Are the Immediate Challenges Faced by the British Dairy Industry Applicable to Canada?

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Take Home Messages

- The UK faces uncertain times and some interesting challenges in the coming years.
- Overall, the way forward is for the dairy sector to be inspirational, efficient and to invest for the future.
- Farmers should adopt an optimal dairy system approach that drives profitability and competitiveness.
- There is opportunity to raise our standards of animal welfare even higher and differentiate our products in new markets around the world.

Introduction

We face uncertain times and interesting challenges over the next few years in the UK. We can look at these as fairly disastrous or the “kick up the backside” we need in order to improve our farm management and supply chain which in turn, increases our productivity and competitiveness. Looking at the positives, we could also lift our good record on animal welfare even higher and differentiate our products from imports as our government strikes trade deals around the world.

What do our dairy farmers need to do?

At the Agricultural and Horticulture Development Board (AHDB) we agreed upon a strategy with our industry that focused on inspiring our farmers and assisting them to do better in a more competitive world. The dairy strategy focused on improving performance by collaborating with the private sector (vets, consultants, banks, milk buyers, etc) when delivering our Knowledge Exchange programme. Our portfolio of research and delivery in genetics, health, welfare and nutrition will continue to play its part. The dairy promotional campaign further provides a platform for dairy companies to market their brands (this was co-funded by Dairy UK, which is the milk processing organisation in the UK).

▪ Optimal Dairy Systems

When it came to delivery, The AHDB Dairy Board supported tackling the issue of dairy farming from first principles and in the area which in the past has been tolerated or ignored: systems. Unlike many countries, especially exporting countries where a definitive way of producing milk is applied (extensive production where it's all about producing milk from grass; e.g. New Zealand and Ireland) or Holland and Denmark (intensive high yielding systems), we have more ways of producing milk in the UK than you can shake a stick at!

Our approach has therefore been to very simply divide the industry into two 'Optimal Dairy Systems' (block calving and all year round calving). Our surveys show that 81% of our dairy farmers describe themselves as calving all year round and given that we believe a vast number of these farmers are nowhere near the performance needed, it demonstrates the scale of the challenge. To help focus the mind, we describe our block calving system as a herd of cows which calves in 12 weeks, spring or autumn, or indeed any other time of the year.

According to our research and Brexit scenarios, only the top 25% across all agriculture sectors are safe and will be able to continue without change. Given both greater competition from imports and the partial removal of farm payments, the economic climate will be very different.

Our first question to a dairy farmer is 'Which system do you operate?' Our second question is 'Have you deliberately chosen this system of operation?' Many of the 81% who calve all year round have carried on what their father did in the past, failed to maintain a block calving system, or have been pressured by their milk buyer to supply milk over most of the year through seasonality payments and penalties.

There are of course some excellent farmers who calve all year round who have chosen the system and made it work very well for them; however, we know that a high proportion of the farmers who struggle or actually lose money dairy farming are also in this cohort. There are three main reasons for this: fertility, feed conversion and fixed costs. In 2016, the average calving interval in the UK was 407 days (Hanks and Kossaibati, 2016), very similar to that here in Canada of 408 days (CanWest DHI, 2016). We know that shortening the calving index on any herd can result in financial rewards.

Block calvers do not have poor fertility performance for the simple reason that if they do, they are no longer block calvers! Yes it is intense when the herd has to calve down and they all need to be put back in calf, but intense spotting and serving of bulling cows over a few weeks can be done due to the short duration of that maximum effort.

An average farmer calving all year round will be calving, spotting bullers and inseminating cows most days of the year. Not only is that approach impossible to keep up, but it is much harder to see when things are not going right and slippage occurs. Our key performance indicators for block calvers is 80% of all cows in the herd calved in 6 weeks. That is a clear message that getting cows in calf on this system is of paramount importance, with proper bulling observation both during the day and late at night.

There are lifestyle benefits from block calving and whilst the older generation might not know what this is, our younger farmers and workers certainly do. The calving period is intense and after a short break the insemination period is all consuming. But after that, the next few months are much easier and include a month of no milking at all, when holidays can be taken before it starts again. With labour shortages in the UK today, which are going to get worse in the coming years, offering a lifestyle balance is increasingly important.

We must also be more imaginative in our thinking and try and match farmers who are not doing that well or unwilling to change, with young people who want a foot on the ladder in dairy farming. Providing the facilities on the farm, and encouraging farmers and their families to allow new people to make use of the farm and their facilities in return for a share in the profit, can work for both parties. In the UK, share farming has provided great opportunities and the young people (some new to farming) have really made a go of it.

Block calving has been the choice of system as it offers lower costs and greater opportunity for profit due to the cost of production being much lower. Most of this is happening in the west of the country where grass growth is far better due to frequent rainfall. For this reason, there are also many more dairy farms and opportunities on the western side of the UK. Some limitations also exist, such as seasonal labour requirements (if needed) and potentially lower milk price overall due to seasonality. However, higher milk prices due to milk solids compensate for this to some extent.

All year round calving has the benefit of a more regular labour approach, is more aligned to milk buyers and has a potentially higher milk price (due to seasonality). Its limitations include a potentially higher labour cost, no break in the regime, potentially lower margins and farm inefficiencies could remain hidden.

The very best all year calvers are well established, profitable and very good at what they do. Their capital investment can often be much higher and the best systems carry high costs that are covered by high performance. Those who have the same high costs but do not attain the high performance are the ones in trouble and it's a difficult problem to fix. We believe that the average farmer who is struggling would benefit from taking a long look at a block-calving system, where things are simpler and all errors are easily spotted.

The best block calvers approach their farming by applying ruthless simplicity and cost control to everything they do. If they are block calving in the autumn, they will be using their silage clamp (bags, pile, or pit) as a 'vertical paddock', self-feeding behind an electric wire in the way the spring block calves strip graze their grass paddocks.

I know many autumn block calves that are consistently amongst the most profitable dairy farmers in the UK. They are mainly in the East of the country where maize (corn) silage can be successfully grown, which makes up for the drier summers and lack of grass growth. The herd is dry in the worst summer months for grass growth and the grass silage made in the spring combined with the maize (both often self-fed) sets the milk production up for winter with minimum bought-in feed.

All production systems can be profitable and can work well, but there are issues with milk buyers. Milk buyers want level supply in their factories. Whilst we do not necessarily agree with that and we see other countries operating very differently, we took the pragmatic approach of accepting the collective voice of processors. However, that does not mean a level supply from each farm. We have spent our time persuading processors that what they need is a level supply from their milk pool and that a simple computer model can match autumn block calving farms with spring calvers in order to deliver the level supply they need.

We have shown them that a spring calving farm, matched up with an autumn calving farm, delivers a reasonable supply pattern; but if two autumn calving farms are matched up with a spring calving farm, then the milk delivery profile practically matches what they have currently. Given the challenges of Brexit, processors are concerned about their potential milk supply and are therefore interested in ways of ensuring dairy farmers are kept competitive so that they remain in business.

Furthermore, any expansion in dairy farming in this country would currently need to be block spring calving, which produces a heap of cheap spring milk from grass, which does not suit the flat profile processor's demand. They react by penalising these producers, who are the most efficient, with ever greater seasonality adjustments, which is a crazy approach and something no other industry does. We now see several processors looking at our model and some are actively putting it into action, recruiting spring or autumn calving farms to balance some of the current farmers that supply them or assisting and encouraging those who want to change.

We believe that most dairy farmers who want to block calve in the spring are already doing so or planning to do so in the near future, therefore we believe the greatest opportunity, given that farmers seems to be die-hard spring calving grass enthusiasts, or absolutely hate the system with equal passion, is with block autumn calving conversions.

Given the scale of the task, there is a long way to go. With 81% of farmers calving all year round and only 25% of them doing a good enough job to face the future with any confidence, then logically, 20% should be calving all year round with 80% block-calving. That is such a massive change that we do not think will happen. Whilst Brexit will take its toll and accelerate the leaving rate, some farmers will be able to lift their game and do well enough to continue with all year calving. Many farmers will need to think very seriously about what they are doing and what the future holds for them.

▪ Challenges & Opportunities

With challenges comes opportunities and there will be some great opportunities for the best operators, entrepreneurs, and young and new entrants. Land values should fall following the drop in profitability and the end of Common Agricultural Payments (CAP). However, in the UK, land is no longer valued for its agricultural worth. I expect to see land prices easing in the short term and poorer land where it is far removed from the population and tourist areas could fall in value. Land appreciation has kept many inefficient businesses going over recent years. Should land values fall, banks will change gear on loans and borrowed money, which will add extra pressure.

Data

We lack proper and meaningful full data in agriculture in the UK, which is a big problem. We have a lot of data from various sources but not national data that is needed to give us a better understanding of what is happening and the ability to extract proper figures and detailed analysis of farms. There are data sets, but they are for a sample of farms collected by government that are accurate but far from comprehensive. Small retail groups have very good data but are reluctant to share that data, which is understandable. Various large consultant groups have data sets, but like the retail groups, these tend to represent the better farmers.

We do have a good data set for Wales, as we managed to persuade the Welsh Government to exchange EU money given as assistance to dairy farmers in the tough market conditions of 2016, for data from farmers. Farmers were in effect given the money in exchange for data which is now being analysed and will be used to help them improve. Around 60% of farmers participated, which was less than I expected, but way above Welsh Government expectations!

With the data set we have at our disposal, we have calculated that a block spring calving system will typically achieve an extra margin of 2.4p ($ 0.04) per litre over an all year round operation and an autumn block calving system would achieve 1.4p ($0.02) per litre. These figures were replicated when comparing the top 25% which gives consistency. However we believe that greater savings are possible as the data sets were from farms which did not have as tight a block (12 weeks with 80% in the first 6 weeks) as we described.

Furthermore, we believe that with effort, an average performer in an all year round system could lift his or her performance in a block calving system as it is simpler (putting all the effort to dealing with one thing at a time) and shows any mistakes easier and earlier. One would imagine that if a farmer takes the big decision of changing systems, then he or she would be committed to making it work well.

We will launch our AHDB ‘Farm Bench’ system in the spring of next year, where famers can submit data on-line for bench-marking purposes. This will give us more data which will be more representative. We will also launch our International Bench-marking tool, where UK dairy farmers can compare themselves with countries signed up to this tool, namely New Zealand, Australia, USA and Ireland. These are the most important countries for UK farmers to compare themselves with once we leave the EU.

We are planning to get some EU countries to join and submit data into this model for their own benefit, namely the Netherlands, Denmark, Germany, France and Poland. These are the other major producing countries in the EU and it would be mutually beneficial to have them involved.

Land, Single Farm Payment and Retailers

From all the data we do have, we can see that most farmers would not survive without the combination of the CAP Single Farm Payment each year, land appreciation and in some cases retail premiums received by members of a retailer group that have a milk price based on the cost of production.

The reality facing this rather uncertain picture is that the single farm payment is likely to diminish if not disappear for most farmers, land is unlikely to continue appreciating at the same rate as interest rates rise, which will attract investment money away from land, and a weaker UK economy will also take its toll. Retailers are now pushing their suppliers very hard on all fronts and those who do not measure up are being dropped. The retail premium is therefore dropping as farmers improve, lowering the cost of production which the model follows, and it slowly spirals downwards and will end up being much nearer to the price everyone else receives.

