variation.

This paper will focus on the impact on milk yield, milk composition and feed efficiency. The general economic issues will be covered and presented in visual analytical tools (dashboards) that can be used to evaluate the economic impact and facilitate management decision making.

■ Milk Response Evaluation

The milk response should be evaluated in terms of incremental increase in yield and changes in composition (fat and protein %). The economic value of the associated increase in yield should reflect any compositional changes. A convenient approach is to look at the energy composition of milk as a function of the component values (milk fat, protein and other solids) and thus the total energy required to produce a given yield. The ration cost can be partitioned by the portion of feed energy used for animal maintenance (a function of body weight) and the portion used to produce a given yield and composition of milk.

A visual analytic (dashboard) has been created called the Feed Analytic Evaluator, which can be used to facilitate the economic evaluation of feed additives. This interactive tool can be found at Dapdairy.org (Logon: guest, Password: guest) under the Dashboard menu and in the Economics subsection.

Figure 1 is a screen shot of the baseline screen. Here, baseline parameters are entered to describe the herd in terms of animal weight, milk level, milk composition, ration energy density and ration cost. From these parameters, the average and marginal feed cost of producing an additional lb. of milk can be estimated and expressed on a per cwt milk basis (Note: all prices are in US$). The average feed cost was estimated by taking the ration cost ($6.30) divided by milk yield (80 lbs/day) multiplied by 100 giving $7.88/cwt of milk. The marginal feed cost can be determined by estimating the portion of feed energy used to support maintenance versus yield. Based on the entered values, 39.5 Mcals of net energy are required for maintenance and production; approximately 67% of the total energy is used for production while 33% is used for maintenance (Figure 1). The ration cost can be partitioned (based on energy use) into $4.20 for production and $2.10 for maintenance. The $4.20 can be divided by the milk level (80 lbs) to yield a marginal cost of $.0525/lb of milk or $5.25/cwt milk. If there is no change in feed efficiency, the next marginal lb of milk is estimated to cost $.0525 to produce. The energy required per lb of milk at the entered composition is 0.329 Mcals/lb of milk and the cow is estimated to have an intake level of 50.6 lbs of dry matter.

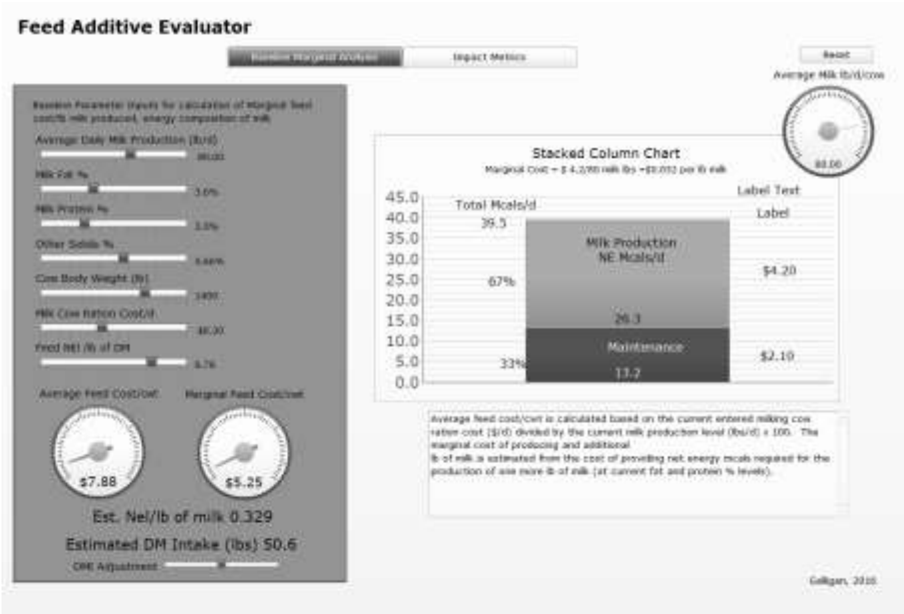

Figure 1: Base parameter screen of the Feed Additive Evaluator dashboard.

The next steps in determining the economic value of a feed additive are to describe its observed impact and various parameters. Figure 2 is an example of a product costing $0.10/cow/day and expected to increase milk yield by 1.5 lbs/cow/day with the baseline composition parameters. Feed efficiency is not changed, the probability of success is expected at 100% and the % of treated cows responding to treatment is set at 100%. Based on these parameters, 1.03 lbs of milk are required to cover the cost of the product and associated change in feed intake to at least break even. The actual partial budget is presented on the lower left of Figure 2, where a milk revenue is estimated at $0.225 and an associated marginal feed cost of $0.0787. After accounting for the daily cost of the product, the net marginal returns above costs is $0.0463/cow per day, yielding a 46% net rate of return per dollar of the additive cost and a 26% net return on the products and feed costs.

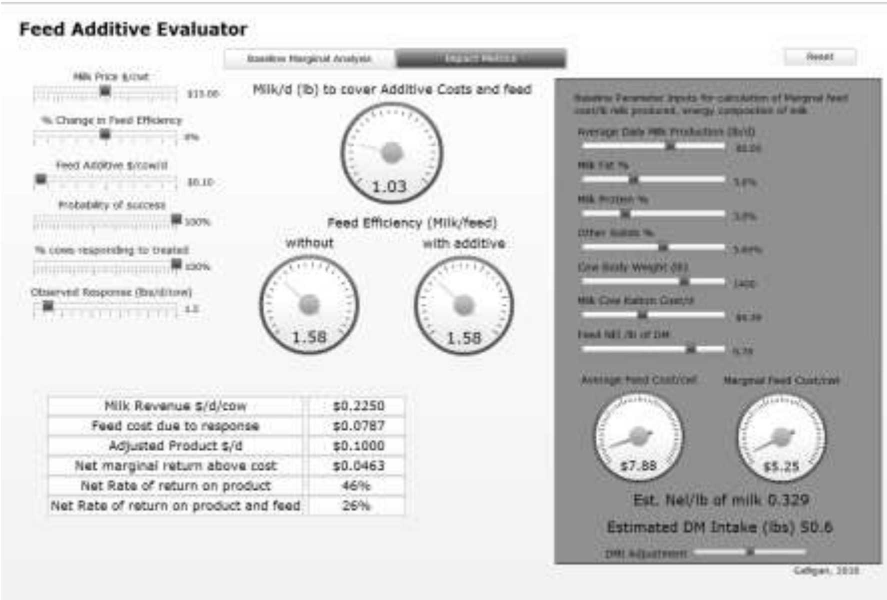

Figure 2: Screen shot of the feed additive impact screen.

These economic estimates will change as the parameters of the model are changed (Figure 3). For example, if the product improves feed efficiency by 23%, thus changing the milk/feed ratio from 1.58 to 2.05, the net marginal return above cost increases to $0.0644/cow/day, the net rate of return on product increases to 64%, and the net rate of return on product and feed costs increases to 36%.

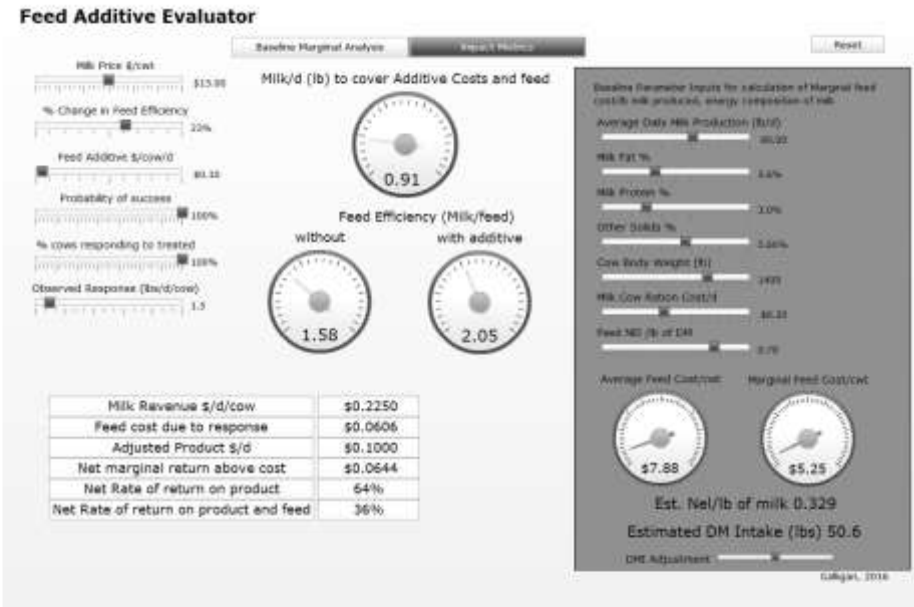

Figure 3: Screen shot of the feed additive impact screen with an improvement of feed efficiency of 23% (i.e. 23% less feed per lb. of milk response)

▪ Type I and II Error Analysis

In addition to changes in the mean response, products also can vary in the variation of response (Galligan, 1991a, b). For a product to be economically competitive, it must not only have a favorable mean response, but its expected value of success should exceed its expected value of failure. A convenient approach to evaluate these dimensions of a product can be done by comparing the expected values of Type I and Type II error associating with using a product (Figure 4). For a product to have a favorable economic response, it must have an impact on milk yield and/or composition (breakeven values), the value of which exceeds the cost of using the product along with any other associated cost (feed intake, cost of implementation). Responses below the breakeven level result in economic losses while those that exceed it will result in positive economic rewards. These concepts can be integrated into the general question facing management, that is, to use or not use a product and evaluating the potential relative cost of management error. A product either works (is above breakeven) or does not work (is below breakeven). If management uses a product and the response is below breakeven, a type I error has been committed. If management fails to use a product and the response if it had been used was above breakeven, a type II error has been committed. The first criterion of evaluation of type I and II error analysis is to make the decision that has the minimum error cost. If type I error is less than type II error, then the product should be used with the rationale being that the cost of potential failure is less than the cost of failing to take advantage of favorable outcomes. Further criteria could be to evaluate the relative magnitude of the errors.

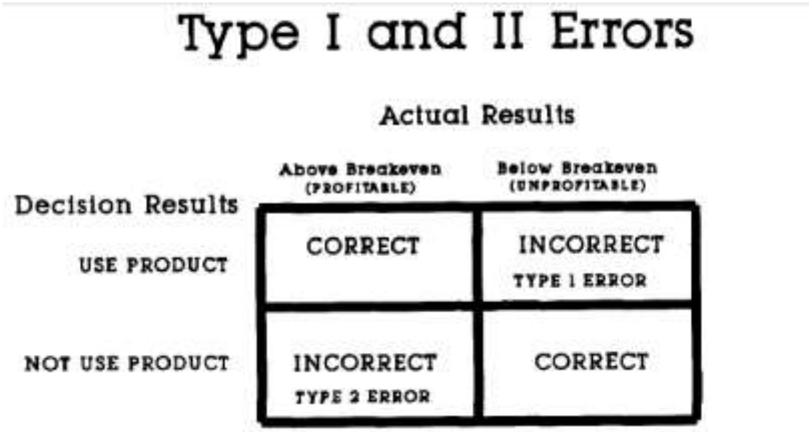

Figure 4: Decisions and outcome possibilities.

Example Calculation

A sample calculation of type I and II error analysis will be done to demonstrate the fundamental concepts using sodium bicarbonate as an example (Galligan et al. 1991a). A summary of the research literature suggests that the mean response to sodium bicarbonate is about 1.4 kg of milk/day per cow fed the product. The variation of this response across trials was estimated to be 1.13 kg (standard deviation). The marginal increase in milk yield was assumed to be associated with an increase in feed intake that was valued at $0.09/kg of milk response. Based on a product cost of $0.05/cow/day, a milk value of $0.26/kg of milk and the above marginal feed cost, a breakeven level of response is estimated to be 0.3 kg/cow/day. These error costs will change if any of the underlying parameters change.

■ Stochastic Dominance

When comparing products, one can calculate the cumulative distribution curves of the expected net values for each product and the varying levels of response. Products can be ranked based on position of the curves (1st order stochastic dominance) where curves further to the right have more favorable economic value relative to risk compared to curves to the left. In the example presented, bovine somatotropin (BST) has a much greater profile than sodium bicarbonate or MEGALAC, as reflected by it being further to the right. For situations where the curves cross, one can use the 2nd order of stochastic dominance, where the products are ranked by the area under the cumulative curves and products with the least area are viewed as more favorable. Megalac would rank in the middle based on second order stochastic dominance.

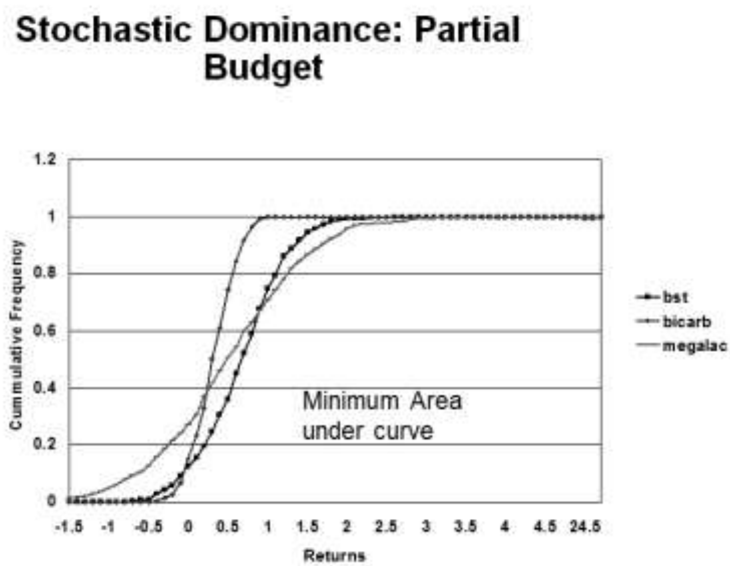

Figure 5: Cumulative distributions of expected net returns (probability x (revenue-cost)) for 3 products with different means and variations in response.

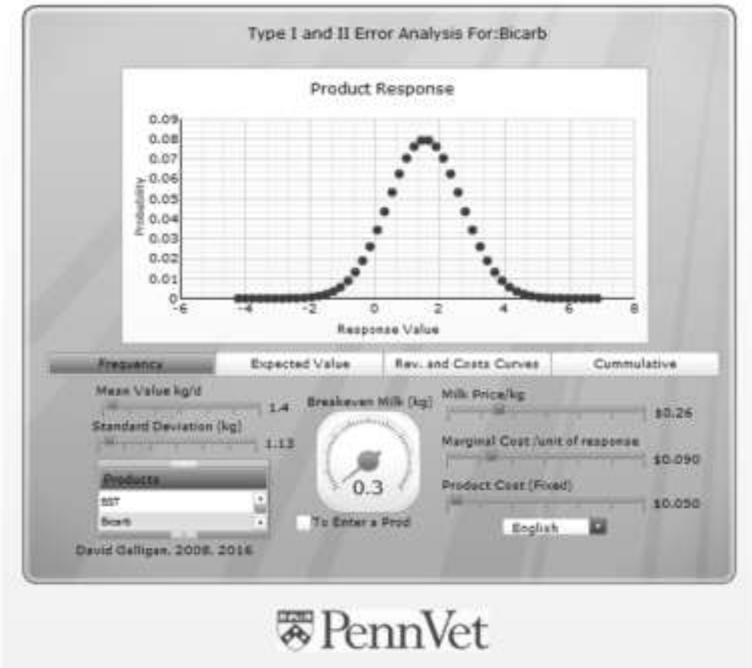

Figure 6: Screen shot of the Type I and II error analysis dashboard, showing the distribution of milk responses to sodium bicarbonate feed additive.

The breakeven level of response determines the boundary between a type I and type II error. This boundary level can change if any of the input parameters change. The next attribute of the product to be evaluated is the frequency of these errors and more importantly their expected values. The expected value is the probability of a given level of response occurring (from the distribution curve) multiplied by the net value of the response level (revenues less costs). From the distribution of the response and the breakeven level, the two error costs be can calculated by integrating the expected value area of the distribution below breakeven (type I) and above breakeven (type II).

In Figure 7 the expected value curve for sodium bicarbonate is shown. The inflection point of the curve occurs at the breakeven level (0.3 kg). Type I error, which occurs when the product is used and the response is below breakeven, has an expected value of -$0.013/cow/d. This cost is presented as a negative value to reflect a direct expense. The type II error occurs when management fails to use the product, and yet the response is above breakeven and has an estimated lost opportunity cost of $0.23/cow/day. The absolute value of type I error is much smaller than type II error and thus the appropriate decision would be to use the product and bear the risk that it might not work.