Twenty-one percent of dairy farmers have a retail aligned contract and these farmers will at least be shielded from volatility, enabling them to plan and invest more easily. Volatility will be one of the biggest challenges to dairy farm businesses and the timing of major investment will be crucial.

There are few instruments available to a dairy farmer that allows him or her to manage volatility effectively. There is no properly functioning futures market and even in the USA there is not enough liquidity to make this work as effectively as it needs to. We do have a few companies offering future contracts in the UK now and some farmers have been using that mechanism. We have only seen them working on a rising market in recent months though and the real test comes now when the market is turning and farmers face selling their milk in future months for a lot less than they are getting this month.

It is very easy for all these mechanisms to work on a rising market as futures tend to rise ahead of the market offering good prices (which may not be quite as good by the time one arrives at that point) and the worst that can happen is that the farmer has sold for a little less than if he had not. On a falling market, the same is true and farmers are reluctant to sell for less in the first place, but the future prices tend to look worse than predictions and the natural instinct is not to sell. Few farmers have covered themselves by using future contracts for next spring.

Many other tools are being developed (and invented!) and I am sure we will see greater sophistication as time goes on. And if production falls due to hardship and volatility, I expect to see intervention by some processors to assist with this problem. However we believe that 80% of volatility management needs to be on the farm and the best way to manage volatility is to make sure the business is performing well and the money made when the milk price is high is not spent on shiny machinery (deferred rust) enabling the business to survive the troughs.

Brexit

We could argue that Brexit is the “kick up the backside” that British agriculture (dairy included) needs in order for it to do all the things that it should have been doing anyway. Sixty percent of farmers voted to leave the EU and whilst many were angry and lashing out at any easy target, others thought it could not possibly happen and registered a protest vote. Some farmers seriously wanted change and saw Brexit as taking back control and ridding ourselves of the suffocating EU bureaucracy and ever closer political union.

I am not going to comment further on this other than to say that this was not as simple as turkeys voting for Christmas, which has been the label many have attached to these farmers. I believe many of them would still vote to leave today. Where do we stand as a dairy industry in the UK and what does the future hold for us? What are the opportunities? How can we prosper? Can the UK actually increase its milk production as a nation? Can we compete?

The UK is the best country to produce milk in the EU bar none. That is a fact. We have the climate, the farm size, the farm structure, our very best farmers are as good as any in the world, they are not carrying huge debt and we have a fantastic domestic market that is undersupplied. No other country in the EU has more than two or three of those six points.

I will give two examples from the opposite ends of the spectrum. Ireland for example has also a good climate and very good farmers, but not much of a home market and the farm size and structure is poor. Denmark has the largest average dairy farm size (cow numbers) in the EU, but not the climate, and some environmental challenges and huge average farm borrowings. EU farms will of course benefit from the Single Market and CAP payments in the future which will tilt the balance once we leave the EU, assuming we will not have unfettered access to the single market (highly unlikely).

So we are in a good place to start and if we lift performance by either making a conscious step-change in performance or changing systems, we put ourselves in a competitive position to increase supply to our home market by displacing imports. We need to enhance our offer by lifting animal health and welfare and environmental credentials (already good) higher, but that alone will not be enough.

Productivity and Competitiveness

Productivity and competitiveness are therefore taken as a given and if that can be achieved we can begin to displace imports. Farmers will in the main look at added value and assume that displacing added value yoghurts and desserts, speciality cheeses and so on is the place to be. I do not disagree with that, but if we are really looking at products that use a lot of milk we need volume and that means commodity cheeses. Our market is the second largest net importer of dairy (after China) and we have good public support as farmers for our fresh milk and dairy products; what an opportunity!

Given that we have a deficit in dairy in the UK, a lack of added value products in our offer, we should be investing in world class processing to both displace added value and more importantly commodity. We have world class liquid milk processing but our manufacturing processing needs investment. We attract that investment by offering milk pools, which are competitively and sustainably produced. It’s chicken and egg; we lift our game which attracts investment, more demand for milk as we displace product and take more of our own market which has an effect on farm-gate price.

We do not export very much dairy from the UK but it should not be ignored. Just as specialist imports into our own markets will continue to satisfy consumers who look for that product (French cheese is a good example), so are consumers in other countries looking for something different, something they have had before or tried when on holiday. It is important that we compete on the International market too and of course the same rules apply.

Whether this is achieved by supplying a Public Limited Company (PLC) or through a Co-operative, it is important the farmer understands where he stands in the scheme of things. We do see more and more dairy farmers in the UK understanding markets and where they are in the supply chain. Shouting at processors and retailers has not made a difference. Calling for consumers to be ‘educated’ is often misplaced and raging against the world gets you nowhere.

Understanding where you are and becoming comfortable in that environment is important. A dairy farmer is the best definition of a ‘weak seller’ that I can think of – a producer of an undifferentiated perishable commodity in temporary oversupply. It’s important to get to grips with that and understand that the only thing that will raise the milk price is more demand. Competitive, sustainable pools of milk attract investment which increases demand, lifting prices.

We are looking at how we match young people and new entrants in the dairy industry with dairy farmers who are struggling, but have reasonable or good facilities, setting up share-farming or other contractual options, which result in a win-win. The young entrant gets to apply his or her skills, energy and ideas, making a future for themselves whilst the now retired farmer keeps the farm going profitably. We have examples of this already in the UK and the retired farmers say it has transformed their lives.

Again, a block calving system (spring or autumn) is cheaper to set up and operate for the new entrant, offering a simpler system with real lifestyle benefits. It can be difficult for some retired farmers to accept this change in the first instance, but a change from loss-making to a profit-making enterprise does help convince.

Entrepreneurs who expand and have more than one farm offer opportunities for young farmers and new entrants. We have many examples of these in the UK too and some have encouraged their best young people to enter into a share-farming partnership in order to assist them but also retain them in the business. Most of the current ones tend to be block spring calving operations in the west of the country, Wales in particular, and it is really good to see these young people running large herds.

■ Animal Health and Welfare

The dairy industry is faced with the challenge of animal health and welfare and consumer understanding and interest in this area. The market and its demands, and of course the pressure groups and NGO's, are a constant irritant and real threat in some respects. The best defense for the farmer of course is to make sure everything is right and proper attention from skilled stockmen over animal care is a given. Treat every day as if there are hidden cameras recording your every move is one approach, and whilst it sounds rather Orwellian, it does at least keep standards very high. Open your farm to the public on occasions, such as 'Open Farm Sunday', liaise with your local community, involve yourself with local schools, go and speak at local events or write a column for your local paper are many tips offered to dairy farmers in the UK.

We accept that one of the greatest challenges that the dairy industry faces is public acceptability of production systems and management practices. The main concerns of our customers and pressure groups are: large herds, all year round housed cows, separation of cow and calf, the fate of dairy bull calves and general well-being (mastitis, lameness, condition score and longevity).

The strategic vision is focused on 'tackling transparency' to help maintain consumers trust and reassure those in the food chain delivering dairy products to consumers. To achieve this vision, dairy farming must be responsible. A responsible dairy farming industry is one that acknowledges its weaknesses, pledges its duty of care to animals by driving for the highest standards of animal welfare, while respecting local communities and the need for good environmental stewardship.

Industry harmonisation and consensus on a range of welfare outcome measures has assisted with the successful roll-out and uptake of these. Since 2013, all major British insurers and retailers score welfare outcome measures during the farm assessment, which helps refocus the assessment onto the animals. In addition, a variety of industry activities promoting better engagement in lameness and improvement in foot health of British dairy cows is having a positive impact, resulting in a downturn in lameness levels. There continues to be year-on-year improvement in udder health performance, with an increasing percentage of British dairy cows receiving proactive mastitis control.

Despite these successes, there is still a way to go. Tackling the priority issues that need to be addressed (continuous housing, fate of bull calves and cow-calf separation) will require improved alignment between industry practices and societal values, based upon leadership from within the industry and sustained engagement with other interested participants, including retailers, processors, researchers, consumers and the general public.

To address and close the ‘transparency gap’ between the British dairy industry and consumers, a successful strategy requires significant advancement in leadership and developing an ambitious vision, and the delivery of that vision by direct actions. These include gathering evidence to report and track trends of welfare standards on continually housed dairy systems, better understanding of what is considered acceptable to consumers, building better engagement and empowering key stakeholders.

Higher Voluntary Standards

Currently, there is a push to label dairy products based on system of production; however, labelling welfare outcomes would be a more meaningful and sensible measure to enhance transparency.

Specialists often argue that the public’s concern and in some cases rejection of continuous housing and other management practices is a lack of understanding of science and that this knowledge deficit can be overcome by educating the public. Education is an unlikely solution to this scenario. Instead, we should consider viewing this as not just a risk management issue but as a potential source of competitive advantage which could be a central component in building the ‘proud of dairy’ brand. We can opt to take a proactive approach and create a higher voluntary standard for dairy farming.

This standard will not be specific about how the farm business should run, the system the cows are kept in or what the facilities look like, but instead focus on how healthy and content the dairy cattle are and how the farm observes its responsibility to the environment and the local community.

All metrics to be included in this standard will be based on a weight of scientific evidence with thresholds set to the highest level in the UK, and potentially in the world. The standard will be independently audited, with every cow examined, to ensure these farmers really are delivering on their commitment.

A progressive standard would need to:

- Measure welfare outcomes focusing on survivability (rate of no-economic value losses of cows and calves), disease (including use of antibiotics), mobility, comfort (e.g. injury and cleanliness), nutrition, behaviour and calf management (including bull calf policy).
- Measure environmental outcome focusing on carbon footprint, including soil improvement, biodiversity, energy neutrality and resource efficiency.
- Capture creative solutions and innovations on farm.

Better Understanding of Our Consumers

Whilst better understanding of what is considered acceptable to consumers is important we should not forget that Vegans make up a very small (1%) (The Vegan Society), but growing (x3 over past ten years-source: Kantar World-panel) proportion of the UK population. Although still small, the noisy but well-funded and well-organised vegan lobby represents a disproportionate share of the online and media conversations relating to the dairy industry.

Documentaries and films such as ‘Cowspiracy’ and ‘Carnage’ have entered the media debate and have fuelled greater interest in this area. However, in terms of impact on mainstream consumers those messages are not cutting through strongly. Of 7.2 million online conversations pertaining to Dairy, only 2.4% are related to dairy-free or veganism (Edelman report 2017). Additionally, interest in veganism doesn’t necessarily equate to a wholescale change in behaviour.

Ethical considerations currently play a minimal role in most consumers’ decision making process when purchasing dairy, much less so than for meat. Drivers such as price and quality are much more important at this point and amazingly consumers worry more over the question of ethics when buying juice than when buying milk!

However, we do know that younger consumers, in particular, are more open and receptive to these kinds of messages and 39% of younger consumers say they are cutting back on dairy. By contrast only 14% of older (55 plus) consumers say they are cutting back (Harris Interactive 2017). To address this it is important that we understand the real barriers and concerns that are emerging, particularly amongst younger consumers.

In general, most consumers (60%) feel that UK farmers do a good job looking after their dairy cattle. However, when prompted, 61% report some concern around housed systems, with a need for access to grazing reported as a specific concern. If welfare needs are met, only 23% would actively not purchase milk from cows that are housed for the majority of the year (AHDB

YouGov Consumer Tracker Aug 2017), which does finesse the picture somewhat.

There is a level of concern around housing and fully housed systems would be a concern for 61% of consumers, but for most not a barrier to purchase. Farm size is less of a concern and there is little sign that this is a growing trend. For most consumers issues around cattle housing are not currently on their radar until prompted. However, that does not preclude it becoming a problem in the future and there are currently some gaps in our knowledge in this area.

Further research to deepen our understanding of consumer attitudes towards these issues will be needed as follows:

1. Establish whether the importance of ethics as a purchase driver is growing for the dairy sector specifically and understand how specific ethical concerns, including housing, come through for consumers on a spontaneous basis.

2. Assess what the remaining knowledge gaps are in understanding specific consumer concerns. AHDB Dairy are currently funding a programme of work in this area.

Building Better Engagement

Communication alone is not the solution. A successful strategy must recognise operational practices and decisions have to be able to stand scrutiny of the ‘reasonableness’ test. Consumer and citizen expectation is that farmers and others in the supply chain will do the ‘right’ thing and in return the public freely give their trust. Consumer behaviour is influenced by many things, but emotion usually over-rules logic.

The dairy industry needs to continue to communicate proactively, in a creative way that is not perceived as defensive. Working with key stakeholders (e.g. DairyUK, Dairy Council, BCVA, retailers, processors and the unions in the UK) will assist with re-balancing the debates around dairy production systems and welfare – specifically to increase dialogue around public trust and build our reputation with influencers (e.g. government, journalists, dietitians, science writers and food bloggers).

Responsible Use of Antibiotics

Our other pressing issue in dairy farming, as it is in the whole of livestock farming across the world, is antimicrobial resistance in humans. This is a huge global threat, causing severe problems in human medicine, and shining a light on what we do in agriculture. There is no doubt that globally, agriculture is not in a good place, with 70% of medically important antibiotics used in animals (O'Neill, 2015).

The EU is leading the way here as it puts huge effort into solving this problem, led by Scandinavian countries which use the least, the north west of Europe using less than the south and east. As part of the north west of Europe, the UK has a good record here, but needs to do more in order to place itself in an even better position from an animal health and welfare perspective. Responsible use of antibiotics has a good story to tell when marketing dairy products both at home and abroad post Brexit.

I Chair the Responsible Use of Medicines in Agriculture Alliance (RUMA), which celebrated its 20th anniversary this year, showing that in UK agriculture we have been promoting responsible use of antibiotics (and all other medicines), well ahead of the recent interest in this subject by the general media, politicians and pressure groups.

Why are we under such pressure to reduce antibiotics in agriculture? Our history in this area does not help us. Throughout the 1950s and 60s, agriculture was transformed around the developed world as a combination of science and technology, breeding and genetics, medicine and veterinary input completely changed our industry. This was hailed at the time as the green revolution. Starvation in mainland Europe (following the Second World War) and food rationing in the UK (until 1954) were both solved by a huge increase in food production. Agriculture was seen as a technological marvel.

Governments across mainland Europe and the UK had a policy to drive modern agriculture to provide plentiful food of high quality. Then a cheap food policy followed, where the percentage of disposable income spent on food would fall. We are now into the consumer society, moneyed and fashion conscious teenagers, holidays and cars, household appliances and so on.

The UK joined the EU in the early seventies (called The Common Market in those days) and farmers benefitted from greater production subsidies and encouragement to continue developing the industry and provide even more food at even lower prices. The agricultural miracle was often used in the UK to compare the huge productivity gains achieved on farms with our car industry and other manufacturing sectors who struggled with poor management, trade union dominance and so on.

However, government policies are blunt instruments which are slow to react and as farmers increasingly reacted to government/EU policy (and not the market), developed more intensive systems, removed hedges and trees in order to improve productivity and increase efficiency, compromised animal welfare and used antibiotics and other substances to increase production in our livestock systems, there was a backlash.

It was a small minority to begin with, but it quickly grew and agriculture policy started to change, but it was far too late and severe reputational damage had been done. We now live with the aftermath and whilst our systems and approach to livestock farming has changed hugely, the environmental lobby and animal welfare lobby are very powerful and they want to see things change further.

As a result of that, politics and public pressure, not science, drive the agenda. We also see past practices which have been banned in the EU for many years, used against us as if they continue to this day. Global 'Anti-Microbial Resistance' figures and statistics, which are a huge concern, are talked about as if it is the same in the UK. This has led to a blame culture which permeates throughout our industry and is uncomfortable.

When antimicrobial resistance first became a big issue and the UK government decided to lead the world in its defeat, it was seen as a human medicine issue. Government's own strategy on the subject states '*Increasing scientific evidence suggests that the clinical issues with antimicrobial resistance that we face in human medicine are primarily the result of antibiotic use in people, rather than the use of antibiotic use in animals'*. However, agriculture has been blamed for this problem, largely driven from the human medical fraternity including the senior medics.

This has been a huge problem for us and we are only now making inroads to putting it right by hosting senior medics on farm and accepting invites to speak at human medicine conferences and universities across the UK. The problem was that medics had no idea of what veterinary practitioners did in agriculture and of course no understanding of agriculture itself. Given that their information was all provided by NGO's and pressure groups, it was no wonder that they acted as they did.

Having joined 'Antibiotic Guardian' and spoken at many events and universities, I have been able to inform at least some in the medical fraternity of what goes on in farming and the role of the farmer and veterinary surgeon as the primary link in the food chain. I have also been able to inform them that we have reacted positively to our government deciding to lead the world on antimicrobial resistance.

Having reached our overall government antibiotic use target of 50 mg/kg two years early, reducing antibiotic sales to farmers by 27% (the lowest since records began), and reducing critically important antibiotics (Colistin by a huge 83%), we are on the right road. Our critics are now struggling as we forge ahead in each sector to deliver the targets set by our RUMA Targets Task Force. This will continue to drive usage down, but in a way which safeguards welfare – the critical balance which must be maintained.

Poultry have led the way with a huge 71% reduction in use over the last 5 years and many lessons can be learnt in the way they achieved this, especially for the pig sector. Poultry is, of course, a fully integrated system, where there is whole-chain involvement and fewer very large players in the main. However, the risks taken in order to ‘test’ the traditional reliance on antibiotics, the attention to infrastructure (especially water quality), removal of in-feed antibiotics and eventual removal of some critical antibiotics should be a lesson to us all in how to approach radical change and improvement.

We hosted a large group of very impressive and knowledgeable senior medics, including the Chief Medical Officer, on a pig farm recently and they were very surprised by certain aspects of the operation. Agriculture is, in fact, ahead of human medicine in some respects and many of those medics now speak very differently about our industry. But there is more to do and I would encourage the veterinary profession to join us in talking about what we all do and how agriculture works.

In agriculture it is vital we protect and look after the antibiotics we have. Any new antibiotic development will not benefit us and, therefore, it is important we minimise use by highlighting responsible use in our sector. After all, healthy animals are more profitable and easier to look after and all farmers should be encouraged to look at how best to achieve high welfare.

There is a need to recognise that we do have a cohort of farmers in the UK who are unable to invest in better infrastructure which is vital in order for them to have the same opportunity to improve animal health and welfare, cutting their use of antibiotics. As we leave the EU and the new Agricultural Bill is being drawn up, there is a need for government to take some responsibility to enable these farmers to invest and raise their game, benefiting their animals and having the chance to reduce antibiotic use.

There is no shortage of challenges as we strive to compete and increase productivity, change and adapt some of our practices, improve health and welfare further, cut down on unnecessary antibiotic use and live by the ‘responsible use’ mantra. Interestingly, all these things are linked and will provide UK farmers with a better and more prosperous future.

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What Does the Re-vamp of the Canadian Food Guide Mean for Dairy?

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Take Home Messages

- Health Canada is currently developing the Healthy Eating Strategy (HES) which includes revamping the Canada's Food Guide (CFG) and front-of-pack (FOP) nutrition labelling.
- The new CFG will likely encourage more plant-based food consumption and FOP labelling will focus on reducing intakes of sugars, sodium and saturated fats.
- Dietary advice should emphasize whole foods and dietary patterns and move away from the current individual nutrient focus.
- It is expected that dairy will remain a part of dietary guidance in Canada.

The Healthy Eating Strategy (HES) and other food policy initiatives currently being developed by Health Canada and Agriculture and Agri-Food Canada may dramatically change food guidance in Canada. These initiatives, particularly the HES, are intended to improve the food environment and encourage our population to consume a healthier diet. While the HES may positively impact the quality of foods produced, processed and consumed in Canada, it also has the potential to affect the agri-food system, including dairy production and consumption.

The HES is made up of several initiatives, including revamping of Canada's Food Guide (CFG) and food labelling updates. Both of these policies have undergone public consultation and initial proposal stages, and plan to be finalized and implemented by 2021. The labelling changes have a strong focus on 'negative" nutrients (sugars, sodium and saturated fats) and the CFG consultations have endorsed encouraging Canadians to choose more plant and fewer animal based foods.

Milk and dairy products have been an integral contributor to the nourishment of populations around the world for over 7,500 years, and should continue to be (Itan, 2009). Dairy products contain many important nutrients that contribute to human health including high quality protein, vitamins and minerals. Dairy has an established positive role in human health, including reducing risk of chronic diseases (osteoporosis, heart disease, diabetes, stroke and obesity) and regulating body weight and blood glucose response. Yet its contribution of saturated fat, a “negative” nutrient, and environmental impact are frequently raised as reasons to reduce dairy consumption and to encourage plant-based alternatives. So where dairy will fit into the CFG is uncertain, but we predict it will be included. Health Canada has emphasized that food policies need to be evidence based. With that in mind, we expect that dairy will continue to be encouraged in a healthy dietary pattern, despite the HES emphasis on reducing animal based foods, sugars and saturated fat.

▪ The Healthy Eating Strategy

The Healthy Eating Strategy (HES), led by Health Canada, was prompted by Prime Minister Trudeau’s mandate letter to then Health Minister Dr. Jane Philpott in November 2015. In this published letter there was a call for action on several food and nutrition policies including restricting marketing of unhealthy foods and beverages to children, eliminating trans fat and reducing salt (sodium) in processed foods, and providing more information to consumers on added sugars. The prioritization of these issues was also influenced by advocacy groups and consumers. Health Canada has been working tirelessly since receiving these mandates and has developed the Healthy Eating Strategy, part of the larger vision for a healthy Canada, which includes Healthy Living and Healthy Mind initiatives.

The healthy eating strategy has five main policy initiatives:

1. **Revising Canada’s Food Guide (CFG)**
2. Restricting marketing of unhealthy foods and beverages to children, with a focus on foods high in sugars, sodium and saturated fats.
3. Strengthening food labelling through changes to the nutrition facts table and ingredients list (completed in 2016, enforced in 2021) and the introduction of **front-of-pack (FOP) nutrition labelling, focused on sugars, sodium and saturated fats.**
4. Banning <u>industrially produced</u> (excludes dairy) trans fat in foods (completed in 2017, enforced in fall 2018) and reducing sodium in packaged and restaurant foods.
5. Expansion of the Nutrition North Canada program, increasing access and availability of nutritious foods in isolated northern communities.