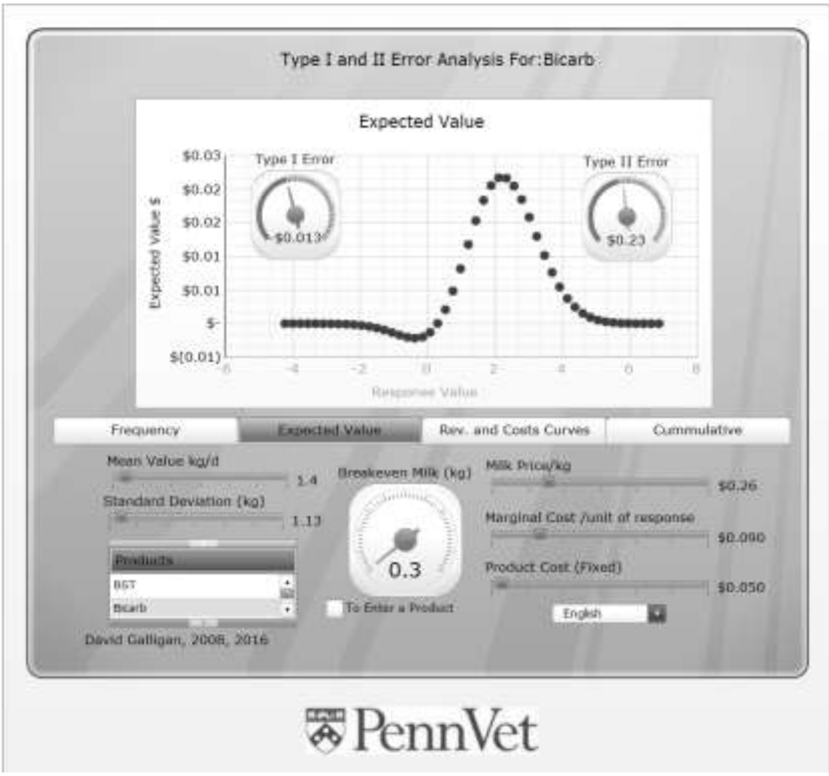

Figure 7: Screen shot of the expected values of the Type I and II errors.

▪ Option Value of Feed Additive Products

In addition to direct impacts on milk production and feed efficiency, and other elements of economic importance (disease frequency, reproduction, longevity, etc.), some feed additives have another dimension of value that is important in risk management (Galligan, 2002). Let’s consider two feed related products, one is given to the cow in its daily ration while the other is added during ensiling. For discussion purposes, let’s assume that the products ultimately have the same impact on production (Figure 8, yield and composition), the same variation in response, and are priced so that the daily costs/cow are identical. Based on this information, these products would be valued identically using all the methods described above. However, the product that is fed to the cow daily has an additional dimension of value in that management can immediately remove the product if it does not work (i.e., if the response is below breakeven). This is a type of real option referred to as an abandonment option, and confers additional value to products that have it as an attribute. This requires active management in that management must make the effort to evaluate the response (respond to the resolution of uncertainly) and have the tools to make the evaluation and determine and alternative use of resources. Passive management will not respond to resolved uncertainly and continue to use an inferior product.

Figure 8: The structure of an abandonment option decision.

■ Summary

Feed additives can be an important part of the technologies used in the modern dairy to promote economic efficiency. Change in milk yield and composition must be valued relative to the cost of the additive and its implementation. In addition to the cost of the additive, the analysis should include an appropriate accommodation of the associated feed cost due to any changes in feed efficiency associated with the product. Products also have risk characteristics that can be evaluated using type I and II error analysis and further ranked using stochastic dominance principles. Additionally, many products might have additional value in the form of real options such as an abandonment option. This value is realized when good management is actively involved in the management and evaluation of the use of a product.

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Milk Progesterone Profiles Before and After AI and Their Association with Pregnancy and Pregnancy Loss in Alberta Dairy Farms

T.C. Bruinjé[1], M. Colazo[2], M. Gobikrushanth[1], D.J. Ambrose[1,2]

[1]Department of AFNS, University of Alberta; [2]Livestock Research & Extension Branch, Alberta Agriculture and Forestry, Edmonton, AB, Canada T6H 5T6
E-mail: tcbruinje@ualberta.ca

The assessment of reproductive function through in-line milk progesterone (mP4) profiles is a new opportunity to evaluate characteristics of ovarian activity associated with fertility. No such report currently exists for North American herds. The objectives were to evaluate if postpartum ovarian activity before first AI and mP4 levels around time of AI are associated with fertility in primiparous and multiparous cows. In-line mP4 records were assessed from two dairies in Alberta using the Herd Navigator system (DeLaval Inc). Days in milk (DIM) to first ovulation (FOV) and presence of abnormal cycles (short/long) from ~20 DIM until first AI were defined based on mP4 levels (high vs. low; 5ng/mL threshold) in 785 cows. Levels of mP4 from ~7d before to ~14d after 605 AI were also evaluated, and outcomes of AI determined based on mP4 levels until ~55d after AI to define pregnancy (PREG) and pregnancy loss (P-Loss). Effects of FOV and presence of abnormal cycles were tested using logistic regressions, while mP4 levels around AI were compared using mixed-effects ANOVA. Only significant differences ($P \leq 0.05$) are presented. Fewer primiparous cows had FOV by 28 DIM than multiparous cows (20 vs 30%). Primiparous cows having early FOV (≤28 DIM) had higher PREG per AI than those with later FOV (47 vs 32%), while multiparous cows with delayed FOV (>56 DIM) had lower PREG per AI (11 vs 29%) and higher P-Loss (62 vs 35%) than those with earlier FOV. The absence of abnormal cycles increased PREG per AI (40 vs 30%) and reduced P-Loss (11 vs 29%) in primiparous cows. Levels of mP4 were greater in primiparous than in multiparous cows from 5 to ~17d after AI. Primiparous cows that suffered P-Loss had higher mP4 at d5 after AI than those PREG (5.7 vs 4.4ng/mL), while multiparous cows that suffered P-Loss had higher mP4 2d before AI than those PREG (3.5 vs 3.2ng/mL). Beyond d10 after AI, PREG cows had higher mP4 levels than open cows. **Take Home Messages**: An early first ovulation highly benefited pregnancy per AI, while a late first ovulation and the presence of abnormal cycles reduced pregnancy per AI and increased pregnancy loss. Greater milk P4 levels near time of AI and lesser milk P4 beyond d10 were negatively associated with fertility. Using in-line milk P4 data, we determined significant effects of ovarian activity and milk P4 levels on parity and fertility. A wider use of this technology in future research will improve our understanding of the factors affecting reproductive physiology of the modern dairy cow, facilitating informed decision making to enhance fertility in dairy herds.

Use of Canola Meal and Micro-Encapsulated Sodium Butyrate in Starter Feed for Dairy Calves

K. Burakowska[1], G.B. Penner[1], P. Górka[2]

[1]University of Saskatchewan, 51 Campus Dr., Saskatoon, SK S7N 5A8, Canada, greg.penner@usask.ca
[2]University of Agriculture in Kraków, al. Mickiewicza 24/28, 30-059 Kraków, Poland

The objective of the two studies was to compare the use of canola meal (CM) and soybean meal (SM) with or without micro-encapsulated sodium butyrate (MSB) in starter feed for Holstein-Friesian calves. Sixty heifer calves (9.1 ± 0.8 d of age; 43.2 ± 4.2 kg) were used in a performance study, while twenty-eight bull calves (8.7 ± 0.8 d of age; 43.0 ± 4.4 kg) were used in a performance and metabolism study. Calves were weaned using a step-down approach. Weaning occurred for heifers at 59.1± 0.8 d of age and for bulls at 51.7 ± 0.8 d of age. Data collection continued post-weaning for 2 wk for heifers and 3 wk for bulls. In both studies, pelleted starters contained: 1) SM; 2) SM+MSB; 3) CM; and 4) CM+MSB. The CM constituted 35.2%, SB 24.2%, and MSB 0.3% of the respective starters on DM basis. Data were analyzed as a 2 × 2 factorial design using PROC MIXED of SAS (ver. 9.4). In the heifer study, there were no differences ($P>0.05$) observed for the MSB inclusion on starter intake and average daily gain (ADG). Protein source have not affected ADG; however, CM tended to increase starter intake post-weaning relative to SM (2.08 vs. 2.25 kg/d; $P=0.086$). In the bull study, SM had greater ($P = 0.012$) pre-weaning starter intake (256 g/d) than CM (229 g/d) and tended ($P = 0.10$) to have greater ADG (708 g/d vs. 648 g/d) than CM. Feeding CM resulted in greater jejunum tissue weight (2.13 vs. 2.43 kg; $P = 0.046$) and length (20.65 vs. 22.51 m; $P = 0.065$). Bulls fed CM also tended to have lower rumen fluid ammonia concentration (19.1 vs. 13.9 mg/dL; $P = 0.084$); however, there were no differences for the short-chain fatty acid concentrations ($P > 0.05$). Inclusion of MSB tended to increase pre-weaning starter intake (233 vs. 253 g/d; $P = 0.064$) and had a negative effect on the rumen absorptive surface area in the ventral sac (1192.9 vs. 954.3 mm2/cm2; $P = 0.019$).

Implications: Results of this study suggest that MSB may not be beneficial in starter feeds for calves following weaning; however, its use pre-weaning, especially in early stages of development, might still be considered. Canola meal can be used a replacement for soybean meal in calf starters for dairy calves. Our results further suggest that canola meal use may positively affect gastrointestinal tract development with no, or only minor, effects on ADG. Thus, use of canola meal may be one strategy to optimize calf starter cost.

Effect of Delaying Colostrum Feeding on Passive Transfer and Intestinal Bacterial Colonization in Neonatal Male Holstein Calves

A.J. Fischer, Y. Song, Z. He, L.L. Guan, M.A. Steele[1]

Department of Agricultural, Food, and Nutritional Science, University of Alberta, Edmonton, AB, T6G 2P5, Canada
[1]Corresponding Author: Michael A. Steele. Telephone: +1(519) 400-6556. Fax: +1(780) 492-4265. E-mail: masteele@ualberta.ca

Dairy calves are born without an active immune system, and therefore rely on good-quality, adequate volumes of colostrum to ensure the passive transfer of IgG. Despite this knowledge, poor colostrum management still occurs on farm, with one of the main reasons for failure of passive transfer being due to feeding colostrum more than 6 hours after birth. The objective of this study was to investigate how delaying the first colostrum feeding can impact the passive transfer of IgG, as well as bacterial colonization in the distal intestine of neonatal dairy calves. Twenty-seven male Holstein calves were randomly assigned to 1 of 3 treatments at birth: calves were fed colostrum at 45 minutes after birth (0hr, n=9), at 6hr after birth (6hr, n=9), or at 12hr after birth (12hr, n=9). Calves were fed pooled colostrum containing 62g/L of IgG at their respective feeding times at 7.5% of birth body weight, and fed milk replacer at 2.5% every 6hr thereafter. Blood samples were taken every three hours using a jugular catheter. At 51hr of life, calves were euthanized and tissue and digesta of the distal jejunum, ileum and colon was collected. Calves fed colostrum at 0hr of life had significantly higher ($P<0.001$) serum IgG concentration (g/L;24.77 ±1.91) when compared to 6hr calves (17.13 ±0.91) or 12hr calves (16.88 ±1.50). However, there were no differences in IgG concentration between 6hr and 12hr calves throughout the study. In addition to increased passive transfer, calves fed colostrum at 0hr had greater ($P<0.05$) *Bifidobacteria* (copy number of 16S rRNA gene/g; $3.39 \pm 1.48 \times 10^7$) attached to colon tissue compared to those fed at 6hr ($5.74 \pm 8.44 \times 10^6$) and 12hr ($5.74 \pm 1.44 \times 10^6$), respectively. In addition, calves fed colostrum at 0hr tended ($P<0.10$) to have a higher abundance of total bacteria (copy number/g; $2.27 \times 10^8 \pm 4.28 \times 10^7$) attached to the distal jejunum. In contrast, there were no differences ($P>0.05$) in *E. coli, Clostridium*, and *Faecalibacterium* colonization among treatments in the digesta or tissue of the distal intestine. These findings suggest that feeding dairy calves colostrum immediately after birth can increase the passive transfer of IgG and the colonization of beneficial bacteria in the colon; both of which are hypothesized to assist in protecting the calf from enteric infections during the pre-weaning period.

Fresh Cow Illness Detection Using Milk and Rumination Data in Robotic Milking Systems

M. T. M. King[1], E. A. Pajor[2], S. J. LeBlanc[3], T. C. Wright[1], and T. J. DeVries[1,*].

[1]Dept. of Animal Biosciences, University of Guelph, 50 Stone Rd E, Guelph, ON, N1G 2W1. [2]Fac. of Veterinary Medicine, University of Calgary, 2500 University Dr NW, Calgary, AB, T2N 1N4. [3]Dept. of Population Medicine, University of Guelph.
*Corresponding author: Trevor DeVries, Email: tdevries@uoguelph.ca

The objective of this study was to investigate potential changes in productivity and behaviour useful for earlier or automated illness detection in early lactation.

We collected daily production and behaviour data for early lactation cows in two studies: (1) one research herd for 13 months (n = 57 cows), and (2) nine commercial herds for 6 months (n = 607 cows). Data on rumination time, milk yield, and many other parameters were recorded electronically. Cases of illness were diagnosed and recorded, including subclinical ketosis (SCK), displaced abomasum (DA), mastitis, and pneumonia. For each disease, analyses were performed to identify the day on which each measure deviated significantly from a healthy baseline. The following results describe reductions in daily milk yield and rumination time, while accounting for DIM, from that day of deviation until the day before diagnosis, when treatment took place and recovery began.

In the first study, daily rumination time declined by 41, 20, and 51 min/d from 8, 6, and 5 d prior to diagnosis of DA (n = 5), SCK (n = 23), and pneumonia (n = 8), respectively. Milk production declined by 4.7 and 4.0 kg/d from 4 d prior to DA and pneumonia diagnoses, respectively, and by 1.1 kg/d from 5 d before SCK detection, when accounting for DIM.

In the larger study of 9 farms, daily rumination time declined by 29 min/d from 6 d before DA (n = 7), by 17 min/d from 5 d to mastitis diagnosis (n = 39), and by 5 min/d for 10 days before SCK detection (n = 199). Milk production dropped by 2.7 kg/d from 5 d before DA and by 1.7 kg/d from 4 d before mastitis. In the case of SCK, milk yield did not decline with illness or increase as it should with DIM, but plateaued before SCK detection and declined afterwards.

Implications: Before the diagnosis of many different types of early lactation health disorders, daily rumination time often declined prior to milk yield. This suggests that rumination behaviour, in addition to milk production, could contribute to more refined alerts for fresh cow illness detection. Accounting for DIM could further improve the sensitivity of alerts to identify more subtle deviations in early lactation.

Early Post-Partum Physical Activity and Estrus Expression and Their Associations with Fertility and Ovulation Rate in Lactating Dairy Cows

A.M.L. Madureira[*], L. B. Polsky[*], B.F. Silper[*], T. A. Burnett[*], J. L. M. Vasconcelos[‡], R.L.A. Cerri[*]

[*]University of British Columbia, 2357 Main Mall, Vancouver, BC, V6T1Z4; email: a.ml.madureira@gmail.com; [‡]São Paulo State University, Botucatu, Brazil 18168-000

The aim of this study was to evaluate the effect of early post-partum physical activity at estrus and artificial insemination (AI) on pregnancy per AI (P/AI) and ovulation rates. A total of 436 lactating Holstein cows were enrolled. Cows were monitored continuously by a leg-mounted pedometer (AfiMilk®, Afitag™). Data was recorded and retrieved at each milking (every 8 h). Ovulation was induced in cows by a timed AI protocol based on estradiol and progesterone. Body condition score (BCS; 1 to 5 scale) was measured at the time of AI and the ovaries were scanned on d 7 post-AI to check for the presence of a corpus luteum. Calving score and incidence of endometritis were recorded. An estrus event was recorded when the relative increase in activity exceeded 100% of the cow's baseline activity, within the first 30 DIM (30D) and at AI. Pregnancy diagnosis was performed 30 d after AI. Only first AI were included in the analysis. Relative increase in physical activity was (mean ± SE) 274.1±97.3% at estrus within the first 30 DIM and 494.9±159.6% at the time of AI. Low BCS (≤2.75) tended to affect relative increase of physical activity at both 30D (P=0.09) and AI (P=0.12). Milk production was not correlated with increased physical activity (r=0.06; P=0.20). Multiparous cows expressed lower activity than primiparous (479.8±11.3% vs. 513.1±12.3%; P=0.04). Cows with endometritis and difficult calving had lower physical activity at 30D compared with those that were healthy and without dystocia (204.3±21.9% vs. 285.7±8.9%; 213.8±26.9% vs. 282.3±13.0%, respectively). Cows that had at least one episode of high activity at 30D had higher fertility (47.5% vs. 32.8% P/AI; P<0.05) and higher intensity of activity at AI (533.1 ± 14.8% vs. 477.7 ± 9.9% relative increase; P<0.05). Cows with high estrous expression at AI had higher fertility (43.6 % vs. 22.8%; P < 0.05) and higher ovulation rates (94.8% vs. 85.7%; P = 0.03). Cows that had increased activity at 30D as well as at AI had higher fertility when compared with those that did not express estrus at either (52.7% vs. 32.9%, P<0.001) and were more likely to ovulate (98.8% vs. 91.6%; P=0.01). Greater activity at 30D and at AI improved fertility and ovulation rates.

Implications: Quantitative data from AAM can be used to identify and predict fertility measures in dairy cows. Animals with higher relative increase in activity at estrus early post-partum and at AI have higher fertility and ovulation rates.

Ovarian Dysfunction in Dairy Cows

James Ferguson

University of Pennsylvania, School of Veterinary Medicine, Kennett Square, PA, USA
Email: ferguson@upenn.edu

Take Home Messages

- For this paper, lactating dairy cows that fail to ovulate by 40 to 60 days postpartum are defined as having ovulatory dysfunction. Delayed ovulation is associated with lower conception rates and longer open days. Incidence may range from 10% to 50% of cows across herds.
- Two main conditions are observed in cows with ovulatory dysfunction: recurrent follicular waves with anovulation of a dominant follicle or development of a follicular cyst.
- Metabolic, infectious, inflammatory and stress conditions may predispose to ovulatory dysfunction. Heritability estimated by Zwald et al. (2004) is 0.07 for first lactation animals to 0.05 across all lactations.
- Programmed hormonal breeding programs (OvSynch) can ensure timely insemination postpartum, but conception rate may be only 20% at first insemination. Intravaginal CIDR combined with OvSynch protocols may improve conception rate to timed artificial insemination in these cows.

Introduction

Reproductive efficiency is an important factor influencing profitable milk production. Reproductive efficiency is best measured by pregnancy rate (PR), the proportion of open cows which become pregnant every 21 days from the voluntary waiting period (VWP). Heat detection (insemination) rates and conception rates determine PR. Economic losses are 6x greater when PR is below 20% than when PR is above 20%. A reasonable herd goal is to achieve a PR of 25% or greater. With a PR of 25% or greater, 50 to 70% of cows in the herd will have calving intervals under 14 months, or days open less than 145 days. To achieve this, ovarian cycling needs to resume and uterine involution needs to be complete by 40 to 50 days postpartum, respectively. A major cause of reproductive inefficiency in dairy herds is ovulatory dysfunction, failure to ovulate by 40 days postpartum.

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▪ Definition Ovarian Dysfunction

Butler (2003) has described the reduction in fertility when cows fail to ovulate the first dominant follicle by 20 days postpartum, and first ovulation is delayed to 40 to 60 days postcalving. In this paper, ovarian dysfunction will be defined as a delay in first ovulation beyond 40 to 60 days postpartum in lactating dairy cows. The delay in ovulation may be associated with two dysfunctions: repeated follicular waves with failure to ovulate a dominant follicle ≥10 mm in size (Butler 2003; Chong et al., 2015; Peter et al. 2009; Wiltbank et al. 2002), or development of an ovarian follicular cyst (OFC), an ovarian structure > 25 mm in size that persists on the ovary for more than 10 days in the absence of a corpus luteum (CL) (Peter et al., 2004; Vanholder et al., 2006). A rare third condition may exist, anovulation with failure to develop a follicle ≥10 mm in size, commonly referred to as atretic ovaries (Peter et al., 2009, Wiltbank et al., 2002). This condition is associated with a genetic component or extreme malnutrition, and is not common in dairy herds and will not be discussed in this paper. Estrous cycles may also be inhibited from retention of a CL, but this condition is usually associated with uterine infection and will not be considered a component of ovarian dysfunction.

▪ The Players

The reproductive axis consists of the hypothalamus, the anterior pituitary gland, the ovary and uterus. The hypothalamus is a region of the brain that coordinates many homeostatic processes by integrating neural, endocrine, and metabolic inputs. The hypothalamus releases pulses of gonadotropin hormone (GnRH), which regulates ovarian function through stimulating anterior pituitary release of follicle stimulating hormone (FSH) and luteinizing hormone (LH). Hormones from the anterior pituitary gland stimulate the emergence of follicular waves on the ovary (FSH) and stimulate growth, development and ovulation of a dominant ovarian follicle (LH). Ovarian follicular waves emerge every 7 to 8 days due to an increase in FSH. Follicular waves first appear as a cohort of 4 to 6 follicles 4 to 6 mm in diameter. When a follicle reaches 8.5 mm in size, it deviates from the follicular pool, producing estradiol and inhibin, and repressing the growth of other ovarian follicles. When greater than 10 mm in size, the follicle is dominant and potentially ovulatory if a surge in LH occurs. If there is no surge in LH, the follicle becomes atretic in 4 to 6 days, and a new follicular wave emerges associated with an increase in FSH.

When the follicle ovulates, a CL forms from the follicular theca and granulosa cells producing progesterone. If pregnancy is not established, the uterus produces prostaglandin F2 alpha (PGF2α) after 16 days, causing regression of the CL and initiating a new estrous cycle. A typical estrous cycle averages

21 days with a range of 18 to 24 days. During the estrous cycle, 2, 3 or 4 follicular waves may occur.

■ Normal Postpartum Function

After calving, a surge in FSH from the anterior pituitary gland occurs within the first week post-calving (Adams et al., 2008; Butler, 2003; Wiltbank et al., 2002). This stimulates the emergence of the first follicular wave, about 4 to 6 days post-calving. This wave is detectable as a pool of follicles greater than 4 mm on each ovary. Butler (2003) reports that by 6 to 8 days postpartum all cows develop at least one large follicle. When a follicle reaches 8.5 mm in size it deviates from the remaining follicles and develops dominance. Dominance is associated with the expression of LH receptors on granulosa cells and production of estradiol and inhibin. Inhibin causes other follicles to regress. Sensitivity to LH causes the dominant follicle to continue to grow and increase estradiol production. Increasing estradiol stimulates further production of LH from the pituitary gland, and LH further stimulates follicular growth in a positive feedback loop. Increasing estradiol production leads to a surge release of LH and ovulation of the dominant follicle, typically when about 17 mm in size (range 10 to 20 mm). If all occurs in a coordinated fashion with adequate hormonal concentrations, first ovulation should occur between 14 to 21 days postpartum. Metabolic hormones, particularly insulin and insulin-like growth factor 1 (IGF-1), influence follicular maturation and response to, and production of, the critical sex hormones to initiate ovulation.

Typically postpartum, serum concentrations of estradiol and progesterone decline rapidly from precalving concentrations. Progesterone concentration is less than 0.2 ng/ml and estradiol concentration is less than 2 pg/ml by 2 to 4 days postcalving. With the emergence of an ovulatory dominant follicle, serum estradiol concentrations increase above 2.0 pg/ml. With ovulation, serum progesterone concentrations will increase to greater than 1.0 ng/ml, indicating active luteal tissue on the ovary.

Beam and Butler (1997) observed the ovulation of the first dominant follicle in 45% of animals. If the first dominant follicle failed to ovulate, they observed two outcomes. In 35% of cows, the follicle regressed and subsequent follicular waves emerged on a frequency of about 8 days until ovulation occurred, which was on average 51 days postpartum. In the remaining 20% of cows, a large OFC developed, ≥25 mm in size, which was associated with a depression in follicular waves to a 19-day frequency, and delayed first ovulation until 48 days on average. Fertility was reduced and days to pregnancy was increased in cows that failed to ovulate the first dominant follicle postpartum.

Risk Factors for Delayed Ovulation

Butler (2003) identified negative energy balance, or metabolic stress, as a major risk factor for delayed ovulation. However, uterine infection, mastitis, and inflammation and stress in general may also impair the initiation of ovarian cycling. Cows typically experience negative energy balance during the first 8 weeks postpartum (range 4 to 12 weeks), with the greatest negative deficit occurring between 5 to 14 days postcalving. After 2 weeks postcalving, cows steadily increase in energy balance and go into positive energy balance by, on average, 8 weeks postcalving. Dominant follicles (≥10 mm) that emerge after energy balance nadir postpartum are more likely to ovulate than dominant follicles that emerge before the energy balance nadir postpartum (Butler 2003; Chong, 2015).

Dominant follicles that fail to ovulate have lower production of estradiol and fewer LH receptors, and tend to grow more slowly than follicles that ovulate. This is associated with reduced LH pulse frequency and lower mean serum concentration of LH and estradiol. Failure to ovulate the first dominant follicle is associated with lower serum insulin and IGF-1, higher serum nonesterified fatty acids, lower body condition score and greater body condition loss (Ambrose et al., 204; Beam and Butler, 1997, 1999; Butler, 2003; Butler et al., 2004; Chong et al., 2015, Vanholder et al., 2005). Pituitary release of LH is diminished and ovarian sensitivity to LH stimulation of steroidogenesis is diminished.

Incidence of Ovulatory Dysfunction

The incidence of ovulatory dysfunction is quite variable across herds and depends on the number of days in milk that defines anovulation, but reports range from 28 to 54.1% for primiparous cows and 15 to 31.5% for multiparous cows from 49 to 71 days in milk. Beam and Butler (1997, 1999), Butler (2003) and Chong et al. (2015) suggest about 40 to 45% of cows ovulate the first dominant follicle postpartum, 35% undergo successive follicular waves before first ovulation, and about 20% of cows develop an OFC. Garverick (1997) reported anovulatory failure occurred in 10 to 13.5% of cows due to development of an OFC. Zwald et al. (2004), using herd records collected through on farm data systems, reported that lactational incidence rates of OFC ranged from 3 to 39% across 340 herds, with a mean lactation incidence rate of 8%. In one study, Roth et al. (2012) observed an incidence of 10.3% anovulatory cows, whereas in a second study, they observed 36% of postpartum cows as anovulatory due to repeated regression of dominant follicles or development of OFC.

■ Etiology

Causes of ovulatory failure with repetitive follicular waves seem to be related to low LH secretion from the pituitary due to dampened pulse generation from the hypothalamus and reduced responsiveness to LH in granulosa cells in the follicle. Dominant follicles form, but fail to produce adequate estradiol to effect a surge in LH to cause ovulation. In the majority of cases, dominant follicles develop, but steroidogenic capacity is limited. The GnRH pulse generator in the hypothalamus is reduced, reducing LH pulse frequency and amplitude. However, granulosa cells in the dominant follicle have fewer LH receptors and a reduced production of estradiol, which appears associated with reduced insulin and IGF-1. Insulin infusion early postpartum increases estradiol secretion independently of changes in LH pulse frequency (Butler et al., 2004) suggesting insulin concentrations in follicular fluid influence aromatase activity and steroidogenesis. Metabolic signals associated with nutritional stress seem to dampen the hypothalamic pulse generator for LH but not FSH, reducing ovarian follicular stimulation of the dominant follicle but not diminishing follicular waves. The dominant follicle is less responsive to LH inputs. Ovulation is delayed due to dampening of the hypothalamic-ovarian axis.

It is less clear why some cows form OFC, which result from continued growth of the dominant follicle rather than regression. It seems to be an imbalance between apoptosis and growth (Halter et al., 2003; Peter, 2004; Silva et al., 2002; Vanholder et al., 2005). As with anovulatory dominant follicles, cows that develop OFC have lower insulin and IGF-1 in serum and in follicular fluid (Hein et al., 2005; Rodriguez, 2011). The defect, as in anovulation of a dominant follicle, is in the hypothalamic-pituitary-ovarian axis, but in OFC, LH tends to have higher serum concentrations than observed with anovulatory follicles, estradiol production from the OFC may be quite high, and progesterone production may be between 0.2 to 1.0 ng/ml (Halter et al., 2003; Roth et al., 2012). Unlike anovulatory follicles that regress, OFC continue to grow past 20 mm, due to the LH stimulation, and continue to produce estradiol. However, despite very high concentrations of estradiol, the hypothalamus is unresponsive to the positive feedback of estradiol and fails to elicit an LH surge to cause ovulation. The defect is in the hypothalamic response to estradiol.

Responsiveness of the hypothalamus to estradiol to release LH requires progesterone in cows with OFC. Serum progesterone concentrations >2 ng/ml restore the responsiveness of the hypothalamus to estradiol. Progesterone treatment can result in an LH surge and ovulation (Halter et al., 2003). Vanholder (2006) reports that when OFC become non-steroidogenic, or if they develop luteal tissue producing progesterone, they will no longer interfere with cyclicity. A major difference between OFC and anovulatory follicles is OFC depress follicular turnover to 19 days whereas anovulatory follicles are associated with normal follicular waves of 6 to 8 days.

Ovarian follicular cysts tend to develop in the first 20 to 30 days postpartum in 20 to 30% of cows (Butler, 2004; Vanholder et al., 2006). However, 50% (Roth et al., 2012) to 65% (Garverick, 1997) of these early cysts spontaneously cure before 40 days postpartum and ovarian cyclicity resumes. On average, OFC persist for 13 days, but they may regress and new cysts form (Vanholder, et al., 2006). Hooijer et al. (2001) reported in a large data set from 40 herds, an incidence of 6.3% based on postpartum examinations. Bartolome et al. (2005) reported an incidence of 9 to 25% for OFC. However, studies from Argentina and Norway report incidence rates under 2%. My personal experience has been OFC in cows after 30 days postcalving is less than 1.8%.

■ Diagnosis and Treatment

Ovarian follicular cysts were classically defined as a structure ≥25 mm in diameter that persisted on the ovary for at least 10 days in the absence of a CL. Historically, rectal palpation was the method of choice for detection of OFC. However, rectal palpation has a low sensitivity and specificity for diagnosis (Douthwaite and Dobson, 2000). In addition, luteinization of the cyst wall (luteal cyst) cannot be readily detected by rectal palpation. Behavioural changes were used to suggest OFC if cows exhibited nymphomania behavior, but a majority of cystic cows are anestrus. Rectal examination using ultrasound imaging with a 7.5 MHz linear array probe has become the method of choice. However ancillary tests for serum progesterone are also useful.

Currently, the classic definition for a cyst has come under criticism. Halter et al. (2003) have recommended an OFC be defined as a fluid filled structure ≥17 mm in diameter that persists on the ovary for 6 days. Bartolome et al. (2005) have adopted a similar definition, but include multiple fluid filled structures ≥ 17 mm in diameter that persist for 6 days. A problem with these definitions is that ovulatory follicles may be >20 mm in size (20% of follicles reported by Wiltbank et al., 2002), thereby classifying ovulatory follicles as cysts. Accurately characterizing pathology of OFC is made difficult due to the variation in definition across studies, and the further difficulty in following OFC development prospectively postcalving.

Treatments for OFC include GnRH or GnRH analogs, human chorionic gonadotropin (hCG) or other LH type preparations, progesterone, and PGF2α (Ambrose et al., 2004; Douthwaite and Dobson, 2000; Probo et al., Trebble et al., 2001; Vanholder et al. 2006). An injection of GnRH initiates a release of LH from the pituitary. In about 50% of cows, a dominant follicle ovulates after GnRH and a new follicular wave is initiated with subsequent ovulation in 6 to 8 days. The follicular cyst does not ovulate but luteinizes in the majority of cases treated with GnRH. In 80 to 90% of cows given GnRH, progesterone rises, hypothalamic sensitivity to estradiol is restored, and ovulation and estrous cycles commence in 21 to 25 days. Prostaglandin F2α may be given 7 to 14 days post GnRH injection to hasten time to next estrus. Conception rate is usually somewhat lower at the subsequent estrus than in “normal” cows. Insertion of a CIDR or some other progesterone device for 7 to 9 days following the GnRH injection can enhance fertility at the subsequent estrus.

The most effective management strategy to control pregnancy in anovulatory cows is employing a PreSynch-OvSynch program to manage reproduction (Pursley et al. 1995). At least 20% of anovulatory cows will become pregnant at first timed insemination. Fertility will improve with subsequent cycles.

■ Conclusions

Ovulatory dysfunction may affect 10 to 50% of dairy cows within a herd. Cows that fail to ovulate by 40 to 60 days postpartum have reduced fertility. Nutritional and metabolic stress, infectious disease, inflammation, and stress in general are risk factors associated with the condition. Ovulatory dysfunction may present as sequential waves of dominant follicles that fail to ovulate or as ovarian cystic structures. Good transition cow management and nutrition can minimize the condition.

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Factors Affecting Preimplantation Embryonic Development in Dairy Cows

Eduardo de Souza Ribeiro

Department of Animal Biosciences, University of Guelph, Guelph, ON, N1G 2W1 Canada
Email: eribeiro@uoguelph.ca

■ Take Home Messages

- Pregnancy losses during the preimplantation period (up to day 20 of development) are substantial in lactating dairy cows.
- Genetic and non-genetic factors influence the likelihood of preimplantation conceptus development and survival.
- Genetic factors refer to genetic variations in genomes of cows, sires, and embryos that are linked to the success of preimplantation conceptus development.
- Recessive lethal alleles are good examples of genetic variations in the embryo genome that directly affect conceptus survival.
- The non-genetic factors known to impair preimplantation conceptus development include extensive loss of body condition postpartum, inflammatory diseases postpartum, low concentration of progesterone during the ovulatory follicle development, and hyperthermia of cows caused by heat stress before or shortly after breeding.
- Strategies to improve preimplantation conceptus development and survival include 1) genetic selection for reproductive traits; 2) elimination of recessive lethal alleles from the population; and 3) reduction of the prevalence of non-genetic predisposition factors for pregnancy failures.
- Development of pharmaceutical and nutraceutical strategies to improve preimplantation conceptus survival is ongoing.

■ Introduction

Reproduction is a major component in dairy sustainability because it impacts the overall milk yield in a herd and its production efficiency. Establishment of pregnancy in an optimal time postpartum, and maintenance of the pregnancy until term have important economic consequences (DeVries, 2006; Ribeiro et al. 2012). Although reproductive management in dairy farms has evolved in the last 15 years, reproductive efficiency in dairy cattle is still not optimal. For instance, the average 21-day cycle pregnancy rate in lactating dairy cows in Canada is only 17% (Denis-Robichaud et al., 2016), and increments beyond 17% are economically attractive (Ribeiro et al. 2012).

Low pregnancy rate is a result of low insemination rate and/or low pregnancy per artificial insemination (P/AI). The development of strategies and technology to improve estrous detection, and the development of ovulation synchronization programs for insemination of cows not detected in estrus have optimized insemination rate and time of first breeding postpartum in lactating cows (Bisinotto et al., 2014). On the other hand, low P/AI remains a major contributor to suboptimal reproduction in lactating dairy cows and, although considerable progress has been made on the understanding of early pregnancy biology in cattle, only modest progress has been made on the understanding of developmental failures.