Revisions of Canada's Food Guide

Health Canada began the evidence review for dietary guidance in 2013, a cyclical process involving three main steps to examine evidence: (1) the scientific basis of the evidence including relationships between health and foods, (2) the Canadian context including characteristics of the Canadian population and eating behaviours, and (3) use of existing guidance. A report was published in 2016 (Health Canada, 2016a) from this evidence review highlighting several key relationships between food intake and health. The relationships with the strongest evidence included: sodium and risk of high blood pressure; trans fat and risk of cardiovascular disease; dietary patterns with high intake of vegetables, fruits, whole grains, seafood and low-fat dairy; patterns with low intake of red and processed meats, refined grains, sugar sweetened beverages (SSB), and foods with positive cardiovascular disease outcomes. Several diet-health relationships were identified as needing further evidence including replacing saturated fat with unsaturated fat to reduce cardiovascular disease and type 2 diabetes risk, red and processed meat intake and colorectal cancer, soy protein intake and lowering blood cholesterol, and added sugar intake (particularly SSB) and obesity and type 2 diabetes risk. Other findings from the review include challenges with consumer understanding of certain aspects of dietary guidance including food guide servings, and the current CFG format not meeting the needs of all audiences.

Health Canada conducted open consultation in fall of 2016 to collect information on the needs and expectations of stakeholders and Canadians for the new CFG. This was followed up with an online stakeholder discussion and focus groups in spring 2017. Guiding principles and recommendations for healthy eating were published in summer 2017 and a second open consultation was conducted to gather feedback on the proposed recommendations. The three guiding principles are:

1. A variety of nutritious foods and beverages are the foundation for healthy eating. This includes eating vegetables, fruit, whole grains and protein-rich foods (especially plant-based sources of protein), the inclusion of foods that contain mostly unsaturated fat instead of saturated fats, and regular intake of water.
2. Processed or prepared foods and beverages high in sodium, sugars or saturated fat undermine healthy eating. Limit intake of processed/prepared foods high in these nutrients and avoid processed/prepared beverages high in sugars.
3. Knowledge and skills are needed to navigate the complex food environment and support healthy eating. Select nutritious foods when shopping or eating out, plan and prepare healthy meals and snacks, and share meals with family and friends whenever possible.

The continued development of the CFG will occur in two phases. Phase 1 (2018) will be a report for health professionals and policy makers consisting of general eating recommendations and supporting key messages and resources. Phase 2 (2019) will be a report on healthy eating patterns, including the amounts and types of foods, and additional resources.

Front-of-Package (FOP) Nutrition Labelling

FOP nutrition labelling is information located on the front of packaged foods to provide consumers with simple, easily accessible information about the nutrients in the product. These can include simple summary grades or symbols (star rating, NuVal scores, healthy choices check, Nordic keyhole), nutrient specific systems (source of a nutrient, facts up front, ‘high in’ stop signs) or food group specific symbols (whole grain, fruits and vegetables). As part of the HES, Health Canada has proposed mandatory FOP labelling on packaged foods. A proposal was released by Health Canada in November 2016 followed by an open consultation and public opinion research. The proposed FOP system focuses exclusively on sugars, sodium and saturated fat, requiring a ‘high in’ symbol on packaged foods that exceed the proposed threshold for each nutrient. This threshold is set at 15% of the daily value (345 mg sodium, 3 g saturated fat and 15 g total sugar) per reference amount and serving size. As this policy will have significant impacts on the food landscape in Canada, Health Canada hosted a stakeholder meeting in September 2017 to review evidence and explore options for the FOP system. It is expected the next proposal and open consultation on FOP labelling will occur in early 2018.

▪ Dairy and Dietary Guidance in Canada

Policies stemming from the HES will be long lasting and could dramatically change the food landscape in Canada. Health Canada has established a rigorous roadmap for collecting and evaluating scientific evidence to support its policy decisions and has indicated a commitment to using the most recent and best available evidence throughout their HES platform. For dairy, this is good news. As highlighted briefly in the following, and reviewed extensively elsewhere (Thorning, 2016), dairy has an established positive impact on human health, particularly in reducing the risk of many chronic diseases targeted in the HES, including heart disease and diabetes. It would be inconsistent with the HES to eliminate dairy from the CFG or provide guidance to reduce dairy consumption.

Health Canada acknowledged the strong scientific support for low-fat dairy as part of a healthy dietary pattern (along with vegetables, fruit, whole grains and seafood, and reducing red and processed meat, refined grains and SSBs) to improve cardiovascular disease outcomes in their evidence review report in 2016 (Health Canada, 2016a). The guiding principles published in 2017 do not explicitly include dairy and seafood in the foundation for healthy eating (but do include vegetables, fruit and whole grains) and opted instead for 'protein-rich foods', with an emphasis on plant-based sources. It is expected that this recommendation to consume more plant based foods and reduce animal based foods will be included in the revamped CFG. This guidance is already reflected in the infographic 'Let's Eat Healthy Canada!' published in 2017 which promotes plant-based proteins, including legumes, nuts and seeds. One approach Health Canada may use for the new CFG is a 'protein' food group opposed to the current 'meat and alternatives' food group. This group could have subcategories and additional messaging on preferred protein sources that would span both plant and animal-based foods. An important consideration when promoting plant-based products is the potential for consumers to substitute plant-based milk beverages for dairy assuming they have equivalent nutritional value (see below fortification section). The evidence for equality is not convincing, and indeed, recent reports on the effect of consuming the plant based substitutes by children shows a dose-dependent negative effect on height (Morency, 2017). In this study, for every cup of non-cow milk consumed per day children were 0.4 cm shorter. Thus, the present evidence supports the continued inclusion of dairy as a healthy source of high quality protein, vitamins, minerals and fats, which is readily accessible, economical and sustainable compared to some other animal-based protein sources.

The proposal for mandatory FOP nutrition labeling on packaged food may have an impact on certain dairy products. As mentioned previously, milk and dairy products may contain added sugars (mainly sucrose), and are naturally relatively high in sodium and saturated fat. For some, these levels exceed the proposed nutrients thresholds and may require the FOP warning symbol on packaging. However, in the 2016 FOP proposal certain types of foods were exempt from the policy (Health Canada, 2016b). This exemption currently applies to foods consistent with Canadian dietary guidance (including 2% milk), foods always exempt from nutrition labeling (including dairy in refillable glass containers), and foods conditionally exempt from labeling (including those made and sold in retail settings, farmers markets and roadside stands). The exemption for 'foods consistent with Canadian dietary guidance' may be impacted by the concurrent revamping of the CFG. A webinar hosted by Health Canada in December 2016 indicated that these exemptions are still being fine-tuned and there would be consideration for other foods if met with supporting evidence. The table below highlights some dairy products and the requirement for FOP labelling based on the current policy proposal. Overall, it is expected that many dairy products will be impacted by FOP labelling despite their many health benefits.

Product	FOP for Sugars	FOP for Saturated Fat	FOP for Sodium
Unsweetened Skim Milk (250ml)	No (13.4 g)	No (1.6 g)	No (113 mg)
Unsweetened 2% Milk (250ml)	No (13.05 g)	EXEMPT (3.2 g)	No (121 mg)
Whole Milk (250ml)	No (13.02 g)	**Yes (4.8 g)**	No (111 mg)
1% Chocolate Milk (250ml)	**Yes (26 g)**	No (1.6 g)	No (161 mg)
Fruit Flavoured Yogurt (175 g)	**Yes (24.2 g)**	**Yes (3.5 g)**	No (93 mg)
Plain Yogurt (175 g)	No (6.4 g)	No (2.4 g)	No (74 mg)
Plain Greek Yogurt (175 g)	No (6 g)	No (2 g)	No (90 mg)
Low-fat Cheddar Cheese (30 g)	No (0.1 g)	**Yes (3.8 g)**	No (239 mg)
Full-fat Cheddar Cheese (30 g)	No (0.1 g)	**Yes (6.4 g)**	No (212 mg)
Low-fat Ice Cream (125 ml)	No (14.5 g)	No (1 g)	No (54 mg)
Full-fat Ice Cream (125 ml)	**Yes (17.7 g)**	**Yes (4.7 g)**	No (53 mg)

* Nutrient values obtained from Canadian Nutrient File (Government of Canada, 2016)

The Silver Lining

While some elements of the HES may be concerning for dairy, namely the focus on reducing sugars, saturated fats and animal-based protein sources, we believe dairy will continue to be recommended as part of a healthy diet. There is strong evidence linking dairy to reduced chronic disease risk and improved disease outcomes which cannot be dismissed. Health Canada has already recognized this by proposing an exemption of low-fat dairy from mandatory FOP labelling. Additionally Health Canada's Director General of Nutrition Policy and Promotion, the office responsible for the CFG revisions, indicated that dairy would continue to be included in the new CFG (iPOLITICS, 2018).

As mentioned, Heath Canada has committed to using science-based evidence in decision making. In the following, we review briefly the evidence that must be considered.

▪ Impact of Dairy Consumption on Health

Dairy foods and beverages are a diverse group of products that have been consumed by humans as part of a healthy diet for many years. From birth humans rely on dairy in the form of breast milk or infant formula as the sole source of nourishment. After weening, dairy continues to play an important role in providing calories and important macro and micronutrients needed for development throughout life stages. The importance of dairy in our diets throughout history is no surprise when its composition and nutritional profile is examined.

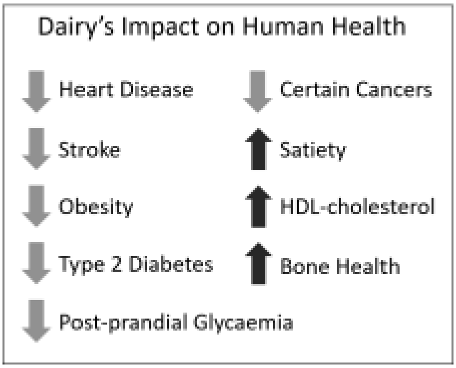
Composition of Dairy

The role of dairy in providing essential nutrients has been the basis for its inclusion in the CFG since its inception. Overall dairy products are an important source of minerals (calcium, phosphorous, potassium, magnesium, zinc, and selenium), water-soluble vitamins (B-complex and C) and fat-soluble vitamins (A, D, E), high quality proteins (casein and whey), and a unique mixture of fatty acids. Dairy products also contain nutrients that are currently considered a potential detriment to health, including added sugars, sodium, and saturated fats. Although dairy is a source of trans fat, it is chemically different than industrially produced trans fats and associated with health benefits. In addition to the essential vitamins and minerals in dairy, the unique protein and fat make-up of milk may infer additional human health benefits. The casein and whey proteins found in milk not only provide essential amino acids but also have functional properties that regulate physiological functions. The proteins and bioactive peptides (BAP) and amino acids released from them have a variety of positive physiological effects (Anderson, 2011; Haque, 2008). BAPs are also found in milk fat in the form of conjugated linoleic acids (Molkentin, 2000). The atypical fatty acid profile of dairy (short- and medium-chain monounsaturated and branch-chain fatty acids, palmitic, stearic, monounsaturated oleic, pentadecanoic and heptadecanoic acids) also infer positive physiological responses, including increasing 'good cholesterol' (high density lipoprotein, HDL) and reducing risk of type 2 diabetes and insulin resistance (Mozaffarian, 2010).