Pregnancy losses are substantial in dairy cows. Fertilization of single ovulated oocytes (eggs; n = 419) was 83% in commercial North American dairy herds in which the survival of the potential zygotes (fertilized eggs) at the end of first and fourth week of development averaged 67 and 41%, and the proportion of pregnancies resulting in a calving averaged 33% (Ribeiro et al. 2016a). These numbers indicate that approximately 19% of the potential zygotes fail to survive the first week of development; 39% of the live morulas (6-day embryos) fail to survive until the end of the fourth week of development; and 19.5% of the fourth week pregnancies do not result in a calving. Thus, overall, 60% of the fertilized oocytes are lost during uterine development (Ribeiro et al. 2016a).

The success of pregnancy establishment and maintenance until calving is influenced by a multitude of factors. Suboptimal uterine conditions and less competent embryos are the major reasons for pregnancy failures, and these two traits are affected complexly by genetic and non-genetic (environmental) factors. In this article, success of pregnancy establishment and survival will be discussed as a phenotypic trait, whose variability would be explained mostly by a genetic component, an environmental component, and their interaction. Genetic and environmental components will be discussed below after a brief review of early conceptus development in cattle for appreciation of crucial events in developmental biology and their complexity.

▪ Preimplantation Conceptus Development in Cattle

This section is a summary of a more extensive review on the same subject (Ribeiro et al., 2015) in which an extensive list of references containing the following information can be found.

Early embryonic development up to the blastocyst (day 7) stage is very similar among eutherian species and can be reproduced in vitro, which is a valuable source of information for better understanding of developmental biology during these early stages of development. After fertilization of the oocyte in the oviduct, maternal and paternal pronuclei are formed and merged to form the zygote. Embryonic cells derive from cleavages of the zygote and stay enclosed in the zona pellucida, forming a morula by day 4 of development. These early events are highly dependent on oocyte inherited molecules and on lactate, pyruvate, glucose, amino acids, growth factors, cytokines, vitamins, lipids, oxygen and other metabolites secreted by the oviduct.

The morula undergoes compaction and enters the uterus by day 5 of development, where the embryonic cells undergo the first round of cell differentiation. Cells differentiate into either inner cell mass or trophectoderm cells, forming the blastocyst around day 6 of development. The inner cell mass gathers in one pole of the embryo and will originate the embryonic tissues. The trophectoderm cells create the outside layer of cells and will originate the extra-embryonic membranes. After additional rounds of cell differentiation, the spherical blastocyst expands and hatches from the zona pellucida by day 9 of development.

Embryonic development after hatching from the zona pellucida in ruminants is distinct from other eutherian species and difficult to reproduce in vitro, which limits our understanding of the processes required for maintenance of pregnancy. Instead of starting implantation soon after hatching from the zona pellucida as it occurs in rodents and humans, trophectoderm cells of the spherical blastocyst have to proliferate and elongate along the uterine lumen before the initiation of implantation. In a first moment, the spherical embryo stays free-floating into the uterine lumen and cell proliferation leads to formation of an ovoid conceptus (embryo and associated extra-embryonic membranes) by day 13. Up to this point, endometrial physiology is coordinated mainly by progesterone and there is no major distinction between the endometrium of a pregnant and a nonpregnant female.

Around day 14, however, the 1-mm ovoid conceptus starts to elongate by intensive proliferation of trophoblast cells and becomes a 20-cm filamentous structure by day 17. This process of conceptus elongation is dependent on histotroph secretion by the endometrium. The uterine histotroph is a complex combination of molecules including glucose, amino acids, proteins, ions, growth factors, and cytokines, among others that are fundamental for the early embryo development in all mammalian species, but especially important for ruminants whose implantation is shallow and late, starting only at day 20 of development.

Concomitant with conceptus elongation, the highly active trophoblast cells secrete bioactive products that affect endometrial physiology, establishing a complex crosstalk between the two tissues that coordinate critical events for pregnancy establishment, formation of a functional placenta, and pregnancy survival to term. Among these critical events are: 1) maternal recognition of pregnancy associated with corpus luteum (CL) maintenance; 2) establishment of a servomechanism of conceptus nourishment; 3) differentiation of binucleated trophoblast cells; and 4) immunomodulation in the endometrium. Completion of implantation resulting in a fully functional synepitheliochorial placenta will occur only around day 60 of development.

In addition to the changes in the trophoblast and endometrial physiology, important changes also occur on and around the embryoblast. Cells continue to proliferate, and differentiate in the many tissues of the body. Functional structures of main embryonic organs are formed by day 42 of development, and the embryo is then called fetus.

All the aforementioned events highlight the importance, complexity, and potential reasons for developmental failures during early pregnancy, which impairs reproductive efficiency in dairy cattle. Reduced oocyte quality, impaired competence of embryonic development, altered oviduct environment, unbalanced histotroph composition, and impaired receptivity of endometrial cells are just a few examples of things that can go wrong during early conceptus development in cattle. Nonetheless, little progress has been made on the holistic understanding of reproductive failures and on the development of strategies to reduce embryonic mortality.

▪ Predisposition Factors for Embryonic Mortality

Pregnancy failures do not occur randomly in dairy herds, but have predisposition factors, which can be of genetic or non-genetic nature. The genetic factors refer to allelic variations in the genetics of the cow, in the genetics of the breeding sire, or in the resulting genetics of the embryo that influence the likelihood of pregnancy establishment and survival to term. Chromosomal abnormality is another genetic cause of embryonic mortality. The non-genetic factors refer to environmental factors that impact reproductive biology of dairy cows with direct consequences for pregnancy success, and include: nutritional status, health, anovulation or low progesterone during ovulatory follicle development, and heat stress.

Genetics

A small but important portion of the variation in pregnancy success among dairy cows within and across herds is explained by the genetics of the cow, the genetics of the breeding sire, and the resulting genetics of the embryo. In general, the genetic heritability of reproductive traits is relatively low, generally less than 10%, and suggests that reproductive success is affected mainly by non-genetic factors. Nonetheless, fertility traits should not be neglected in the genetic selection program of a dairy farm because they affect reproductive performance of the herds in the long-term.

Incorporation of fertility traits in the genetic evaluations of dairy sires started in 2003 in the U.S. and in 2004 in Canada. Predicted transmitting ability (PTA) for traits such as daughter pregnancy rate (DPR) started to be evaluated and be provided in sire proofs (VanRaden et al., 2004). Fertility traits were also included in composite indexes such as the Lifetime Profit Index and Pro$ (Canada) and Net Merit (USA). Despite estimated low heritability, implementation of these new reproductive traits in the genetic evaluation likely contributed for improvements observed in the reproductive performance of Holstein and Jersey breeds in recent years, and represented an important change in breeding strategies of dairy herds. More recently, new fertility traits such as sire conception rate, cow conception rate and heifer conception rate were developed and are available in some sire proofs. Selection for reproduction traits currently available does not need to be performed at the expense of productive traits, considering that a significant proportion of the active AI sires have predicted genetic gains for both production and reproduction traits (Santos et al., 2010).

The development of next generation sequencing methods, sequencing of the bovine genome, and development of bovine chip arrays for identification of single nucleotide polymorphisms (SNPs) resulted in the advent of the genomics era in dairy cattle breeding. Genomic predictions of genetic merit for several traits can now be determined at affordable prices. Samples of DNA of individual animals are placed on a chip that provides information on genotypes of thousands of SNPs distributed across the 30 bovine chromosomes. The genomic information can then be incorporated into the traditional genetic evaluations for estimation of genomic PTA (GPTA). Compared to proven sires, the reliability of genomic prediction by itself is good (60-80%) for most traits evaluated, and the inclusion of genomic information into genetic predictions of young animals by parent average increases the reliability results expressively. Not surprisingly, genomics has cause significant changes in genetic selection of dairy cattle. Today, every young bull acquired by AI companies is genotyped, and more than 60% of all AIs performed in North America use semen from young sires (with no traditional proofs), reducing the average generation interval and speeding the genetic gains.

In addition to genomic information of AI bulls, the number of females genotyped in commercial herds has also increased significantly in the last decade. In fact, the total number of genotyped dairy cattle in North America has exceeded 1 million (over 100,000 in Canada). Several of these genotyped females have phenotype data on fertility traits and, therefore, this information is also used to estimate genetic contributions in fertility traits of dairy cows.

This new information has also increased our understanding on developmental failures and improved the selection methods for fertility in dairy cattle.

One important contribution of genomic information in dairy cattle was the identification of recessive disorders, including the identification of lethal recessive alleles that cause embryonic mortality (Cole et al., 2016). In general, this information is obtained by identifying haplotypes that are common in the population but never as homozygous. The genome of the embryo is a composite of the cow's genome (inherited from the maternal pronucleus) and the bull's genome (inherited from the paternal pronucleus). When lethal allelic variations in specific genes are inherited in haplotypes from both mother and father resulting in a homozygous embryo for the specific gene, the embryo fails to develop and to survive in the uterus, pregnancy is lost, and homozygous individuals are never born. On the other hand, heterozygous embryos are capable of developing and surviving in the uterus, generating live individuals that are carriers of the recessive lethal alleles. The frequency of lethal alleles in the population can be increased by increasing inbreeding, which has been reported in dairy breeds. Several lethal alleles have been identified and the genomic information of individual animals can now be used in genetic selection to avoid homozygotes or to eliminate carriers from the population (VanRaden et al., 2011).

Among the lethal recessive alleles/haplotypes that have been identified are: deficiency of uridine monophosphate synthase (DUMPS), complex vertebral malformation (CVM), brachyspina, HH1, HH2, HH3, HH4, and HH5 (VanRaden et al. 2011). The causative mutation has been identified in some cases, such as in the HH1 recessive haplotype, in which a nonsense mutation was found in the gene called apoptotic protease activating factor 1 (*APAF1)* and predictably result in a truncated and nonfunctional protein (Adams et al., 2016). This mutation was traced back to the bull Pawnee Farm Arlinda Chief that was born in 1962. This sire and several of his sons were used extensively in the dairy industry worldwide and were important for the evolution of the breed. Their recessive lethal mutation, however, was estimated to have caused more than 500,000 abortions over 30 years (Adams et al., 2016).

In addition to recessive lethal alleles, the allelic variation of other genes (not lethal) might influence the developmental competence of the embryo in more subtle differences, increasing or decreasing the likelihood of survival. Similarly, allelic variation in a cow's genome could also be associated with oocyte quality and its developmental competence, as well as with the uterine receptivity to pregnancy, influencing the success of pregnancy establishment and maintenance. Finally, allelic variation in the sire's genome could be associated with the sperm potential to fertilize oocytes and to activate the zygote's genome for development. Several research groups worldwide are working to identify allelic variations associated with these traits, and new platforms for identification of genetic markers of fertility will likely be developed in the near future. As examples, Ortega et al. (2016) reported that allelic variation in the gene coenzyme Q9 (*COQ9*) explained 3.2% of the genetic variation for DPR; and Han and Peñagaricano (2016) found 8 regions in bulls' genomes significantly associated with sire conception rate.

Nutritional Status

Transition from the dry period (nonlactating pregnant state) to lactation (nonpregnant lactating state) requires the dairy cow to drastically adjust her metabolism so that nutrients can be partitioned to support milk synthesis by homeorhesis. With the onset of lactation, a sharp increase in nutrient requirements occurs. Feed intake, however, is usually depressed around parturition, and consequently, the caloric and nutrient requirements of the cow postpartum are only partially met by feed consumption, which causes extensive mobilization of nutrients from body tissues. Adipose tissue is particularly affected by reduced circulating concentrations of glucose and insulin that up-regulate lipolytic signals for hydrolysis of stored triglycerides and increase availability of nonesterified fatty acids (NEFA) to be used as an energy source. The imbalance in energy, however, is extended to nutrients such as amino acids, minerals and vitamins, which need to be mobilized from muscle and bones. Consequently, lactating dairy cows usually lose significant amounts of body mass postpartum. The amount of body weight loss, however, varies according to the extent of the negative energy balance which, in turn, is mainly determined by energy intake.

Body condition scoring reflects the amount of subcutaneous body fat of cows. In commercial herds, cows are often scored during the dry and early lactation periods to monitor overall nutrition management, which is linked with subsequent lactation performance. Santos et al. (2009) evaluated the body condition score (BCS) in cows at parturition and at the time of first breeding postpartum after synchronized ovulation. The authors observed that cows with extensive reductions in BCS between parturition and AI (1 unit or more in a 1 to 5 scale) are likely to have an extended anovulatory period, decreased P/AI, and increased risk of pregnancy loss compared with cows that had moderate loss of BCS (< 1 unit) or no loss in BCS. Ribeiro et al. (2016a) reported similar results for cows with low BCS (BCS < 3.0) at the moment of AI compared to those with moderate BCS (BCS ≥ 3). These studies suggest the existence of a negative effect of extensive loss of BCS postpartum and resulting low BCS at the time of AI in the success of pregnancy establishment and maintenance. The biological mechanisms involved, however, are still not completely elucidated.

Lactating cows are usually around the peak of milk production by the time of the first breeding postpartum. Similar to high-performance athletes, modern high-producing dairy cows have remarkable nutrient requirements, with total requirements averaging 4 times the maintenance requirements. Accordingly, feeding nutritionally balanced diets undoubtedly plays a central role in any dairy operation. Meeting all nutrient requirements is crucial not only for cows to demonstrate their full genetic potential to produce milk, but also to demonstrate their full genetic potential to support an early developing embryo and generate a healthy pregnancy. Several micronutrients such as glucose, arginine, trace minerals and fatty acids, and growth factors affected by nutritional status such as IGF-1 impact conceptus development and survival; therefore, nutritional deficiencies during preimplantation conceptus development might also lead to pregnancy losses (Ribeiro et al., 2015).

Health

The metabolic and physiological scenario of dairy cows postpartum explained above does not favor function of immune cells. Studies have drawn attention to the negative impact of periparturient metabolic profile on immune cell competence to fight infections. Increased concentrations of NEFA and ß-hydroxybutyrate (BHBA), and reduced concentrations of glucose, insulin, calcium, and vitamins A and E have all been associated with impaired immune cell function and increased susceptibility to infection. In fact, capability of cells to migrate into tissues and kill pathogens is, in general, compromised during the peripartum period. As a consequence of the impaired immune competence during early lactation, the incidence of infectious diseases is substantial. Epidemiological studies indicate that approximately 40% of lactating cows present at least one case of clinical inflammatory disease in the first 60 days postpartum (Santos et al., 2010; Ribeiro et al. 2016a).

Although 78% of these diseases occur in the first 3 weeks postpartum and breeding occurs usually after day 50 postpartum, inflammatory diseases occurring before breeding have a carryover effect, and reduce fertilization of oocytes and development to morula, and impair early conceptus elongation and secretion of interferon-tau in the uterine lumen. These changes in conceptus development are concurrent with inflammation-like changes in the transcriptome of conceptus cells, increased pregnancy loss, and reduced pregnancy and calving per breeding (Ribeiro et al. 2016a). The negative impacts of disease on reproduction are observed independently of estrous cyclicity status and the BCS of cows at the onset of the synchronization program, both of which are known to influence fertility of dairy cows as discussed above. Moreover, the 3 factors (disease postpartum, low BCS, and anovulation) have negative additive effects on fertility of cows bred after synchronized ovulation (Ribeiro et al., 2016a). Furthermore, disease at the preantral or at antral stages of ovulatory follicle development has similar negative impact on pregnancy per AI and pregnancy losses.

The fact that diseases postpartum also increase late pregnancy losses (after day 90 of development) suggests that the carryover consequences of diseases on developmental biology are longer than four months. Interestingly, the compromised maintenance of pregnancy caused by inflammatory diseases postpartum is also observed in cows receiving a random viable blastocyst on day 7 of the estrous cycle. Thus, not only reduced oocyte competence is a likely reason for the low fertility of this cohort of cows, but impaired uterine environment is also involved (Ribeiro et al., 2016a).

Anovulation

Anovulation is a normal and temporary physiological condition of cows during pregnancy and early postpartum. It is characterized by lack of regular estrous cycles and ovulation, although follicle growth remains. Time for first ovulation postpartum and resumption of estrous cyclicity is variable among cows and directly associated with the energy balance postpartum. Low concentrations of glucose, insulin and IGF-1, and high concentrations of NEFA and BHBA in blood, and consequently in follicular fluid, are all resulting scenarios from severe negative energy balance postpartum that restrict follicular growth and synthesis of estradiol, and delay resumption of postpartum ovulation.

Anovulation becomes a problem for reproductive management because on average 18 to 43% of dairy cows are still anovular at the end of the voluntary waiting period (Santos et al., 2009). If the reproductive management relies on breeding after detection of estrus, insemination of these cows will be delayed and, consequently, time to pregnancy will be extended causing reproductive inefficiency and economic loss. Adoption of timed AI programs maximizes submission rates to AI and lessens the problem of anovular cows in reproductive efficiency. Nevertheless, pregnancy per AI of anovular cows after synchronized ovulation is reduced compared with estrous cyclic herdmates (Santos et al., 2009; Ribeiro et al., 2016b) and, therefore, anovulation still impairs pregnancy rates and reproductive efficiency even when a timed AI program is used. Because there is no evidence that synchronization of ovulation in anovular cows is less efficient, it has been hypothesized that their reduced fertility results from impaired capability to establish and/or maintain pregnancy (Bisinotto et al., 2010).

Low concentration of progesterone during the ovulatory follicle development seems to be the major cause of alterations in developmental biology in anovular cows. Estrous cyclic cows that are induced to ovulate a follicle that grew under low concentrations of progesterone, mimicking the endocrine scenario observed in anovular cows, have similar reduction in pregnancy per AI as that observed in anovular cows (Bisinotto et al., 2010). Moreover, sufficient progesterone supplementation during ovulatory follicle development is able to rescue pregnancy per AI in anovular or low progesterone cows (Bisinotto et al., 2013). Nonetheless, timing and biology of the events leading to impaired embryonic development by anovulation before the synchronization of the estrous cycle are not completely understood.

One of the consequences of low concentrations of progesterone during the development of the ovulatory follicle is overexposure of the oocyte to luteinizing hormone, that in turn could impair the kinetics of oocyte meiotic resumption, the maturation process, and its developmental competence (Santos et al., 2016). Additionally, low concentration of progesterone during development of the ovulatory follicle alters the composition of the follicular fluid and uterine physiology in the subsequent estrous cycle (Santos et al., 2016). Interestingly, day 15 conceptuses from anovular cows were longer and secreted greater amounts of IFN-τ than conceptuses from estrous cyclic cows, likely a consequence of differences in the progesterone concentrations before and after breeding (Ribeiro et al., 2016b). Anovular cows, as expected, had lower concentrations of progesterone during ovulatory follicle development. This difference allowed accelerated growth of the dominant follicle and ovulation of a larger follicle that, in turn, resulted in the formation of a larger CL in the following cycle and greater concentrations of progesterone that likely anticipated conceptus elongation. Nonetheless, anovular cows had reduced concentrations of IGF-1 in plasma, and their conceptuses presented remarkable differences in the transcriptome. Some of the altered transcripts indicate that conceptus cells from anovular cows were under greater cellular stress and present increased rates of apoptosis and autophagy, which could lead to increased conceptus mortality after day 15 of development (Ribeiro et al., 2016b).

Heat Stress

Dairy cows undergo hyperthermia during the summer months in most of the world (including Canada), which causes a dramatic reduction in establishment and maintenance of pregnancy. Hyperthermia has numerous effects on cellular metabolism and function that help explain reductions in fertility. Some of these effects directly affect reproductive biology of dairy cows, resulting in altered periods of follicle dominance, reduced steroidogenic capacity of follicular and luteal cells, altered endometrial activity, and impaired oocyte quality (Hansen, 2009). Other effects are caused indirectly by reduced nutrient intake and impaired immune system that lead to high incidence of diseases postpartum as discussed above, and consequently, reduced reproductive efficiency. Elevated temperature and humidity during the hot months also alter the environment, and might increase the pathogen challenge and facilitate infection. Although data on the associations between season and risk of uterine diseases in dairy cattle are scarce, recent epidemiological studies indicate that incidence of retained placenta and metritis increases during the hot season. This multitude of direct and indirect effects causes reduced fertilization and impairs early embryo development, reducing establishment and maintenance of pregnancy, and compromising reproductive efficiency during the summer months (Schüller et al., 2014).

▪ Strategies to Improve Preimplantation Conceptus Survival

The best strategy to improve preimplantation conceptus development and survival in dairy cows is to minimize the prevalence of predisposition factors for developmental failures. Genetic selection of bulls for AI and replacement heifers should always consider fertility and health traits. Moreover, if genomic information is available, recessive lethal alleles should be avoided and eliminated from the herd if possible. Culling decisions of lactating dairy cows should also consider genetic potential for reproductive success and health traits. Adequate nutritional management during the transition period is critical to minimize the incidence of extensive loss of BCS, metabolic problems, clinical diseases, and anovulation at the end of the voluntary waiting period. Monitoring the prevalence of all non-genetic predisposition factors (disease, anovulation, low BCS) is important, and the information should be used to take decisions. Training of farm personnel for fast identification of sick cows, and administration of adequate treatment in early stages of the health problem is critical. In addition, heat abatement system in barns and parlor is recommended to avoid losses in reproduction related to heat stress during the summer months.

In addition to genetic selection for fertility traits and minimization of non-genomic predisposition factors for early pregnancy loss, we have also worked to develop pharmaceutical and nutraceutical treatments to improve preimplantation conceptus development and consequently minimize early pregnancy losses. For example, our group tested a translational approach by supplementing low doses of growth hormone (GH) to lactating dairy cows during the pre and peri-implantation periods, between days 0 and 28 relative to AI, with the objectives to increase circulating concentrations of IGF-1 and improve embryo development and survival. Both objectives were obtained with success. Supplementation of low doses of GH during the preimplantation period resulted in increased concentrations of IGF-1 in plasma, improved pregnancy per AI, and reduced pregnancy losses, resulting in a 28% increase in calving per AI (Ribeiro et al., 2014). Signaling of IGF-1 plays an important role in different stages of preimplantation conceptus development and might be deficient in some cows at time of breeding. Additional measurements obtained in this study demonstrated that the treatment was effective on improving preimplantation conceptus development and survival.

■ Conclusions

Pregnancy per AI in dairy cows in North America has not changed over the last 15 years, and advances in reproductive efficiency observed in the same period were obtained mainly by improving strategies of reproductive management and genetic selection. Losses of pregnancy during the preimplantation period are still significant and cause important economic losses. Further improvements in reproductive efficiency will require reductions in early embryonic mortality, which in turn will require a better elucidation of critical events in developmental biology and commitment of producers to reduce the prevalence of predisposition factors for pregnancy losses and to include fertility traits in the genetic selection and culling decisions.

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Estrus: Association with Production Parameters and Implications on Fertility

R.L.A. Cerri,[1] B.F. Silper,[1] T.A. Burnett,[1] A.M.L. Madureira,[1] L.B. Polsky,[1] M. Kaur,[1] D. Veira,[1] J.L.M. Vasconcelos[2]

[1]Applied Animal Biology, Faculty of Land and Food Systems, University of British Columbia
[2]Department of Animal Production, Faculty of Veterinary Medicine and Animal Science, Sao Paulo State University
Email: Ronaldo.cerri@ubc.ca

Take Home Messages

- Information obtained from activity monitors is useful.
    - Milk production, estradiol and follicle diameter are not as correlated with estrus as initially expected.
    - Intensity of estrus is closely associated with fertility.
    - Expression of estrus and its intensity can affect artificial insemination (AI) and embryo transfer success.
- Reproductive programs with strong reliance on estrus detection are highly efficient.
    - Combination with timed-AI is still necessary.
    - Expect more variability among farms.

Next Steps

- Refine estrus-based reproduction programs.
    - Voluntary waiting period, types of protocols, selective synchronization.
- Improve knowledge related with estrus detection, behaviour and ovulation timing.
    - Standing, lying and rumination data.
    - Different sensors, analyses of multiple sensors.
- Genetic selection.

- Collection of correct phenotype for genomics.
- Individual variation and association with body condition, parity and milk production.

Estrus

The most recent studies have shown that not only proestrus length or estradiol concentrations during estrus affects reproductive tissues, but also the actual display of estrous behaviour seems to have a profound effect on fertility (Madureira et al., 2015a,b). Most of the data currently available in dairy cows on the effect of proestrus and estradiol pertains to the manipulation of the timing of luteolysis and ovulation induction, therefore modifying the proestrus only. Studies that decrease follicular dominance length (Cerri et al., 2009), increase concentrations of progesterone during diestrus (Cerri et al., 2011), proestrus length (Mussard et al., 2003), and production parameters (e.g. lactation and age; Sartori et al., 2002) have shown positive effects on fertilization, uterine environment, and embryonic development (Ribeiro et al., 2012). However, in spite of marked effects related with the afore mentioned modifications of the estrous cycle, not much emphasis has been placed on the isolated or additive analyses of the effect of expression of estrus (within a variety of different treatments) on reproductive tissues. The effect of estrus on fertility will be discussed in the last section of this manuscript, but it is clear that estrus has a positive impact on fertility. Moreover, this effect also seems to be associated with the intensity of estrus, which collectively leads us to questions regarding the detailed physiological mechanisms associated with this improvement in fertility associated with estrus.

In order to answer some of these questions, we aimed to investigate the association of estrus expression at the time of AI with the expression of critical genes in the endometrium, corpus luteum (CL) and embryo during the pre-implantation period (Davoodi et al., 2016). In addition, we evaluated the difference in estrus expression for reproductive parameters such as CL volume, conceptus size, concentration of progesterone in plasma, and follicle diameter. Evidence from this study supports our hypothesis that estrus expression positively influences the expression of target genes important for embryo survivability. Cows that expressed estrous behaviour near AI had a significant improvement in the profile of endometrium gene expression critical for suppressing the local maternal immune system and likely improving adhesion between endometrium epithelial cells and conceptus, as well as partly inhibiting the mRNA machinery for prostaglandin (PG) synthesis. Genes related to immune system and adhesion group in the endometrium were also significantly affected by concentration of progesterone in plasma on day 7. Results from the gene analysis of the CL also confirmed down-regulation of cellular pathways associated with apoptosis and prostaglandin synthesis, which favors CL maintenance and secretion of progesterone, both key to sustain pregnancy (Davoodi et al., 2016). Moreover, cows that displayed estrus yielded longer conceptuses, which is associated with better chances of survival. The effects of expression of estrus seems to interact with progesterone concentration on d 7 of the estrous cycle in a way that positively influences endometrium receptivity and embryo development. The specific causes that lead to the presence or absence of estrus expression are unknown based on the data collected in this study (Davoodi et al., 2016) and warrant further investigations. The expression of estrus can indicate the state of sensitivity of the hypothalamus to estradiol and perhaps the best timing for the optimal function of all other reproductive tissues related with the survivability of the early embryo.

■ Production Parameters and Expression of Estrus

The detection of estrus in confined dairy cows became a greater challenge as milk production increased. Previous studies that took into account only mounting behaviours as a measure of intensity and duration of estrus have consistently recorded a decrease in this behaviour as milk production increased (Lopez et al., 2004; Rivera et al., 2010). A major question still unanswered is if mounting behaviour can be used as a gold standard for estrus expression (i.e. intensity and duration), considering the challenges faced by dairy cows in free stall barns with concrete flooring that leads to significant physical stress on foot and legs. The estrus detection rate in a recent survey (Denis-Robichaud et al., 2016) was below 50%, but the proportion of cows truly bred upon estrus detection is still unclear as these data are confounded by timed-AI (TAI) use. This extensive failure to submit cows for AI has a major impact on the pregnancy rate of Canadian herds, but also indicates a unique window of opportunity to improve fertility.

Parity, Milk Production and Body Condition

A large field study (Lopez-Gatius et al., 2005) described that the two main factors affecting estrus activity increase were lactation number and milk production, whereas the degree of activity increase was positively correlated with fertility after AI. The authors did not clearly state the latter, but it was recently corroborated in a study by Madureira et al. (2015a). Milk production, for example, seems to affect the overall sensitivity of pedometers or activity monitors to detect true events of estrous behaviours. However, none of the previous studies measured detailed reproductive physiological events associated with natural estrous behaviour and the level of activity of automated activity monitor (AAM) systems associated with those events. Just recently, more robust studies using adequate numbers of observations of estrus and cows have been published for more reliable conclusions.

A recent study by our group identified several risk factors associated with the intensity of estrus expression. Multiparous Holstein cows expressed lower peak activity and duration of episodes of estrus than primiparous cows (Madureira et al., 2015a). Similarly, López-Gatius et al. (2005) found that for each additional parity number, walking activity at estrus was reduced by 21.4%. On the contrary, Walker et al. (1996) described that duration of estrus was nearly 50% shorter for primiparous than for multiparous lactating dairy cows. In addition, two other studies reported no association between parity and physical activity at estrus (VeerKamp et al., 2000; Løvendahl and Chagunda, 2010). Methodological differences may explain variation among different studies on the association between parity and physical activity, such as frequency of data transmission from sensors to software, or different breeds of cows. Moreover, the detailed information about different AAM systems reading correlations will be key to properly use automated behaviour data with physiological parameters. In a simple analysis by our group comparing a neck vs. a leg-mounted AAM, correlation between the peak intensity of estrus episodes of both systems was similar, but not at a level that justifies a seamless translation of the data from one system to the other (Madureira et al., 2015a; Silper et al., 2015c). Different AAM systems will capture different movements, and different algorithms and software filter the background data in specific manners, influencing measurements of baseline levels and relative increases in activity during estrus.

Greater milk production has been negatively correlated with estrus-related activities (Lopez et al., 2004; Rivera et al., 2010). The decrease in concentrations of estradiol, possibly caused by increased hepatic blood flow and steroid clearance, is a possible cause for decreased estrus-related activities, most notably the standing to be mounted behaviour. Madureira et al. (2015a) also found greater peak intensity and duration only in animals in the lowest quartile of milk production, but not among the other categories. Therefore, our data is in partial agreement with previous research (Lopez et al., 2004; Rivera et al., 2010). However, it seems that mounting behaviour is more affected than overall physical activity measured by AAM systems. Recent studies from our group (Silper et al., 2015a; Madureira et al., 2015a) found that heifers and cows with lower baseline levels of activity tend to have greater relative activity increase, but not necessarily greater absolute increases in step counts during estrus. In spite of the results discussed above, peak intensity during estrus was still weakly associated with milk production, emphasizing the influence of other factors such as body condition score (BCS) and parity, and probably group size, health status, and lameness (López-Gatius et al., 2005; Morris et al., 2009).

Some studies have found negative effects of milk production on conception rates (López-Gatius et al., 2005; Valenza et al., 2012), whereas others did not (Madureira et al., 2015a). The ability of individual cows to cope with high milk yield and current management practices are important in determining if a negative effect of lactation on overall fertility is more or less likely to occur. It is difficult to establish this relationship because cows with low milk production might be sick from diseases that also affect the reproductive tract, while high producing cows are often times the healthiest ones (Santos et al., 2009).

Body condition score was the major factor associated with physical activity at estrus and pregnancy per AI (P/AI) (Madureira et al., 2015a), supporting the findings by Løvendahl and Chagunda (2010), who observed that during early postpartum, low BCS had a negative correlation with estrous activity. Furthermore Aungier et al. (2012) reported that a 0.25 increase in BCS was significantly correlated with an increase in physical activity prior to ovulation. Cows that lost less than 100 kg of BW from 2 weeks pre-calving to 5 weeks post-calving had greater intensity of estrus in the first two estrus episodes post-partum (Burnett et al., 2015). The specific mechanism by which a temporary state of negative energy balance reduces estrogen-dependent estrus behaviour is unclear.

Ovarian Follicle Dynamics

Ovulation of larger follicles by lactating cows could be a result of extended follicular dominance or prolonged proestrus, which originate from lower progesterone concentrations, lower estradiol concentrations, and longer time interval for induction of GnRH and LH surges. Follicle diameter and estradiol concentration in plasma have been reported to be negatively correlated in cows (Saumande and Humblot, 2005), or to not correlate at all in heifers and cows (Aungier et al., 2015; Madureira et al., 2015a; Silper et al., 2015c). Larger follicles are more likely to fail to ovulate, and if ovulation occurs, oocytes are less likely to be fertilized. Greater incidence of ovarian abnormalities (e.g. ovulation failure, multiple ovulations, ovarian cysts) in lactating cows might originate from lower circulating estradiol in the preovulatory period of the previous estrous cycle (Sartori et al., 2004).

The correlation between the preovulatory follicle diameter and plasma estradiol is weak (Silper et al., 2015c) and is in agreement with values reported elsewhere (Sartori et al., 2004; Walker et al., 2008). Although a larger follicle is associated with greater concentration of estradiol in plasma (Cerri et al., 2004), it is clear from the current experiment that parity, BCS and ultimately milk production are the factors with the greatest impact on circulating concentrations of estradiol. Cows classified as having high activity had similar preovulatory follicle diameter, but slightly greater concentration of estradiol in plasma than cows classified as low activity (Madureira et al., 2015a). In spite of the differences in estradiol concentrations found when cows were divided in categories by estrous activity, the peak intensity measured by different AAM systems was only weakly correlated with concentration of estradiol in plasma, demonstrating a greater than expected variation. A recent study by Aungier et al. (2015) reported no correlation between activity clusters measured by AAM and follicle stimulating hormone, LH and estradiol profiles. However, a greater peak concentration of estradiol in plasma was associated with standing and estrus-related behaviours.

The ovulation of preovulatory follicles with similar diameter would suggest little change in concentrations of progesterone after AI. Data from Madureira et al. (2015) suggest that concentrations of progesterone 10 days after AI was greater in cows displaying high intensity estrus at AI. The faster increase in progesterone early in the cycle could result in increased early embryonic development (Mann and Lamming, 2001). This could represent, therefore, a possible cause for the increased P/AI found in animals with greater peak activity at estrus.

▪ Detection of Estrus and Relative Intensity: Consequences to Fertility

Some estrus detection methods and aids include visual observation, tail chalk, pressure patches, pedometers and sensors. Visual observation has high labour demands and, normally, low efficiency. Therefore, TAI following hormonal manipulation of the estrous cycle has been used as an alternative for achievement of reproductive goals without the necessity of estrus detection. This implies better overall pregnancy rates because of increased rate of submission to AI. No major improvement in conception rates has been observed with TAI (Santos et al., 2009), although more recent ovulation synchronization protocols that include an intensive pre-synchronization (Double-Ovsynch) and double injections of PG before AI to ensure complete luteolysis (Wiltbank et al., 2015) result in conception rates of ~50% at the first post-partum AI.