Dairy and Chronic Disease

Research in the past 20 years has led to an appreciation of its value in the prevention and management of chronic disease, as well as providing essential nutrients (Thorning, 2016). Canadians are currently battling high rates of obesity, type 2 diabetes, heart disease, stroke and cancers. Our diets play an important role in our health, and changes in our food intake patterns can be a first line of defence and treatment to reduce risk and combat many of these diseases. Dairy has potential to play a greater role.

The graphic below briefly outlines the impact of dairy consumption on a variety of diseases.



Dairy's Role in Weight and Blood Glucose Management

Consumption of dairy, particularly high-fat dairy, is linked to a lower risk of overweight and obesity (Rautiainen, 2016; Stonehouse, 2016). Weight loss diets that included dairy products resulted in greater weight loss and reduction in waist circumference while also retaining a greater amount of lean body weight compared to weight loss diets without dairy (Abargouei, 2012). This may be a by-product of dairy protein and fat stimulating a decrease in appetite, thus assisting individuals to adhere to weight loss program. Milk and dairy products (yogurts and cheeses) are known to supress appetite and reduce food intake in subsequent meals (Akhavan, 2010; Anderson, 2011). The proteins they contain stimulate an appetite suppressing mechanism during and following consumption, while fat has a sustaining effect post consumption. Dairy also has a beneficial effect on blood glucose metabolism, reducing blood glucose 'spikes' following meals (termed post prandial glycaemia - PPG) (Akhavan, 2010; Anderson, 2011). The sugar dairy contains is lactose which is low glycemic, with an impact on blood glucose that is about 50% of the equivalent amount of carbohydrates from bread. In addition, the milk protein casein slows stomach emptying and the release of lactose to the small intestine for digestion. The PPG and satiety response to whole-milk is lower than that predicted by the sum of effects of its individual macronutrient components (expected PPG when adding up the individual components of milk), emphasizing the importance of milk structure and matrix (Panahi, 2014). Thus, dairy components provide signals in the body at different times, so instead of amplifying each other, they interact with one another to provide a steady response controlled over time. Dietary guidance and food policy must consider the physiological effects of whole foods and meals beyond providing essential nutrients.

Fortification of Milk and Milk Substitutes

In Canada there is a mandatory nutrient fortification program that aims to combat nutrient deficiencies in the population by adding vitamins and minerals commonly under-consumed by Canadians to staple foods. When implementing this policy Health Canada recognized the importance of milk in the diet of Canadians and chose it as a vehicle for vitamin D fortification. This policy however does not mandatorily extend to plant-based dairy alternatives such as soy and almond milk beverages. These milk alternatives may opt to fortify, in which case they are labelled 'fortified' or 'enriched'. Consumers are often unaware of the differences in both inherent nutrients and the fortified nutrients in milk and milk substitutes, and may inadvertently be missing out on much needed vitamins, minerals and protein. Studies have now begun to show children fed plant based milk substitutes are often developing severe nutritional deficiencies, including protein-calorie malnutrition, iron-deficiency anemia, nutritional rickets (low vitamin D), hyponatremia (low sodium) and hypocalcemia (low calcium) (Le Louer, 2014). Currently, fortified soy beverage is the only recognized milk alternative in the CFG, and has the most comparable quantity of protein to milk (Eat Right Ontario, 2017; Thorning, 2016). However, as noted earlier, dietary guidance on dairy substitutes as replacements for dairy will need to consider recent evidence that may not be suitable in the diets of children.

▪ Summary

Final HES policy decisions must consider all scientific evidence, and other factors, such as economic impacts and consumer understanding. These policies should be made with a whole-of-government approach, coordinated with other ministries and groups whose jurisdiction the HES will impact – the most important for food and nutrition policy being Agriculture and Agri-Food Canada (AAFC). The policies should also aim to use the most relevant and recent Canadian data. The Canadian Community Health Survey, which provides dietary intake data integral for building nutrition and food policy was conducted in 2015. The data from that study however has not been fully assessed and published, meaning Health Canada is currently forced to rely on outdated data from 2004. As the new data will be analyzed and published in the near future, Health Canada has indicated they will wait for the release of these data to complete HES work relating to healthy eating patterns.

Our diets are only as healthy as our food supply. Health Canada and AAFC need to work together to establish nutrition and food policy that is cohesive and complementary. While there has been separation of these two groups for many years, the mandate letter given to the new Health Minister in October 2017 indicated a positive change on the horizon. In this letter there was a call for greater collaboration between Health Canada and AAFC, alignment of the HES with AAFC's food policy, and for these policy initiatives to be based on high-quality scientific evidence. Our outlook is positive. By HES and AAFC working together, the outcome is more likely to be balanced and evidence-based. One opportunity to explore is the idea of a 'Canadian Diet' which would integrate dietary guidance and our Canadian food system, including our strong dairy sector.

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Managing Dairy Cows with Less Antibiotics!

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Take Home Messages

- The prudent use of antimicrobials is of great importance for human and veterinary medicine (One Health).
- Losing the efficacy of antibiotics means no chemotherapy, no neonatal care and no surgery anymore.
- Following treatment protocols reduces the misuse of antimicrobials.
- Suboptimal hygiene and management is often compensated by extensive use of antimicrobials.
- Time consuming management improvement will be paid back by better herd performance.
- The most important step in preventing antimicrobial resistance is avoiding the use of the critical important antimicrobials (CIA's).

Antimicrobial Resistance

Antimicrobial resistance (AMR) happens when microorganisms (such as bacteria and parasites) change when they are exposed to antimicrobial drugs (such as antibiotics and anthelmintics). Microorganisms that develop antimicrobial resistance are sometimes referred to as "superbugs". As a result, the medicines become ineffective and infections persist in the body. Some bacteria are naturally resistant to certain types of antibiotics. For example, bacteria that have an outer membrane that is impermeable to antibiotics will never be reached by the antibiotic and are therefore resistant. But bacteria may also become resistant. This acquired resistance occurs when a previously susceptible bacterium becomes resistant through mutation or acquisition of new DNA. Several mechanisms of resistance have been described. Some bacteria contain enzymes that de-activate antibiotics.

Bacteria can be resistant to one antibiotic, or to two, or to almost all the available antibiotics. Multi-resistant bacteria are resistant to almost all the available bacteria. It should be clear that it is not the animal or human that are resistant, rather the bacteria in animals or humans

What Factors Effect the Development of AMR?

The extensive and often unnecessary use of antibiotics may induce AMR. Overuse of antibiotics and incorrect prescribing practices are significant problems. Antimicrobials are designed to either limit or prevent the growth of microbes and in so doing create a selective pressure upon microbial communities. Under antimicrobial treatment, only those microbes able to survive and reproduce will predominate within the microbial community, causing their “advantage” to become common. More aggressive and persistent use of antibiotics increases the selective pressure on the microbial community to which they are applied. The widespread and intense application of antibiotics provides a strong and polarized selective pressure that will continue to provoke a strong adaptive response in the microbial world.

Daily routine treatments do not always follow the labels anymore. Sometimes, therapies find their way based on recommendations of farmers or experts who are visiting farms. Another example of overuse is treating a disease with antibiotics that is not caused by bacteria. Viruses are not killed by antibiotics and nutritional diarrhoea in pre-weaned calves does not respond to antibiotic treatment.

What are the Consequences of Antimicrobial Resistance?

The consequences of AMR are that some bacteria will not react to antibiotics. Resistant bacterial infections decrease therapeutic options, increase the costs of health care and can contribute to increased morbidity. If the efficacy of antibiotics decreases many therapeutic options will be lost, such as chemotherapy, surgery and neonatal care. Resistant bacteria can spread from animal to animal, from human to human, but also from human to animal and vice versa. The biggest threat is the spread of multi-resistant bacteria over the world.

▪ Prudent use of Antibiotics

Antibiotics should always be used and managed in relation to animal health and public health. Although the link between the use of antibiotics in animals and the development of antimicrobial resistance in humans is complex and not yet well understood, all veterinarians must promote the most prudent use possible of antibiotics. Producers are worried about bans and restrictions that have been imposed, their impact on the health and welfare of their animals as well as economic impacts on their businesses. In fact, the restrictions and precautions that are requested with regard to the use of antibiotics have more to do with the knowledge and respect of the categories of importance in human medicine for antibiotics. The veterinarian must make a decision based on a rigorous decision process, which is supported by current scientific knowledge and awareness of potential consequences (including the development of resistant strains).

▪ What Happened in the Netherlands?

During the past decade the use of antibiotics in food-producing animals has been a frequently discussed topic in the Netherlands. Differences in the total number of antibiotics between human medicine and veterinary medicine led to intense discussions. Development of AMR resulting from agricultural use of antimicrobials that could impact the treatment of human diseases has become a global public health concern. In 2006 the use of antibiotics in human medicine in the Netherlands was almost the lowest compared with other European countries, whereas the antibiotic use in veterinary medicine was highest in the Netherlands compared to surrounding European countries. This discussion resulted in the formation of a Task Force on Antibiotic Resistance in Food Producing Animals in 2008. Representatives from all parties within the food-production chain (farmer organisations, meat processing industries, feed suppliers), the Royal Dutch Veterinary Association (KNMvD) and the Government were represented in the Task Force. Within each animal production sector (cattle, veal, poultry and pigs) action plans were developed. The main goal of the Task Force was to get more insight into the use of antimicrobials and to focus on a more prudent and restrictive use of antimicrobials. The Minister of Agriculture stated in 2010 that the total use of antibiotics in food-producing animals should be reduced by 20% in 2011, by 50% in 2013 and by 70% in 2015. These reductions are relative to total antibiotic use in 2009.

To get more insight and transparency in the quantitative and qualitative use of antibiotics a study was conducted in the University Farm Animal Practice (ULP) in the Netherlands. In this veterinary practice the use of antibiotics was calculated based on the information of the practice management system (PMS). After the so-called baseline measurement of 2009 and 2010, strategies were undertaken to make farmers and vets more aware of prudent antibiotic use and explain to farmers the public health concerns around antimicrobial resistance.

How to Reduce if We Don't Know What We Use?

The collection and analysis of veterinary use data was not very standardized. Most European countries reported data based on sales figures of the pharmaceutical industry or prescriptions by veterinarians. In some countries a specific veterinary antimicrobial use monitoring program was developed, like in the Netherlands and Belgium (Catry et al., 2007; MARAN, accessed February 2011).

It is necessary to express the amount of sold or prescribed antibiotics relative to the number of treatments such that antibiotic use is related to a relevant denominator. This allows for correct interpretation and fair international comparisons of antimicrobial usage data. In human medicine, antimicrobial usage is expressed in defined daily doses (DDD) per 1000 inhabitants for general practitioner prescription and per 100 hospital bed-days for hospitals.