There are plenty of AAM systems available for dairy farmers, but further exploration of the capability of different systems is necessary. Some of these systems have resources such as adaptable thresholds per farm or groups of cows, but these do not seem to be explored or extensively used. For example, adjustments could be made according to season of the year or level of milk production. These examples of possible adjustments also illustrate a challenge to the allied dairy industry related with sensors in general. There is a learning curve on how to use these systems. Even the simplest of AAM will probably require some time and patience from herd personnel in order to learn and extract the most useful information from sensors and respective software.

Detection of Estrus and Activity Monitors

Automated systems currently can be different regarding their output or variable to be analyzed (e.g. step counts, acceleration of movement, rumination time/frequency, lying time/bouts). Some examples are ALPRO (DeLaval; Sweden), SmartDairy Activity (Boumatic, USA), AfiTag (Afimilk, Israel), CowAlert (IceRobotics, UK) and Heatime HR Tag (SCR Engineers, Israel). These AAM proved to be efficient at detecting estrus. Using Heatime, Valenza et al. (2012) detected 71% of the preovulatory phases, but missed 13% of the recorded ovulations by ultrasonography. Using the same system, Aungier et al. (2012) also reported 72% of the preovulatory follicular phases identified correctly, but 32% of false-positives. It is possible that the percentage of false positives was overestimated because the cut point used to determine high progesterone status (false-positive estrus) was extremely low (progesterone > 0.6 ng/mL). Moreover, a study from Denmark (Løvendahl and Chagunda, 2010) using activity tags also showed a 74.6% estrus detection rate and 1.3% daily error rate when using the most efficient algorithm calculated by the authors. The study demonstrates the great potential of this technology to solve the estrus detection problem in commercial dairy herds.

Rumination is another parameter that can be used for automated detection of estrus. Changes in feeding behaviour, which are in accordance with increased physical activity and restlessness characteristics of estrus, result in decreased rumination time during estrus. Pahl et al. (2015) demonstrated reduction of feeding time and rumination time at day -1 and day 0 relative to AI. Reduction of time spent at each visit to the feed bunk could be another indicator of restlessness. The rumination data in the Heatime system is used in combination (not alone) to assist the activity data in detecting estrus. Probably more research is needed to validate its use as a stand-alone.

There has been little research on the use of lying and standing behaviour for estrus detection. Recently, our group has analyzed lying and standing information in relation to the estrous period in more detail (Silper et al., 2015b; Silper et al., 2017). Results from these studies indicate a large potential to improve the accuracy of estrus detection, as well as the use of quantitative information (e.g. proportional changes on lying behaviour on the day of estrus in relation to the day before and after) from these monitors to assist farm-level decision-making regarding breeding. One AAM system (AfiTag, Afimilk) uses steps, lying time and an index of restlessness in its estrus detection algorithm, but literature regarding its efficiency and measurements of estrus expression is still unclear. Given the variability reported by many and the low levels of estrus expression in general, it seems that combining measurements within one system is potentially a better alternative for reduction of false negatives. A combination of activity and lying behaviour data from IceTags (IceRobotics) significantly reduced error rate (false alerts) and increased probability of estrus detection (Jónsson et al., 2011). Peralta et al. (2005) also suggest combinations of systems are the best alternative to enhance detection and conception rates during period of heat stress. The use of more than one measurement within the same sensor can also enhance specificity and reduce false positives (Firk et al., 2002).

Expression of Estrus and Fertility: Reproduction Programs

A survey of Canadian dairy herds has shown that programs based on estrus detected by AAM result in similar reproductive performance compared to TAI (Neves and LeBlanc, 2015; Denis-Robichaud et al., 2016). A few studies, normally large surveys, have been able to draw a picture of the state of reproductive programs in North America. Caraviello et al. (2006) showed that over half of all dairy farms in USA used TAI programs. In Canada, a recent large survey indicated a strong use of TAI programs, but visual detection remains the management system mostly used by farmers (Denis-Robichaud et al., 2016). This number, however, is highly dependent on region. For example, the province of Quebec, which concentrates a large number of tie-stall farms with a small number of cows, tends to use fewer reproduction programs and other technologies.

In this survey (Denis-Robichaud et al., 2016), we reported the results from 772 survey answers, which represent 6% of the total number of dairy farms in Canada. The average herd size was 84 lactating cows (median = 60; interquartile range = 40-95 cows/herd), and herds were located in all Canadian provinces. Lactating cows were housed in tie-stall (55%) and free-stall barns (45%). Automated activity monitoring systems were used in 28% of the participating herds (4% of the tie-stall, but 59% of the free-stall herds) and were consulted for high activity alerts at least twice daily by almost all (92%) users. Interestingly, 21% of the participants never confirmed heat by visual observation before insemination, while 26% always did. Results from this survey highlight the variability in reproduction management among Canadian dairy herds. Knowledge of producers' attitudes toward different management practices should help optimize the development and implementation of reproduction management tools.

Reproductive programs with intensive use of TAI protocols are still the gold standard regarding improvements in pregnancy rates. Recent field trials have compared different "degrees" of combination of TAI and AI upon estrus detection using AAM. Conception risk (30% vs. 31%) and days to pregnancy (137 and 122 d to pregnancy) were not different among cows bred by TAI or following estrus detection by Heatime (Neves et al., 2012). Other recent studies have experimented with different combinations of use between AAM and TAI programs (Valenza et al., 2012; Burnett et al., 2017) and overall results indicated that it is possible to achieve similar pregnancy rates in more estrus detection-intensive programs. Collectively, these large field trials aimed to modify several factors that are key to the response of the dairy's reproduction program, particularly in the first AI. For instance, the voluntary waiting period varied from 50 to 100 DIM depending of the protocol. The use of pre-synchronization protocols that could either focus on induced estrus (PG based) or cyclicity and ovulation synchrony (GnRH based) were tested. All the studies demonstrated that the combination of methods (TAI and AAM) is perhaps the best option because it maintains high rates of conception while submitting a large number of animals to AI. In this case TAI protocols are still necessary as a safe guard for a proportion of animals that would not be bred upon estrus up to 100 DIM. The question of when to intervene with TAI protocols is probably an area that could still gain valuable information from future research. It is very likely that the adoption of AAM systems as part of a large reproduction program will vary largely from farm to farm. Work from Neves et al. (2012) and Burnett et al. (2017) demonstrated a large variation among farms in the adoption of TAI and AI upon AAM alerts within the same protocol. Another advantage of the combination of the TAI and AAM is probably the reduction in the use of pharmacological interventions. However, it is unknown how these programs would perform in areas where cows are exposed to intense heat stress, as temperature has a major impact on the detection of estrus and its intensity, which is dramatically reduced.

Expression of Estrus and Fertility: Display and Intensity near AI

In the current study, some major risk factors related with peak intensity and duration of estrus events were assessed. Even though new technologies capture physical activity using sensors and algorithms for data processing that are significantly different than those used in recent past, it was interesting to observe a lack of, or relatively weak correlation between measurements of estrus expression and milk production and preovulatory follicle diameter. Several studies using different AAM systems, farms, season and geographical location consistently observed substantial increases in P/AI from events of estrus with high peak activity (Madureira et al., 2015a; Madureira et al., 2015b; Burnett et al., 2017; Figure 1) and large decreases in lying time on the day of estrus (Silper et al., 2015d). Improvement in fertility was somewhat expected from cows with greater intensity of estrus expression; however, this was commonly associated with improvements in BCS, lower milk yield, parity and even health status. In fact, we have observed greater peak intensity and duration as BCS increased as well as in primiparous cows, but greater P/AI still occurred in spite of those and other risk factors known to affect conception rates. It is possible that information already available in herd management software used on commercial dairy farms could be used to adjust AAM systems to take into account present phenotypical conditions of the cow. The use of peak intensity and duration measurements could assist in the prediction of fertility and improve decision-making in reproductive programs using AAM. Moreover, there is potential to use AAM systems as an objective and accurate tool to select animals of superior estrus expression, although this topic still warrants further research.

Cows with high peak intensity had approximately 12 to 14 percentage units greater P/AI than cows with low peak intensity, which represents a 35% improvement in fertility (Madureira et al., 2015a;b). Previously, Lopez-Gatius et al. (2005) reported an improvement of 1.001-fold for every unit of relative increase in walking activity.

It was previously mentioned that preovulatory follicle diameter was not different between peak intensity categories, but that does not imply that proestrus or dominance length was similar as there was no control of follicular emergence in recent studies. Therefore, proestrus and dominance length (Bleach et al., 2004; Cerri et al., 2009) cannot be ruled out as possible causes related to the reduced fertility observed. Another possible factor influencing P/AI is the ovulation response from cows with different peak intensity at estrus. Madureira et al. (2015b) observed a greater failure of ovulation in cows that displayed estrus with a relative increase in peak intensity from 80 to 100%, the lowest relative increase possible after crossing the threshold from the AAM used. In a more recent study using lactating cows (Burnett et al., 2017), authors found a larger variation in ovulation times and a greater prevalence of cows ovulating before the expected ideal time after the beginning of estrus (Figure 2). While this observation is certainly important to explain our observations, it is limited to cows expressing very low peak intensity during estrus, as the threshold dividing high and low peak intensity categories was over 300% relative to the increase in the current study. One of the studies used ECP to induce estrus and ovulation, therefore bringing circulating estradiol to supra-physiological concentrations. In spite of this, the peak intensity measured by a pedometer system still significantly affected P/AI (Madureira et al., 2015b).

The display of estrus at AI has been associated with a reduction in pregnancy losses, regardless of the diameter of the preovulatory follicle (Pereira et al., 2014). Pereira et al. (2015) showed that this effect is true for both AI and embryo transfer based programs, indicating a possible major modification of the uterine environment as the cause for the improved fertility. In addition, results from Pereira et al. (2015) corroborate our data from beef cows that showed an extensive modulation of gene expression of key transcripts related with the immune system and adhesion molecules (Davoodi et al., 2016). Collectively, it seems that the expression of estrus has important positive effects in the maintenance of gestation (decrease in pregnancy losses between 32 and 60 days of gestation).

Bisinotto et al. (2015) aimed to modify concentrations of progesterone during the growth of the preovulatory follicle comparing the first with the second follicular wave. Major results described how exogenous progesterone (2 intravaginal devices) is able to “rescue” a preovulatory follicle of the first follicular wave to yield optimal fertility. An interesting finding from this study, related to estrus, is that animals that ovulated follicles from the first follicular wave growing under low concentrations of progesterone in plasma (worst possible scenario in this study), but that expressed estrus at AI, had P/AI similar to the other treatments.

A potential explanation to correlate intensity of estrus and P/AI, that has not been extensively studied, is that cows could have greater than expected individual variations in the ability to express estrogen receptors in the endometrium and, perhaps more importantly, in the hypothalamus. This would in turn generate cows that are more likely to translate circulating concentrations of estradiol into estrus-related behaviours, and later into a more adequate uterine environment for embryo development.

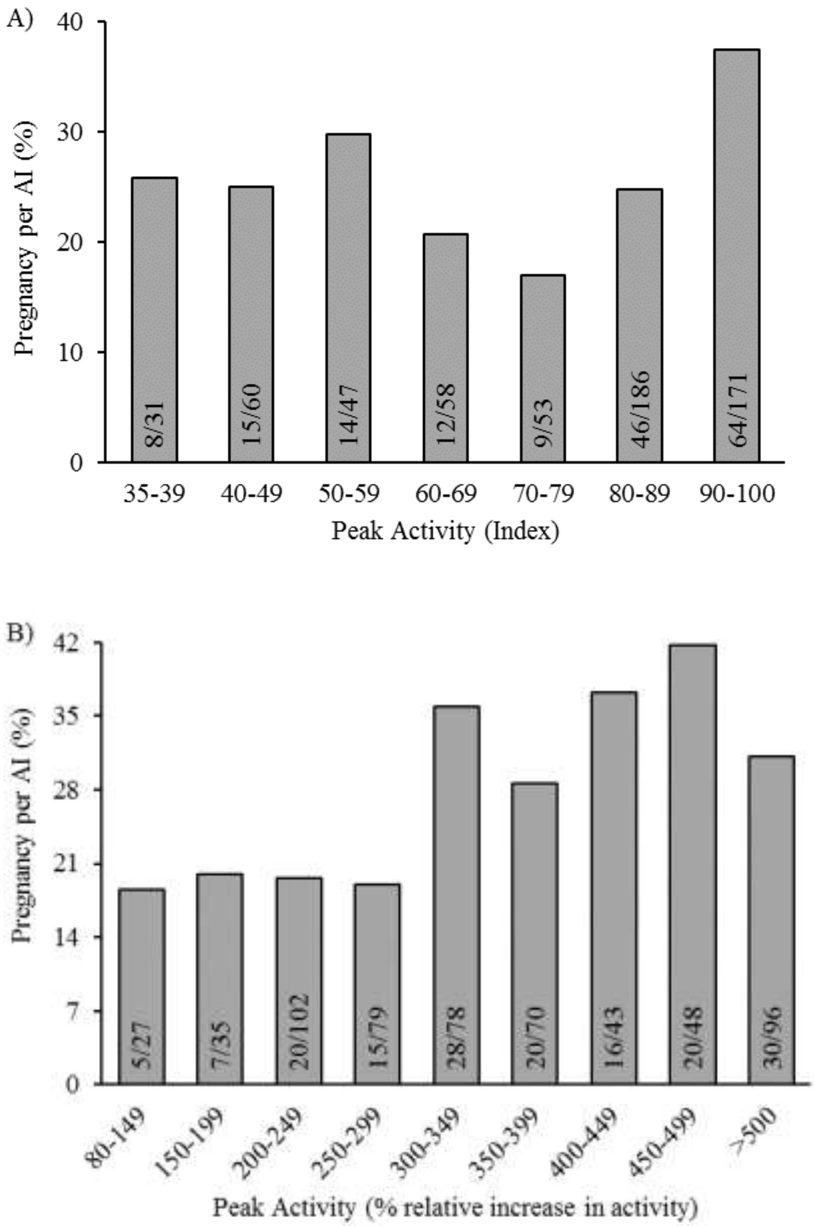

Figure 1. Distribution of pregnancy per AI (%) according to peak activity during estrus detected by A) a collar-mounted sensor and B) a leg-mounted sensor.

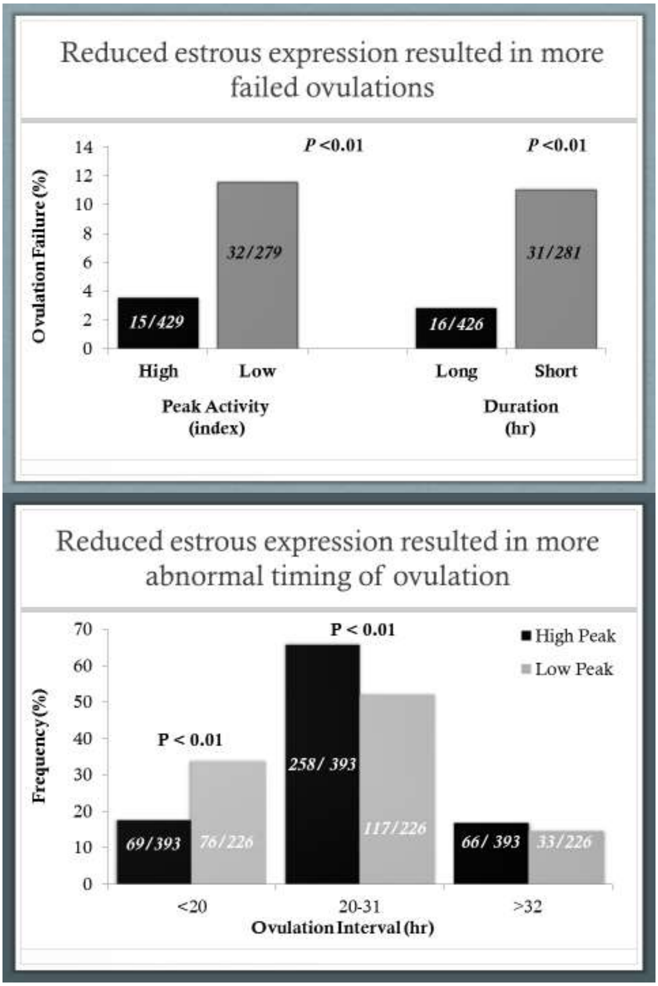

Figure 2. Ovulation failure and ovulation interval (onset of estrus to ovulation) distribution between High (≥ 300%) and Low (< 299%) relative increase at peak intensity of estrus.

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Automated Estrus Detection

Karmella A. Dolecheck and Jeffrey M. Bewley[1]

[1]Associate Extension Professor
University of Kentucky Department of Animal and Food Sciences
jbewley@uky.edu; 859-257-7543

Take Home Messages

- Examples of automatically measured parameters related to behavioural estrus include mounting events, activity, rumination, body temperature, and progesterone (P4) levels.
- Correctly identified estrus events are true positives (TP), non-alerted estrus events are false negatives (FN), non-alerted non-estrus events are true negatives (TN), and alerted non-estrus events are false positives.
- Detection is a balance of sensitivity and specificity.
- Reasons producers may consider adopting automated technologies include current reductions in availability of skilled labor, greater opportunities to meet production goals, and increased electronic record keeping opportunities.
- Producers may reject automated technologies because of lack of confidence in technology and uncertainty in payback period.

Introduction

Automated estrus detection (AED) technologies supplement a producer's ability to collect information about their cows without increasing cow stress through disturbances or handling (Wathes et al., 2008). Examples of automatically measured parameters related to behavioural estrus include mounting events, activity, rumination, body temperature, and progesterone (P4) levels (Senger, 1994; Saint-Dizier and Chastant-Maillard, 2012; Fricke et al., 2014b).