The DDD provide a fixed unit of measurement independent of price and dosage form (e.g. tablet strength) enabling the researcher to assess trends in drug consumption and to perform comparisons between population groups. For veterinary antimicrobial consumption evaluation, therefore, it is essential to calculate Defined Daily Dose Animal per year (DDDA/Y) for each antimicrobial pharmaceutical compound per animal species (Jensen et al., 2004). Drugs are classified in groups at five different levels. This classification, combined with administration route for systemic drugs, enables characterization of prescriptions at a therapeutic group level and at an administration route level, e.g. intra-mammary (drying-off and mastitis), intra uterine, oral and per injection (parenteral).

In the Netherlands the use of antibiotics is reported as Defined Daily Doses per Animal Year (DDDA/Y). This should be interpreted as follows: if the DDDA/Y of a herd is 5.3 it means that on average each cow of the herd has been exposed for 5.3 days per year to antibiotics.

Use of Antibiotics in Dairy Cows

The University Farm Animal Practice is a veterinary practice in the centre of the Netherlands. In this practice students from the Veterinary Faculty follow their ambulatory. The practice consists of 400 dairy herds, representing approximately 28,000 adult cows. Average herd size in 2010 was 71 cows (min = 18, max = 320). Antibiotic use was calculated over three years: 2009, 2010 and 2011. The mean antibiotic use per herd was 4.3, 4.3 and 4.2 Defined Daily Dose Animal/Year, for 2009, 2010 and 2011, respectively. Figure 1 shows the frequency distribution of all herds.

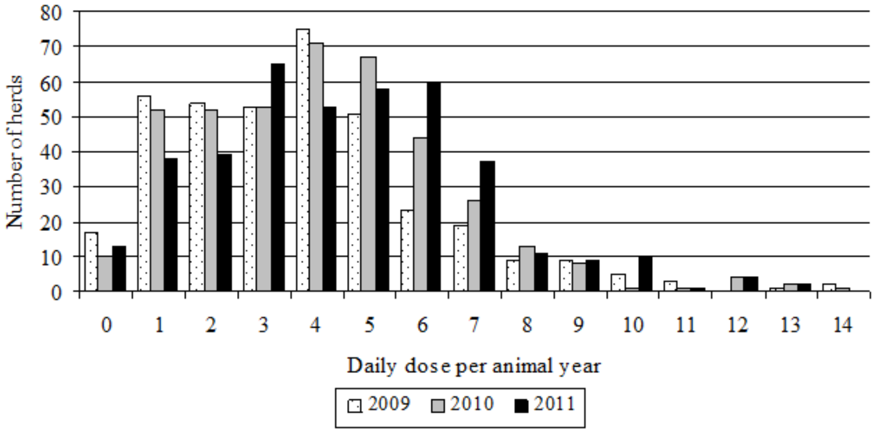
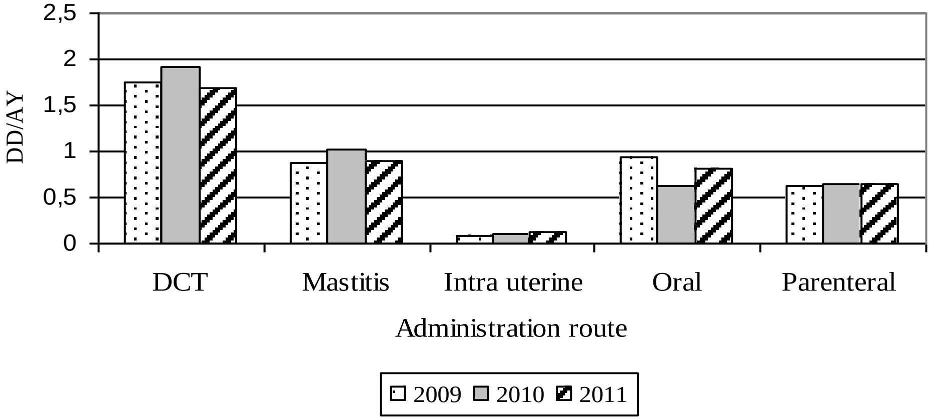


Figure 1. Frequency distribution of antibiotic use in 400 herds expressed as Defined Daily Dose per Animal Year (DDDA/Y), over three consecutive years.

The next step was to divide the total antibiotic use over the different routes of administration. Figure 2 shows the distribution of the five routes of administration. Distribution showed a stable pattern over the three consecutive years. Antimicrobial dry cow treatment (DCT) varied between 1.5 and 2 DDDA/Y followed by approximately 1 DDDA/Y of antibiotics for the treatment of sub-clinical and clinical mastitis. Expressed as a percentage, more than 60% of antibiotic use in dairy cows was for intra- mammary treatment. Included in the 60%, more than 40% was for antimicrobial dry cow treatment and another 22% for treatment of sub-clinical and clinical mastitis. On top of that, about 5% of the parentally used antibiotics were for mastitis treatment. Thus, about 70% of the total antibiotic use is related to the control or treatment of mastitis.

Oral use of antibiotics accounts for 20% of the total use. A substantial part of the antibiotics are fed to unweaned calves to treat diarrhoea. This vulnerable group of animals is already exposed to antibiotics in the first two months of life. Parentally used antibiotics were stable over the years and accounted for 10%-12% of the total use.



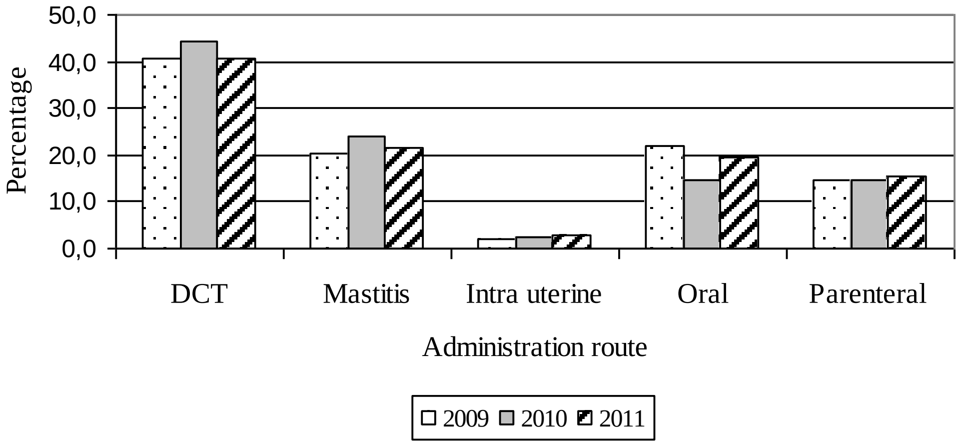


Figure 2. Distribution of the routes of administration expressed as Defined Daily Dose per animal year (DDDA/Y) (upper figure) and as percentage of the total use (lower figure) for the years 2009, 2010 and 2011 calculated for 400 herds. (DCT= dry cow treatment)

How was the Antibiotic Reduction Realized?

Creating Awareness

The first step in reducing the use of antibiotics was creating awareness in both farmers and veterinarians on the prudent use of antibiotics. Since 2010 the University Farm Animal Practice invested a lot of energy into informing and training farmers about the prudent use of antibiotics. Written information was provided, and meetings and study clubs were organized. Farmers and vets expressed anxiety that a reduction of antibiotics would negatively affect animal health and animal welfare. They were afraid that delayed or non-treatment would lead to deteriorating consequences for animal productivity and the economic performance of their farms. It was explained that diseased animals should always be treated as deserved, but treatment should be done in a responsible way!

Optimisation of Management

The second step in reducing antibiotic use was the optimisation of management, housing and nutrition. Keeping cows healthy is the best way to reduce antibiotic use, because healthy cows don't need to be treated. Keeping cows healthy requires a daily challenge of finding the right balance between immune status of the cow and infection pressure from the environment. Incidence of infectious diseases at the farm level can be minimized through strict biosecurity measures and eradication of infectious diseases such as Bovine Viral Diarrhea (BVD). Spending a lot of antibiotics to treat cases of clinical mastitis without knowing the BVD status of the herd is a waste of antibiotics. BVD is a disease that lowers the immune status of the dairy cow in a substantial way and therefore a BVD free herd is the first step to a healthier herd.

Avoiding Misuse and Overuse of Antibiotics

In the first years, the biggest steps towards reduction were made by verifying the current treatment rules on each farm. It seemed that many farms had developed treatment procedures that were not in accordance with the label use and proper treatment rules. Therefore, written treatment protocols were provided and explained. Protocols that described the choice of antibiotic treatment, dose, dose interval and withdrawal time were developed for all diseases of dairy cows. At the beginning of 2010 most farmers did not know about the existence of different classes of antibiotics and had no idea which antibiotics belonged to the critically important antibiotics (CIA), such as 3rd or 4^{rth} generation cephalosporins or fluoro-quinolons. After all the oral and written information sessions, use of these antibiotic groups was reduced by 46% in less than two years!

Therapeutic or Prophylactic Use?

Antimicrobial drugs are used on dairy farms as therapeutics and prophylactics. Therapeutic usage is intended to treat bacterial infections associated with diseases such a pneumonia, metritis and mastitis (Schwarz et al., 2012). The use of prophylactic antibiotics is for treating healthy animals to prevent a disease during periods of increased susceptibility. Antibiotics may also be used for therapeutic and preventive use, such as in dry cow treatment. In 2012 a ban on the preventive use of antimicrobials in Dutch livestock was implemented.

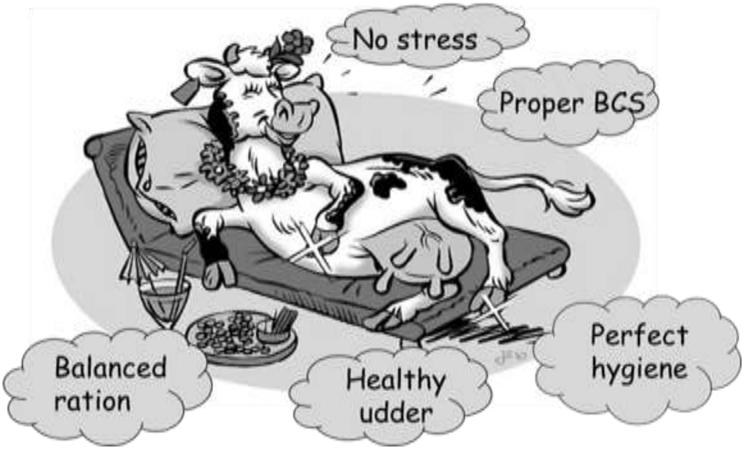
Forced to Selective Dry Cow Treatment

The ban on preventive antibiotic use meant that one significant antimicrobial dry cow treatment, prevention of new infections in the dry period, was not allowed anymore. Labels of dry cow tubes were adjusted and the claim of prevention of new intra-mammary infections during the dry period was omitted. As a result, Dutch dairy farmers were forced to use Selective Dry Cow Treatment (SDCT) rather than Blanket Dry Cow Treatment (BDCT). In January 2014, the Royal Dutch Veterinary Association provided a guideline, ‘The use of antimicrobials at dry-off in dairy cattle’, to support veterinarians in advising dairy farmers in the practice of SDCT (KNMvD, 2014).

The somatic cell count (SCC) thresholds to select cows for SDCT were based on a simulation study by Scherpenzeel et al. (2106) and were assumed to result in an optimal tradeoff between reduced antimicrobial usage associated with udder health versus increased risk of new intra-mammary infection (IMI). It was decided that multiparous cow with a cow SCC > 50,000 cell/ml and first calf heifers with a SCC > 150,000 cells/ml were allowed to dry off with antimicrobials. The interval between last milk recording and drying off should not be longer than 6 weeks.

Legitimate concerns have been raised by farmers and veterinarians about the potential increase in both clinical and subclinical mastitis associated with SDCT and its consequential impact on animal welfare and production. Efficacy of dry DCT was not an issue because protection of BDCT against new IMI in the dry period is in general better than SDCT (Halasa et al., 2009). The challenge was to improve dry cow and transition management in order to minimize the risk of new IMI during the dry period. It was explained to producers that the protection of a dry cow tube should be replaced by improved management. To appeal to the imagination of producers we provided the following cartoon and explained to them that they should treat their dry cows like a princess.

"Treat your dry cow as a Princess"



■ Situation in the Netherlands in 2017

Figure 3 shows the usage of antimicrobials by Dutch dairy herds over the last 6 years. After an initial decrease of 35% from 2009 – 2012, total usage of antimicrobials decreased from 2.9 DDDA/Y in 2012 to 2.09 DDDA/Y in 2017, which was a another decrease of 28%. Decrease in total antimicrobial use resulted from a decrease in intra-mammary antimicrobials for mastitis and by a decrease in intra-mammary antimicrobials for DCT.

Table 1 provides an overview of the antibiotic reduction during the last six years in the Netherlands. Decreased use of antimicrobial DCT started in 2013 and continued in 2014. A kind of steady state was reached by 2016 and 2017. From 2012 through 2017, usage of antimicrobials for DCT decreased by 50%. Usage of antimicrobials for mastitis also showed a decrease of 40% from 2012 until 2017. Use of antimicrobials for intra-mammary treatment decreased from 69% to 65% in 2017 and antimicrobials for DCT accounted for only 44% of the total use of intra-mammary antimicrobials.

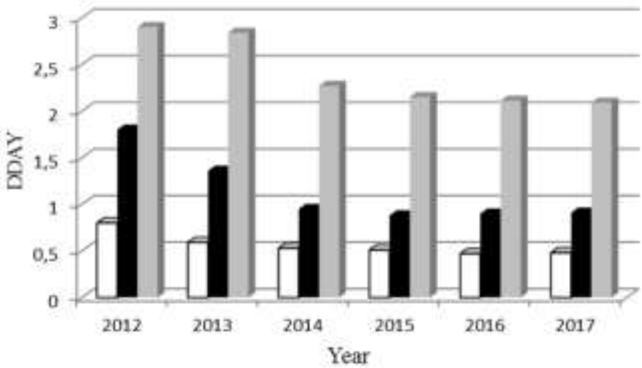


Figure 3. Dutch average of total use of antimicrobials (grey bars), intra-mammary dry cow tubes (black bars) and intra-mammary mastitis tubes (white bars) in defined daily dose per animal year (DDDA/Y) (n = approximately 18,000 dairy herds).

Table 1. Total use of antimicrobials and the intra-mammary (IMM) use of antimicrobials as Defined Daily Dose Animal Year (DDDA/Y) from 2012 through 2017 in all Dutch dairy herds (n = approximately 18,000 herds).

	Year					
Variable	2012	2013	2014	2015	2016	2017
Total use of AB (DDDA/Y)	2.90	2.84	2.27	2.15	2.11	2.09
IMM AB Mastitis (DDDA/Y)	0.8	0.59	0.53	0.51	0.47	0.48
IMM AB DCT (DDDA/Y)	1.8	1.36	0.95	0.88	0.90	0.91
IMM (mastitis + DCT) % of total	69%	70%	64%	63%	66%	65%
IMM DCT % of total IMM use	62%	48%	42%	41%	43%	44%

▪ Conclusion

Reduction in antibiotics was achieved in a relatively short period of time. This successful Dutch approach was enabled by several factors at the right time. The target that had been set by the government, a reduction of 50% in 4 years, helped to focus the initiative. The private sector, including the dairy industry, was motivated which forced farmers and vets to move quickly in the right direction.

The Dutch approach shows that reduction of antibiotics is possible without negative effects on animal welfare, but this requires improvement in management, nutrition and housing.

The forced transition from mainly BDCT to SDCT in the Netherlands resulted in a reduction in the number of intra-mammary antimicrobials used in dairy herds without having a deleterious effect on udder health during the dry period. Those big steps would probably not have been made if SDCT was promoted in a voluntary way. Awareness of the importance of improved management, nutrition and hygiene during transition to the dry period was critical. These management adaptations are not only beneficial for udder health but also improve total performance of the fresh cow, including reproductive performance, claw health, metabolic performance and milk production. Overall, the input of extra labor to improve management is paid back by lower antibiotic costs and better herd performance.

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A Requirement for Dairy Farm Success: Hiring and Retaining an Excellent Workforce

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■ Take Home Messages

- Farmers need to become preferred employers by offering a great place to work and by communicating that excellence to potential applicants.
- Research has dramatically enhanced our understanding that motivated employees possess the psychological feelings of autonomy, relatedness, and competence.
- Clarity in mission, vision, and values is crucial to decision-making, engagement, and motivation of owners and employees.
- Consistent use of active listening can dramatically improve communication, performance, and relatedness.
- Measurement in the form of performance expectations increases clarity, focus, performance, engagement, and autonomy.
- It is crucial, especially for correcting inadequate performance and unacceptable behavior, to provide three – not two – types of high quality, appropriate feedback. The three are positive, redirection, and negative.

■ Becoming a Great Employer

Let's start with a little detour. I am certain some of you had a challenging crop season last year. All of you have had those years at some point. Those years are frustrating. It, however, makes you feel a little better when your crops are the best in the neighborhood.

I expect you are thinking: "How can that possibly apply to our workforce." Look at it this way. Unfortunately, agriculture does not have a good reputation as an employer, i.e. poor crops. Like you wanted to have the best crops, you can become the best employer. We refer to that as a preferred employer – the place where good, qualified candidates want to work.

A farm or other business becomes a preferred employer in two ways. First, the farm or business must be a great place to work, it must have a clearly articulated meaningful vision, a positive business culture, excellent supervision with clear expectations and large quantities of great feedback, opportunities for increased responsibilities and personal growth, and competitive compensation. Second, the farm or other business must communicate that excellence to potential employees through networking in the community and with potential labor pools, and through professional recruitment and selection processes.

This paper focuses on enabling your farm to be a great employer or at least a better place to work. Before proceeding, let me encourage you to improve your recruitment and selection and promote your farm to the community and potential applicants. You do not need an HR department to write professional recruitment materials and develop an effective, consistent interview process. It will, however, require priority setting and take time. Two key points in promoting your farm: a) recruitment is marketing, and b) a large and increasing proportion of hires are reached through networking. Certainly, it is important to include positive attributes in your recruitment materials – marketing. It can also be beneficial to “network” with potential candidates. Perhaps you can assist your local FFA or participate in a job fair.

In this paper, we focus on five points to improve your leadership and supervising, leading to employees with higher productivity and greater job satisfaction.

- Understand employee motivation.
- Provide great clarity about WHY the farm exists, farm policies, and performance expectations.
- Active listening.
- Measurement – performance expectations.
- Use high quality, appropriate feedback.

Understand Employee Motivation

We start our motivation discussion by redefining farm success. First, let’s think about individual success. Success certainly requires us to be smart, meaning skilled in our career and making excellent decisions. To succeed, however, we must also be healthy. An athlete cannot excel if he or she is injured. An owner of a farm or any other business is greatly limited if hindered by poor health. An employee is challenged to succeed or even retain a job if he or she has health issues requiring more than the allotted sick days.

“Smart” and “healthy” have somewhat different meanings for farms or other organization; however, they are both required for a farm or other business to succeed today and tomorrow. Lencioni (2012) recognizes that the fundamentals of business – decision-making, operations (production), strategy, marketing, finance, etc. – are critical. He refers to these as “smart.” Most businesses, including farms, focus almost exclusively on being smart.

To optimize their success, Lencioni articulates that all businesses, farms and agribusinesses included, must also be healthy. A healthy organization is one with high productivity, low turnover among great employees, high morale and job satisfaction, minimal confusion, and minimal politics (often referred to as “drama”). Lencioni’s experience is that almost all business leader/owners recognize the importance of having a healthy business; however, most continue to focus almost exclusively on creating a smart business.

Leading a farm business that is successful in the smart part of our definition of success requires great knowledge of crop and dairy production, the farm business environment, and financial analysis. Leading the same farm business in the healthy part of the success definition requires an understanding of human behavior and motivation.

We begin our focus on human behavior with an analogy. When I was a kid, our cows were on pasture much of the year. When it was milking time, we would go and “get” the cows. Today we use our understanding of animal biology, animal behavior, and nutrition so we no longer “get” the cows. In fact, in the box-type robotic parlors we use today the cows enter to be milked on their own.

Employees, and thus management, first appeared in the industrial revolution less than 200 years ago. At that time, the first management guru, Frederick Taylor, argued that employees were just one more input into production. The obvious implication of this argument was to “get” employees to perform.

We have progressed beyond thinking that employees are only an input into production. However, most of our employee management is still based on carrots (rewards) and sticks (threats/punishments), which is an outgrowth of Taylor’s thinking.

Recent research in psychology, neuropsychology, and psychoneuroimmunology enables us to better understand the workings of our brain {see especially Fowler (2014) and Ward and Robinson (2015)}. This understanding dictates that we move beyond “getting” employees to be productive and happy. We, the owners and leaders, must create a healthy environment where employees excel more from self-motivation and less from carrot and sticks.

Creating an environment where more employee motivation is self-motivation will require thinking differently about our employees. Further, we must view this transformation as a journey that will take time with intermediate and long-term rewards.

A healthy farm has a workforce that has superior productivity and extraordinary job satisfaction, along with a passion for the farm and a desire to thrive and excel. How can that be achieved? Research on human behavior (psychology) and brain function (neuropsychology) sheds great light on the answer to this question. The answer is surprisingly simple, but challenging to implement. As with many animal and crop research results, the answer forces us to abandon generally accepted ways of thinking.

We now know that the answer to this question is that people are productive, engaged, and passionate when their psychological needs for autonomy, relatedness, and competence are fulfilled. Below, each is described with suggestions to implement with farm employees.

Fowler (2014) describes autonomy as "[o]ur human need to perceive we have choices. It is our need to feel that what we are doing is of our own volition. It is our perception that we are the source of our own actions." Autonomy is increased when workforce members believe they are in control of their actions. Autonomy can be increased by a) encouraging ideas and involving employees in decisions, b) giving choices where appropriate, and c) explaining WHY when choices are not available – such as with standard operating procedures (SOP). These actions increase understanding and a feeling of control.

Fowler (2014) describes relatedness as "[o]ur need to care about and be cared about. It is our need to feel connected to others without concerns about ulterior motives. It is our need to feel that we are contributing to something greater than ourselves." Relatedness results from being part of the group and being a part of something meaningful.