Algorithms

A common problem with all information, except mounting behaviour, collected using automated technologies is that some changes in cow behaviour and physiology are not exclusive to estrus. As a result, software specific algorithms (sets of rules to follow during calculations) must be used to compare an animal's current behaviour with a cow-specific reference period, creating an estrus alert when a set threshold is exceeded (Saint-Dizier and Chastant-Maillard, 2012). To determine usefulness of a technology, comparisons are made between estrus events identified by the technology and a gold standard such as visual observation (VO), ultrasonography, blood or milk P4 levels, or a combination of these. Correctly identified estrus events are true positives (TP), non-alerted estrus events are false negatives (FN), non-alerted non-estrus events are true negatives (TN), and alerted non-estrus events are false positives (FP; Firk et al., 2002). Detection is a balance of sensitivity and specificity. Sensitivity, the probability that an event is alerted, is equal to TP/(TP+FN)*100 (Hogeveen et al., 2010). Specificity, the probability that when an event does not occur no alert is generated, is equal to TN/(TN+FP)*100. Because neither sensitivity nor specificity account for the prevalence of the event, other comparative measurements are also useful. These include positive predictive value [PPV = TP/(TP+FP)*100] and negative predictive value [NPV = TN/(TN+FN)*100]. Other common measures of detection ability include error rate [FP/(TP+FP)*100] and accuracy [(TP+TN)/(TP+TN+FP+FN)].

The algorithms used for any technology alert will greatly influence success (Saint-Dizier and Chastant-Maillard, 2012). An Australian study testing 5 different algorithms for AED using automated activity monitoring (AAM) found a variation in sensitivity ranging from 79.4 to 94.1% and a variation in specificity between 90.0 and 98.2% (Hockey et al., 2010). Similar studies testing different algorithms for AED using AAM reported sensitivities from 51 to 87% (Roelofs et al., 2005a; Lovendahl and Chagunda, 2010).

▪ Mounting

Standing estrus is the most definitive sign of estrus because it occurs almost exclusively in animals experiencing estrus. This behaviour has been monitored automatically using pressure-sensitive technologies glued to the tailhead of the cow (Xu et al., 1998; At-Taras and Spahr, 2001; Cavalieri et al., 2003a; Saint-Dizier and Chastant-Maillard, 2012). When activated by a standing event, cow ID, date, time, and duration of mount are sent to a computer to be reviewed. Standing events per estrus and length of standing estrus have been recorded using these devices in multiple studies (Stevenson et al., 1996; Dransfield et al., 1998; Xu et al., 1998; At-Taras and Spahr, 2001; Cavalieri et al., 2003b). The most recent study, conducted by Johnson et al. (2012), found 18.4 ± 8.9 standing events per 6.0 ± 4.9 h estrus period. Each standing event can last 2.3 to 3.8 s (Xu et al., 1998; At-Taras and Spahr, 2001). Season can affect results, with hot weather decreasing duration of estrus, but not number or duration of individual mounts (At-Taras and Spahr, 2001). Number of mounts can be affected by both parity and days in milk (DIM), with primiparous cows and cows <80 DIM having increased occurrence (Xu et al., 1998; At-Taras and Spahr, 2001; Peralta et al., 2005).

Cavalieri et al. (2003b) compared VO of estrus length and number and duration of mounts to rump-mounted pressure-sensitive technologies and found low correlations in synchronized cows. Still, both methods were successful at detecting estrus with sensitivity rates of 97.5% and 93.8% for VO and rump-mounted pressure-sensitive technologies, respectively (Cavalieri et al., 2003b). Additional studies agree that rump-mounted pressure-sensitive technology sensitivity is comparable to or better than VO in both cows (Xu et al., 1998; At-Taras and Spahr, 2001; Saumande, 2002; Peralta et al., 2005) and heifers (Stevenson et al., 1996), with sensitivity and PPV as high as 91.7 and 100%, respectively, using milk P4 as a comparison. Rump-mounted pressure-sensitive technologies have also shown results comparable to tail paint and pedometers (Cavalieri et al., 2003a).

One limitation of rump-mounted pressure-sensitive technologies is the labor required to attach and remove them because they are not left on the animal for an entire lactation like other automated technologies can be (Rorie et al., 2002). Additionally, some studies have reported estrus detection trouble because of lost or displaced monitors (Dohi et al., 1993; Xu et al., 1998). Researchers have considered a subcutaneous implantable device for measuring pressure from mounting, but concerns of animal welfare, consumer perception, and potential residue issues have limited development (Senger, 1994).

Recently, an alternative method of automated mounting detection has shown potential (Homer et al., 2013). An ultra-wideband radio technology captured 3-dimensional positioning of animals to determine height changes associated with cows mounting others or standing to be mounted. Although promising, further commercial demonstration of this method is necessary.

A restraint of both of these mounting behaviour monitors is that mounting behaviour must occur for them to work (Saint-Dizier and Chastant-Maillard, 2012). Multiple studies have reported standing estrus occurrence in fewer than 50% of estrus events (Van Eerdenburg et al., 1996; Heres et al., 2000). Modern facilities, especially concrete, limit mounting behaviour (De Silva et al., 1981; Britt et al., 1986). Additionally, most pressure sensitive systems only detect mounts lasting ≥ 2 s, but 40% of mounts may last < 2 s (Walker et al., 1996).

▪ Activity

An increase in activity associated with estrus was first observed in rats in 1923 (Wang, 1923). Additional research showed this response in other female mammals, including humans, swine, and cattle (Altmann, 1941; Farris, 1944;

Farris, 1954). One of the first activity monitoring studies in cattle found that number of steps per hour increased 2 to 4 times in cows experiencing estrus compared with cows not in estrus (Kiddy, 1977). Duration of the activity increase associated with estrus is 16.1 ± 4.7 hours (Valenza et al., 2012) and multiple studies from a recent review estimated current AAM systems can accurately detect 70% of cows in estrus (Fricke et al., 2014b). Two types of AAM systems are currently available: 1) pedometers, usually attached to the leg and 2) accelerometers, which have been attached to the neck, leg, or ear (Saint-Dizier and Chastant-Maillard, 2012). Pedometers measure the number of steps taken and accelerometers measure three-dimensional movement, estimating overall activity (Fricke et al., 2014b).

In a recent comparison between AAM and VO conducted by Michaelis et al. (2014), no difference in estrus detection rate existed (42.1 vs. 37.3%, respectively). The sensitivity and PPV of AAM (35.6 and 83.3%, respectively) were numerically, but not significantly, greater than VO (34.3 and 75.1%). The ability of AAM to produce similar or better results than VO has also been shown in other research (Peter and Bosu, 1986; Liu and Spahr, 1993; At-Taras and Spahr, 2001). Automated activity monitoring can also be useful in heifers under a variety of housing systems, including pasture, dry lot, and tie stall (Sakaguchi et al., 2007). Comparisons between AAM and other estrus detection methods also exist. Cavalieri et al. (2003a) compared estrus detection of a pedometer, a rump-mounted pressure-sensitive mounting detector, and tail paint using milk P4 levels and pregnancy diagnosis and found no differences in sensitivities (81.4, 88.4, and 91.3%, respectively).

Reports concerning the percent of estrus events identified using AAM vary between 51 and 84% in both confinement and pasture situations (Lewis and Newman, 1984; Redden et al., 1993; Roelofs et al., 2005a; McGowan et al., 2007; Hockey et al., 2010; Kamphuis et al., 2012; Valenza et al., 2012). Yaniz et al. (2006) stated that a reduction in physical activity occurs with increased milk production, parity, and temperature humidity index. Holman et al. (2011) agreed that high milk yield and low BCS may negatively affect AAM sensitivity, additionally adding that lameness can affect results from leg mounted technologies. However, synchronization, parity, cow age, milk yield, season, DIM, and weather have been found in other studies to have no effect on physical activity (At-Taras and Spahr, 2001; Yaniz et al., 2006).

Recently, studies have focused on comparing AAM to timed artificial insemination (TAI). In 2010, Galon (2010) found no difference in first service conception rate (CR) between Ovsynch (17.6%) and pedometers (22.6%). A more comprehensive study compared TAI to AAM using over 900 animals from 3 herds (Neves et al., 2012). Time to pregnancy was shorter (82 vs. 125 days) for cows bred using the AAM.

▪ Rumination

Automated rumination monitoring can use a microphone system that lies on the cow's neck to identify the regurgitation and re-chewing of cud (Burfeind et al., 2011) or an accelerometer to identify motions associated with rumination (Bikker et al., 2014). Schirmann et al. (2009) validated a commercial, microphone-based rumination monitoring device, finding high correlations to VO of 51 cows (r = 0.93). Because of the decrease in feed intake during estrus (Maltz et al., 1997), the resulting decrease in rumination provides another possible method for AED (Reith and Hoy, 2012). Reith and Hoy (2012) showed a reduction in rumination on the day of estrus from a baseline of 429 min/day to 355 min/day. Overall, mean decrease in rumination during 265 estrus events was 17% (74 min), but with high variation (-71 to +16%). In a follow-up study that looked at 453 estrous cycles, rumination time decreased 19.6% (83 min/day) on the day of estrus (Reith et al., 2014). Pahl et al. (2015) also found a decrease in rumination on the day of (19.3%) and the day before (19.8%) inseminations leading to pregnancy.

▪ Temperature

Cow temperature fluctuates throughout the estrous cycle, being lowest just before estrus, high on the day of estrus, and low again at the time of ovulation in comparison to the high temperatures seen throughout the luteal phase of the cycle (Wrenn et al., 1958; Lewis and Newman, 1984; Suthar et al., 2011). The decrease before estrus may result from lowered P4 levels after luteolysis (Wrenn et al., 1958; Kyle et al., 1998), though Suthar et al. (2011) identified no correlation between body temperature and serum P4 concentrations (r = 0.018). The increase in temperature during estrus could be associated with the increase in activity during behavioural estrus (Walton and King, 1986; Redden et al., 1993), yet tie stall cows, whose movement is constricted, have also experienced increases in vaginal temperature during estrus (Suthar et al., 2011). Other hypotheses for increased vaginal temperature surrounding estrus are enhanced blood flow to the area (Suthar et al., 2011) and correlation with the luteinizing hormone (LH) surge (Clapper et al., 1990).

Regardless of reasoning, reticulorumen boluses, vaginal inserts, temperature monitoring ear tags, and milk temperature sensing technologies originally designed for disease detection could provide an additional method of estrus detection. Vaginal temperature increases between 0.10 and 1.02ºC (Lewis and Newman, 1984; Redden et al., 1993; Kyle et al., 1998; Fisher et al., 2008; Suthar et al., 2011). Milk temperature increases of 0.3ºC (Maatje and Rossing, 1976; McArthur et al., 1992) have been recorded during estrus. Rectal temperatures, though non-automated, have even greater reported increases during estrus (1.3ºC; Piccione et al., 2003). These temperature increases last for 6.8 ± 4.6 hours in dairy cows and 6.5 ± 2.7 hours in beef cows (Redden et al., 1993; Kyle et al., 1998).

Maatje and Rossing (1976) found 84% of visually observed estrus events were identifiable using twice-daily milk temperature monitoring. A follow-up study by McArthur et al. (1992) introduced skepticism after only 50% of estrus events were identified via milk temperature monitoring compared to P4 concentrations in the milk. Other studies have focused on vaginal temperature monitoring, finding sensitivities ranging from 69 to 86% compared to P4 concentrations, making them similar to VO (Redden et al., 1993; Kyle et al., 1998). Overall, temperature monitoring as a tool for estrus detection has both potential and difficulties (Ball et al., 1978; Schlünsen et al., 1987; Fordham et al., 1988; Cooper-Prado et al., 2011; Culmer, 2012). Past challenges have included large daily fluctuations in temperature, variability in temperature rises, seasonal variation, and problems with data recovery from reticulorumen temperature boluses. Many studies agree that temperature alone may not be specific enough to use for estrus detection because of the variety of factors (sickness, ambient temperature, water intake, etc.) that may also affect it (Walton and King, 1986; Fordham et al., 1988).

A newly proposed tool for automated temperature monitoring is measurements of body surface temperature using infrared technology (Talukder et al., 2014). Although originally discredited for high rates of FP and FN (Hurnik et al., 1985), new technology has been developed that is much more promising. Talukder et al. (2014) measured surface temperature on the vulva and muzzle of 20 cows and identified a significant decrease in temperature 48 h before, an increase 24 h before, and another decrease at ovulation as determined by ultrasound evaluation. The sensitivity and specificity of this method for estrus detection compared to plasma P4 varied from 58 to 92% and 29 to 57%, respectively, depending on the algorithm used. Creation of an accurate algorithm and automation of vulval temperature monitoring is challenging because of fecal contamination and tail placement. Alternative locations for infrared temperature monitoring such as the eye and back of the ear may be more appropriate (Hoffmann et al., 2013).

▪ Progesterone

Progesterone measurements can be estimated through both blood and milk sampling and are often used as the gold standard comparison when testing other estrus detection methods (Firk et al., 2002). Roelofs et al. (2006) demonstrated that milk P4 concentrations decline to < 5 ng/ml 80 hours before and < 2 ng/ml 71 hours before ovulation, with blood P4 following a similar pattern. Multiple reproductive parameters can be gained from measuring P4, including identification of estrus and estrus detection errors, likelihood of insemination success, pregnancy diagnosis or loss, ovarian cyst diagnosis, anestrus identification, and evaluation of responses to hormone intervention (Nebel, 1988; Blom and Ridder, 2010; Mazeris, 2010; Saint-Dizier and Chastant-Maillard, 2012). On-farm individual milk P4 tests have been developed (Marcus and Hackett, 1986; Worsfold et al., 1987; Nebel, 1988), but are not automated.

An alternative is automated detection through inline milk sampling systems (Pemberton et al., 2001; Gillis et al., 2002; Saint-Dizier and Chastant-Maillard, 2012). The only commercially available system of this kind is Herd Navigator (DeLaval, Tumba, Sweden), which collects milk at specific time points throughout the estrous cycle to determine a P4 curve for each cow (Friggens and Chagunda, 2005; Mazeris, 2010). An algorithm in the system then determines if the cow receives an estrus alert depending on her point in the estrous cycle. A group of Danish herds using the Herd Navigator system have reported CR between 40 and 63% and a mean reduction in days open (DO) of 22 d since adoption (Blom and Ridder, 2010). A separate survey reported that pregnancy rate of Herd Navigator test farms changed from 22.8% pre-installation to 40% two years later (Durkin, 2010).

Compared to inseminations resulting in pregnancy, the high sensitivity (93.3%) and specificity (93.7%) for estrus detection has identified the usefulness of the Herd Navigator as an AED tool (Friggens et al., 2008). Furthermore, the Herd Navigator can also conduct measurements of lactate dehydrogenase, urea, and β-hydroxybutyrate to detect metabolic diseases and mastitis. Regardless, high cost of the system has limited its adoption.

▪ Others

Lewis and Newman (1984) found vaginal pH to be lowest on the day of estrus, milk yield to be decreased surrounding estrus, and heart rate to be slowest during estrus. However, these variations were small and repeated measurements (because of lack of automation) are not yet feasible for commercial dairies. Similar, inability to automate has reduced interest in other areas, including monitoring electrical resistance of vaginal mucus, dry matter concentration and crystallization patterns of vaginal mucus, and blood P4 around estrus (Noonan et al., 1975; Leidl and Stolla, 1976; Heckman et al., 1979).

▪ Technology Combinations

According to de Mol et al. (1997), the missing link in automated technology monitoring is merging all available data. Combinations of multiple parameters would improve estrus detection rate when certain conditions (environmental temperature, pen changes, etc.) interfere with one monitoring method (Firk et al., 2002). Maatje et al. (1997a) considered the combination of activity, milk yield, and milk temperature for estrus detection, finding sensitivity improvements of 10 to 20% over activity alone. Peralta et al. (2005) also tested three parameters, finding the sensitivity of VO, activity monitoring, and mounting detection alone was 49.3%, 37.2% and 48%, respectively. The combination of all three systems increased estrus detection sensitivity to 80.2%. Additional studies have shown the usefulness of combining multiple variables for estrus detection (Redden et al., 1993; de Mol and Woldt, 2001b; Brehme et al., 2008; O'Connell et al., 2011).

Merging automatically collected data (activity, rumination, etc.) with an individual cow's history can also improve estrus detection algorithms. Firk et al. (2003) demonstrated that including information about the length of time since a cow's last estrus period decreased sensitivity from 91.7 to 87.9% but improved error rate from 34.6 to 12.5%.

The potential for multiple parameter combinations in estrus detection requires improved data analysis compared to univariate scenarios. Some multivariate evaluation techniques include statistical process control, fuzzy logic, neural networks, and machine learning.

Statistical process control monitors and detects changes in data over time. Control limits are set through calculations of the mean variation between observations, and when an observation goes outside of those control limits, an alert is triggered (De Vries and Conlin, 2003b). This allows the model to distinguish between natural variation and real change. Statistical process control has been used to manage mastitis (Niza-Ribeiro et al., 2004; Lukas et al., 2005) and reproductive performance (De Vries and Conlin, 2003a, b).

Fuzzy logic analysis involves 3 steps: fuzzification, fuzzy inference, and defuzzification (Firk et al., 2002). Fuzzification is the process of transforming real variables into linguistic variables. Fuzzy inference then applies rules to the transformed variables in a fashion similar to "if, then" statements to classify them. Defuzzification returns the values created by fuzzification and fuzzy inference back to readable values. In the dairy industry, fuzzy logic has been applied to mastitis (De Mol and Woldt, 2001a; Cavero et al., 2006; Kramer et al., 2009), lameness (Kramer et al., 2009), and estrus detection (De Mol and Woldt, 2001a).

Neural networks do not require a specific algorithm to work (Grzesiak et al., 2006). Instead, they learn how to make associations and adapt when presented with new data. Although most commonly used in engineering, business, and medicine, some models can predict milk production (Sanzogni and Kerr, 2001; Grzesiak et al., 2006; Sharma et al., 2007) and mastitis occurrence (Heald et al., 2000; Hassan et al., 2009).

Machine learning is another method of programming that allows for constant algorithm improvement through experience and data analysis (Alpaydin, 2004). Machine learning is applicable to retailers who track customer behaviour, financial institutions when identifying risk, and manufacturing scenarios to help minimize resource consumption. Reproductive performance in the dairy industry has also been evaluated using machine learning (Mitchell et al., 1996; Caraviello et al., 2006a; Shahinfar et al., 2013).

▪ Technology Effect on Timing of Insemination

Pregnancy outcome is dependent on timing of AI relative to ovulation (Nebel et al., 1994). Automated monitoring technologies' ability to predict ovulation may help maximize CR by determining ideal AI time (Senger, 1994). Dransfield et al. (1998) evaluated 2,661 inseminations in 17 herds and reported the highest CR when cows underwent AI 4 to 12 hours after the onset of standing activity as measured by an automated rump-mounted pressure-sensitive technology. A similar study using pedometer readings showed AI 6 to 17 hours after increased activity levels resulted in the highest CR, with no effect of disease, inseminator, or bull on the results (Maatje et al., 1997b). Vaginal temperature has also shown a high correlation ($r = 0.74$) with ovulation (Rajamahendran et al., 1989), and strong relationships with the LH peak (Clapper et al., 1990; Mosher et al., 1990; Fisher et al., 2008).

Automated technologies' ability to measure intensity and duration of estrus may further improve CR. Dransfield et al. (1998) reported that the probability of pregnancy increased with an increased number of standing events. Cows that stood for mounting less than 3 times experienced a 41% lower chance of becoming pregnant compared to cows that stood to be mounted 3 or more times before AI. Stevenson et al. (1983) agreed that increased estrus intensity resulted in a significant positive effect on CR.

▪ Technology Adoption

Technology adoption on dairy farms has been slow (Russell and Bewley, 2013). In 2007, the USDA estimated dairy herds using pedometers and pressure sensing technologies for estrus detection at 1.4 and 5.7%, respectively (USDA, 2007). Nevertheless, Borchers and Bewley (2014) recently conducted a producer survey and identified high adoption interest in mounting and cow activity monitoring technologies.

Reasons producers may consider adopting automated technologies include current reductions in availability of skilled labor, greater opportunities to meet production goals, and increased electronic record keeping opportunities (Wathes et al., 2008). Producers may reject automated technologies because of lack of confidence in technology and uncertainty in payback period. Russell and Bewley (2013) conducted a survey to identify reasons for slow technology adoption in Kentucky herds, and 42% and 30% of producers identified undesirable cost to benefit ratio and no economic value, respectively. Borchers and Bewley (2014) also identified economics (benefit to cost ratio and investment cost) as the two biggest factors influencing technology adoption. These results highlight the importance of evaluating economic feasibility of automated technologies.

■ References Available Upon Request

Identifying Pain Behaviors in Dairy Cattle

Karina Bech Gleerup

University of Copenhagen, Department of Large Animal Sciences, Hojbakkegaard Alle 5, Taastrup, 2630, Denmark
Email: kbg@sund.ku.dk

■ Take Home Messages

- There is nothing in the anatomy and physiology of the cow that suggests that cows are less sensitive to pain than other mammals.
- Cows in pain are likely to have different behavioural priorities compared to healthy cows.
- Pain is a serious welfare problem that needs to be addressed to meet consumer requests in the future. Farmers and veterinarians must address efficient pain treatment, prevention of pain, and early intervention when the cow is in pain.
- Too few veterinarians give proper pain relieving treatments, and a major factor influencing the decision to give pain relieving medicine is the inability to assess pain in cattle.
- Tooth grinding, vocalizing, head pressing or colic behaviour all indicate severe pain.
- A pain scoring regime exists; 'The cow pain scale' is fast and easy to use for both veterinarians and farmers.
- Cows will display some signs of pain whenever they are in pain. These signs are only valuable if someone recognizes them and acts upon them.

Cattle are often described as stoic animals [stoic, from latin 'stoicus': "a person who accepts what happens without complaining or showing emotion"], which may be the main reason why pain evaluation in cattle is not performed often enough. There is nothing in the anatomy and physiology of the cow that suggests that they are less sensitive to pain than other mammals. With the high prevalence of potentially painful conditions like lameness and mastitis in dairy herds, pain evaluation should be part of the daily routine; however, that is not the case. In recent years, scientists from several countries have investigated factors influencing the decision to use analgesia for cattle. The studies have been conducted as surveys including veterinarians and farmers. Certain potentially painful conditions were rated very low; however, only a minority of the survey respondents considered cattle unable to experience the emotional components of pain (Hewson et al., 2007; Kielland et al., 2010). Veterinarians and farmers generally agreed that cattle suffer from painful conditions, and that pain relieving treatment is an advantage for the animals. Despite this overall agreement on painful conditions in cattle, still too few veterinarians give proper pain relieving treatments and farmers are even more reluctant to use analgesics (Thomsen et al., 2012). The reasons for this restricted use of analgesics may be many: economic reasons, practical reasons, habits and lack of knowledge. As cattle are production animals, drug regulations are very restricted and complicated, which also influences the choice of treatment. Another major factor influencing the use of pain relieving medicine is the inability to assess pain in cattle (Flecknell, 2008). This inability to assess pain influences the perceived effect of the given pain medication. This may mean that the initial pain state of the cow is difficult to evaluate, and also, the improvement of the cow's pain state may not seem obvious enough. The lack of a visible benefit of the analgesic treatment will further demotivate the use of pain relieving drugs in the future. Untreated pain may therefore be a consequence of poor pain evaluation tools.

■ Functions and Effects of Pain

Acute pain is a protective mechanism. People with congenital insensitivity (a complete lack of pain sensitivity) will experience repeated injuries like self-mutilation and bone fractures; they have a greatly reduced life expectancy because they never learn to correlate pain to injury. Pain sense is therefore essential for maintaining bodily integrity. The emotional and aversive component of the pain experience promotes the protective motor and learned avoidance response. It supports convalescence and serves a learning function for the animal to avoid a similar injury in the future. This does not mean that cows should not be given pain medication as this does not completely cut off the pain sensation; rather, it reduces the negative effects of pain. Treating post-surgical pain in animals reduces weight loss and speeds up recovery and it is a well-known fact that pain in humans is accompanied by reduced welfare, poor condition and increased death rate.

When a cow is subjected to pain, it evokes an immediate withdrawal response and vigorous activity to escape the pain stimulus and to seek protection from further damage. This is the first line of defence against threats to the integrity of the body. In the case of trauma, this is followed by behaviours to support resting the injured area to promote healing. Licking or rubbing near the painful area can sometimes be seen, as it may soothe pain by segmental inhibition where signals from one part of the body can help reduce pain in another part. Animals may take on abnormal postures to avoid or reduce stimulation of sensitive areas as may be seen in cows with pain standing with an arched back or lying down only on the non-painful side. Quiescence promotes convalescence and this may be seen as a change in social behaviour like isolation from group members, e.g., feeding when it is not so crowded.

Pain is a dynamic condition, which means that if left untreated or if the animal is not protected from further stress, pain may increase in magnitude and may lead to chronic changes in perception of tactile stimuli. This means that a cow suffering long-term pain may begin to perceive a non-painful normal touch as being painful.

■ Why is Pain Evaluation Important?

There is a growing concern about production animal welfare among various stakeholders, including the general public (de Graaf et al., 2016). Farmers are likewise concerned about the welfare of the animals in their care (Von Keyserlingk et al., 2009). Pain is a serious welfare problem that needs to be addressed to meet consumer requests in the future. This includes efficient pain treatment, including prevention of pain and early intervention when a cow is in pain. Some countries have taken legislative actions towards reducing pain caused by husbandry procedures, for example, by proposing compulsory use of local analgesia before a painful event and systemic analgesia after the painful event. Naturally occurring pain cannot always be prevented and for this type of pain, early recognition facilitates timely treatment, which increases the treatment success considerably. Researchers have investigated different measures for pain in dairy cattle and the duration of lying bouts is one example of a behaviour that is adjusted to the wellbeing of the animal; the duration of lying bouts increases when cows are lame. Mastitis also has an impact on cow behaviour; a recent study found that cows have reduced feed intake in the days before mastitis was diagnosed and this continued for up to 10 days after antibiotic treatment. The same cows had an increased kicking rate during milking in the same period (Fogsgaard et al., 2015). The reduced feed intake and the increased kicking may be pain related and could possibly be avoided or reduced by adding analgesia to the traditional treatment.

Since animals do not communicate verbally, veterinarians and farmers include behavioural changes when evaluating cows. Some well recognized pain manifestations are tooth grinding, vocalizing, head pressing, or rarely, colic behaviour. These behaviours will most often be noticed in dairy cattle, but it is important to realize that these are all pain behaviours indicating severe pain. It is necessary to also be aware of more subtle pain behaviours to prevent cows with low to moderate pain proceeding to experience prolonged periods of pain, which becomes difficult to treat and has a poor prognosis for the future.

Our group evaluated pain behaviours in 2 high yielding Danish dairy herds (Gleerup et al., 2015) and found that 40 of 100 randomly selected dairy cows displayed pain behaviours supportive of mild to moderate pain. A thorough clinical examination revealed clinical findings indicative of pain in all the animals, despite the fact that they were supposedly healthy, high-yielding cows. This is a welfare concern as well as a production concern as pain has a negative effect on both milk yield and welfare.

■ Measuring Pain

Pain cannot easily be measured — not in humans and not in animals. There is no one good physiological measure for pain. Behavioural changes can however, be a very important indicator of the presence of pain, as behaviour reflects the internal state of a human or an animal. Severely lame cows or cows with other severe diseases may receive extra care and consideration, whereas cows with mild to moderate cases of clinical disease are more difficult to detect. The risk of failing to see animals in pain increases as farms expand and available labour decreases, resulting in less time spent on each cow. More automated systems are introduced to detect disease and activity as well as milk yield and milk quality, which can all indicate illness or pain. These are all very important resources in modern dairy production but direct animal-based measures may give an earlier warning of pain, and it is therefore important to keep looking at the animals. Cows will display some signs of pain whenever they are in pain (Figure 1) but these signs are only valuable if someone recognizes them and acts upon them.

Figure 1: This photo shows a dairy cow that is in pain and is expressing it with an abnormal positioning of the hind limbs (in front of each other), slightly lowered head carriage and a changed facial expression. (Photo by Karina Bech Gleerup).

The Cow Pain Scale

The cow pain scale (Figure 2) was developed to be quick and easy to use, making it applicable to every day routines in a busy dairy herd (Gleerup et al., 2015). The cow pain scale is intended for veterinarians as well as dairy farmers. Very obvious and well recognized signs of severe pain, like tooth grinding, vocalization, head pressing or kicking toward the belly are not included in the pain scale, but these should always be considered alarming signs of severe pain. The cow pain scale is focused on cows with less obvious pain behaviours as these are often overlooked. The cow pain scale consists of 7 behaviours, evaluated from 0-2 and combined into a total pain score. This pain score is guiding, but if the pain score is above 5, the cow could be in pain and should be observed and re-evaluated or examined by the veterinarian.

The 7 behaviours are:

- **Attention towards the surroundings** — if a cow is in pain, she tends to be less focused on the environment.
- **Head position** — pain will often result in lower head carriage. This behaviour may have several explanations, two of them being an overall changed posture or avoiding social interaction.
- **Ear position** — cows in pain keep their ears straight backwards or very low like lamb's ears
- **Facial expression** — the cow has a changed facial expression when in pain, a so-called pain face.
- **Response to approach** — a cow in pain is less interested in social interaction and will therefore try to avoid an approaching person (described in more detail below).
- **Back position** — pain in legs or abdomen may result in an arched back.
- **Lameness** — lameness is a result of pain in one or several limbs. Pain in more than one limb may result in a very careful walk, rather stand a limp.

The first 4 behaviours are evaluated from a distance, while the cow is not yet alerted to the person observing. Then the cow is approached and the response to approach is evaluated. When the cow is standing up, the back position may be evaluated, and finally the lameness is evaluated. Once accustomed to the scale, this does not take more than about a minute. The pain scoring is obviously not intended routinely for all animal; rather, it is a tool for evaluating the cows that are noticed to look different than normal during the daily round through the barn.

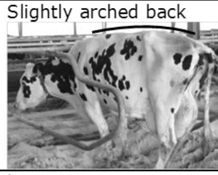
Score	0	1	2
Attention towards the surroundings	Active and attentive 	Not attentive 	
Head position	Head held high 	Lower than withers 	Very low 
Ear position	Both ears forward or actively moving 	Both ears back 	Lamb's ears (low ears) 
Facial expression	Attentive or neutral look 	Tense expression 	
Response to approach	Look at observer, head up, ears forward or occupied with activity (grooming, ruminating)	Look at observer, ears *not* forward, leave when approached	May/may not look at observer, head low, ears *not* forward and may leave slowly
Back position	Straight line 	Slightly arched back 	Arched back 
Lameness	Not lame Normal and rhythmic strides	Lame Shorter and non-rhythmic strides	Very lame No support on one leg or very unequal and short strides

Figure 2: The Cow Pain Scale. The Cow Pain Scale is modified from the original version published in "Pain Evaluation of Dairy Cattle", Appl. Animal Behavioural Science, 2015, Open Access <u>Pain evaluation in dairy cattle</u>

The Cow Pain Face

The spontaneous facial expression of pain is believed to be an innate response, reflecting activity within the pain pathways. Facial expressions of pain are very difficult to suppress and the use of facial expressions is therefore considered a reliable and objective measure of pain. Recently, facial expressions of pain have also been described for several animal species: mice, rats, rabbits, cats, horses, sheep, lambs and cows. In humans, facial expressions of pain may be evident even if other pain behaviours are suppressed. This is very interesting as humans have a specialized neural apparatus for processing facial cues. This is useful when interacting with other people, as facial expressions provide important social information, like mood and level of interest, and it facilitates verbal communication. This may be useful for evaluating facial expressions in animals too (see Figure 3). It is well recognized that people working with a particular species for many years become very skilled at observing different behaviours. If it could be possible to get better at interpreting these behaviours, this may be a quick and useful tool for improving welfare and hence production.

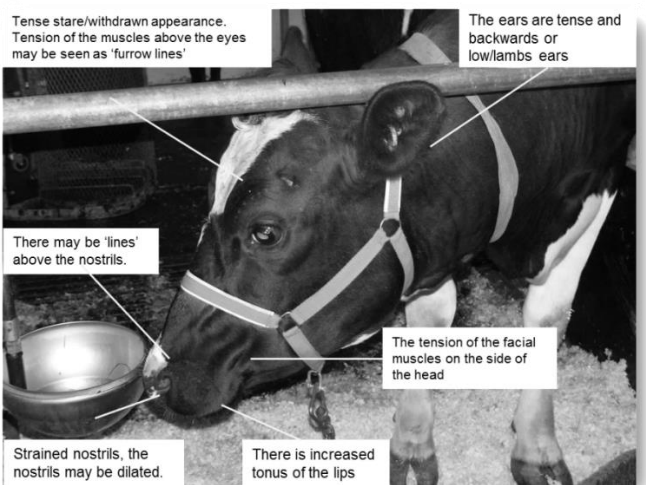


Figure 3: The cow pain face. The different changes occurring on the facial expression of a cow in pain, here pointed out on a cow in pain following surgery.

Response to Approach

Cows are generally curious animals and gentle contact makes the animals more likely to approach people resulting in a shorter avoidance distance (Lensink et al., 2000). When cows are in pain they react differently to an approaching person. They may avoid contact by keeping their heads low with no eye contact, or they may leave before the person is close (Figures 4a and 4b). This behavioural response is also related to the age of the cow, as a young heifer may not be as confident with an approaching person as an older cow may be.

Figure 4a: 'Response to approach', score '0'. As soon as the cow sees a person approaching, she is attentive with her head high and ears forward. This cow is not scared and remains lying, sniffing the hand (after this, she got up and walked off). A sound cow that is less sociable with humans will usually remain lying down with a high head and ears forward until the person approaching is getting near, then she will get up and walk off in a hurry. (Photo by A. M. Michelsen)

Figure 4b: 'Response to approach', score '2'. The cow in this photo is not looking at the person approaching and keeps her ears back. The cow is not interested in contact, and even when the approaching person gets close to her head, she does not look. Had the cow been scared, she would have left but when a cow is in pain, she is not so motivated to get up, especially if the pain comes from the legs or claws. (Photo by A M Michelsen)

Conclusion

Pain evaluation is important to ensure animal welfare in dairy production. Computer technology can assist with surveillance of the animals but it is important to use the option of looking directly at the animals as well. This is useful only if a systematic approach is taken and if there is an action plan if a cow is found to have a high pain score. It is important to recognize abnormal behaviours, like pain behaviours, from normal behaviours. This may be even more difficult in stressed animals, which should further motivate a gentle handling of the animals to reduce stress to a minimum and to facilitate pain evaluation.

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