Most dairy farm owners have relatedness. The relatedness challenge for owners can be in multiple owner situations, including during intergenerational transfer. When there is disagreement over the vision and core values or a lack of collaboration among partners, relatedness can suffer dramatically. With employees, relatedness is increased when they feel included, when there is a bond with other members of the workforce, and when their work is meaningful to them. Relatedness can be increased by a) improving interpersonal relationships – trust – by listening, being fair, expressing encouragement, providing quality feedback, and treating your employees as equal human beings, b) ensuring everyone understands and is committed to the vision, and c) explaining WHY when explaining decisions and making assignments.

Fowler (2014) describes competence as "[o]ur need to feel effective at meeting everyday challenges and opportunities. It is demonstrating skill over time. It is feeling a sense of growth and flourishing." To understand that competence is more than skill, think about why the opposing team calls timeout before a field goal kicker attempts a game winning field goal. We often describe the goal as getting the field goal kicker to "choke." What does that mean? Obviously, the kicker does not have diminished skill in the 2-3-minute delay. The goal is for doubt to enter his mind – to lose confidence, and thus, competence.

Competence, then, is skill plus confidence. As with the field goal kicker, skill precedes confidence. To ensure that employees have competence, not just skill, requires coaching well after they have learned the skill. Competence can be increased by a) training that includes high levels of encouragement and feedback, b) providing opportunities to learn and grow, and c) developing a culture of improvement where redirection and negative feedback are given immediately and received with minimal defensiveness and with a desire to continuously improve.

▪ Provide Great Clarity

Meeting employee need for autonomy, relatedness, and competence requires providing great clarity; I like to call it "chalking the field." Clarity begins with a clear understanding of WHY the farm exists. This then serves as the basis for engaging employees in success – relatedness.

Today, almost all farms have multiple partners from two spouses to multiple family members to non-family partners. In my experience, the greatest source of conflict between partners and even business failure is lack of clarity and/or downright differences in mission, vision, and values. I will never forget the story from one of our first PRO-DAIRY programs. In discussing the farm's mission, a husband and wife both said: "I have thought we should sell the farm for a long time, but have not said anything because I 'know' my spouse is committed to continuing." They moved on to the next step in their lives very quickly.

What, then, should be included as mission, vision, and values are articulated?

- Mission: Mission is the reason the farm exists. Items like business growth, legacy, profitability, productivity, quality, professional development, etc. often are included. Mission is primarily for the owners as it is crucial to the development of the farm's strategy.

- Vision: Vision is the inspirational mental image of a successful future. This is the “why” the farm exists and is crucial to motivation and passion. The vision tells why what we are doing is important. Examples could be: “We feed families just like ours” or “Improving quality of life through quality food products.”
- Values: Mission and vision are drivers of the future. Values tell us what is important and how to behave as we strive for that future. It is easy to make a long list of values. The challenge is to define the small number that are most important to the owners of the farm. Values greatly influence day-to-day decision-making. Examples include honesty, safety, stewardship, community involvement, customer orientation, etc.

There are many ways to articulate mission, vision, and values. How you do it is not important. The key is that you include the what - mission, the why – vision, and the how – values. A great reference is Blanchard, Stoner and Lencioni (2011). They use a fable to illustrate articulating significant purpose, picture of the future, and values.

After articulating the mission/vision/values, significant purpose/picture of the future/values, what/why/how for your farm, the next challenge is determining the best way to translate this information to create motivated, engaged, passionate employees and other stakeholders. One way is to create a “motivational catchphrase” to use as the focal point.

Common examples of “motivation catchphrases” are:

- Apple: challenge the status quo.
- Southwest airlines: you are now free to move about the country.
- Disney: provide good, clean fun.
- University of Minnesota Gophers Women’s Hockey: four values: tough, grateful, disciplined, devoted.

As you articulate the mission, vision, values, and “motivation catchphrase (or other form of communicating to employees) for your farm or other organization, keep in mind the following two criteria:

1. It is meaningful to the owners to serve as the driver for the future and to create the willingness to work hard and to be committed and passionate.

2. It can be articulated in a form that motivates the employees to work hard and be committed and passionate.

▪ Active Listening

Begin by thinking of a recent time when someone – employee, colleague, partner, family member, friend – was not listening when you had something important to say. Now think about how you felt and describe your feelings in one word. Common responses to this situation include: frustrated, ignored, angry, unimportant. To avoid situations where we leave others with these feelings, we need to become better active listeners.

Our tendency is to view listening as a passive activity. Active listening is a very proactive way to enhance communication with employees and others. The listener is now taking "active" responsibility for understanding both the content of and feelings behind what is being said.

Many, perhaps most, of us do not fully listen to what is being said, nor do we then ask follow-up questions to elicit greater understanding or additional information. Often, when someone – an employee, a partner, a customer, a friend, a spouse – initiates a conversation, they have spent time thinking about the idea, the issue, the concern, or the situation. Your responding before they have explained their thinking both loses the fruits of the time they spent and diminishes the quality of the interpersonal relationship with that individual.

The following are two listening practices to assist you in becoming a better active listener:

- Pause 1- 2 seconds before replying. This practice has three advantages:
  - It shows you are carefully listening
  - You avoid or at least reduce the risk of interrupting
  - You hear the other person better

- Ask questions for clarification. I find these two to be especially helpful:
  - "What do you mean?"
  - "Tell me more?"

I find the 1-2 second pause especially helpful on the telephone where interrupting is an even greater danger. In addition to being rude, interrupting often renders the conversation ineffective. I find the "tell me more" phrase to be extremely effective especially when listening to someone who is quiet, has difficulty expressing their thoughts, or someone who is not certain whether I am interested in what they are saying.

The consequences of failing to allow others to fully express ideas, opinions and feelings and/or to not fully listen are often two-fold. First, the current conversation is not brought to successful conclusion. Second, you have communicated the message that you do not want to listen, and even more significant future ideas, concerns and feelings may never be communicated.

▪ Measurement

Measurement is important to employee engagement and productivity. Employee engagement requires that each employee can answer two questions: 1) what is expected of me, and 2) am I meeting expectations – winning. The answers to both requires measurable performance expectations. The performance expectations are the answer to the first. They, then, provide the basis for answering the second question.

To illustrate the importance of measurement, let's look at a hypothetical situation. The next Super Bowl will be here in Minneapolis. In our hypothetical world, it will be like every other Super Bowl except the score will be kept secret. To enable secrecy, touchdowns will be 4, 5, or 6 points randomly determined and field goals 2, 3, or 4 points. Only one person will know the "real" score. My question is: if the game is close, will the unknown score impact the game?

The answer is "yes" because neither team will know how to proceed. Both teams have late game plans for protecting a lead or attempting a comeback. The coaches do not, however, know which to use.

Welcome to the situation faced by most employees. They have an idea how they are performing, but they do not know how that performance compares to what is expected. They are in limbo.

A note of caution to guide how we proceed. The Super Bowl hypothetical is a good analogy to illustrate the importance of measurement. The analogy ends there, however! In sports there is only one winner; on farms and other businesses, we want all employees to be winners.

If winning was the only or primary reason for measuring success, measurement would not be a contributor to engagement. In fact, for many it would be a demotivator. We, therefore, need to look beyond "winning" to understand the importance of measurement. We explore four reasons.

Measurable Accomplishments

Earlier we introduced autonomy – our need as human beings to feel in control of our actions. Perhaps the greatest source of autonomy is seeing our own accomplishments. From Lencioni (2007): "If you don't get a daily sense of measurable accomplishment, you go home at night wondering if your day was worthwhile."

As an owner or key manager, you are probably thinking: “I go home every night knowing what I have accomplished. Don’t employees do the same?” The answer is typically “NO.” Employees do not have the experience and knowledge of the big picture that you do. They require your help to set measurable outcomes. Hill and Lineback (2011) says it well: “A manager’s job is to provide ‘supportive autonomy.’”

Increase and Maintain Focus

Think about playing a card game in a social setting – an evening with friends. We almost always keep score. In a social setting, winning is not paramount, so why do we keep score? The answer is because keeping score causes us to focus on the game. The goal setting (performance expectations are goals) literature is very clear that having goals – performance expectations – increases focus and performance.

I still remember a day as a kid when we were baling hay. In mid-afternoon, a storm was brewing. We focused all our efforts to finish before the storm broke. We did finish just as the skies opened. I was incredibly amazed that it was 7:00 PM. It seemed like just a few minutes had passed. Beating the storm created FOCUS!

Ensure Individual and Farm Business Success

My mentor and friend Dr. Bernie Erven often asks audiences: “Do you know of a farm where the farm is succeeding while the people are failing.” I have never heard anyone answer “yes” to the question. Farm success results from the success of each member of the workforce. We can ensure individual success by defining outcomes – performance expectations – for everyone (or team), routinely comparing actual performance to the performance expectations, and making corrective and continuous improvement adjustments. This process is referred to as a performance management system.

■ Quality feedback

We as human beings need to know how we are doing. There is, however, no obvious scoreboard for our work, like there is for a sports game. The only way for our employees to know how they are doing is by providing feedback. It is crucial to recognize there are three – not two – types of feedback – positive, redirection, and negative.

Positive Feedback

In workshops I often ask participants how many times they have provided positive feedback in the last 24 hours. Most of the few who answer five or more times have been working with small children – coaching sports or teaching Sunday School.

Why are we more comfortable giving positive feedback to children? My answer is that children have not "learned" that they should be reserved in receiving compliments – positive feedback. This is not a good lesson but indeed is one that permeates our society.

Does the reserved response to positive feedback mean that adults do not want or appreciate positive feedback? The answer is a resounding NO! Research and my experience is that adults respond just as positively as children to positive feedback, they just do not show it.

Why then should we provide positive feedback?

- Positive feedback is motivating. In one of the most profound contributions to motivation theory, Frederick Herzberg identified many opportunities to motivate employees. "Feelings of personal accomplishment" and "recognition for achievement" are two of those motivators.
- Positive feedback focuses the recipient on success. To be effective in increasing performance, the feedback must be specific, timely, and accurate.
- Positive feedback builds confidence. Since many members of our workforce are young and often insecure, this advantage is powerful.
- Excellent, specific positive feedback engages the employee in their performance.

Feedback for inadequate performance

Traditionally we have talked about two types of feedback – positive and negative. This is logical as there are two outcomes of every behavior (including performance) – meet or exceed expectations and fail to meet expectations.

As we discussed above, the appropriate outcome of "good performance" is positive feedback. It does not follow, however, that the appropriate outcome of "unacceptable performance" is negative feedback. Thus, the need for three, not two, types of feedback.

The key to improving unacceptable performance is appropriately choosing between the two – not one – feedback responses. Redirection feedback is required when the unacceptable performance is caused by the situation, not by the employee's lack of motivation, focus, etc. Negative feedback is only appropriate when the cause of the unacceptable performance is the employee's motivation, energy, focus, concentration – good performance was under the employee's control.

Most managers dread dealing with unacceptable performance. You must, however, be proactive in determining the cause. You can then work to institute changes that will lead to employee success. Based on your analysis of the reason for the failure to perform, you can redirect and/or provide a consequence for failure to change.

Redirection Feedback

Redirection feedback is required when the unacceptable performance is caused by the situation, not by the employee's lack of motivation, focus, etc.

I believe that many managers are aware that negative feedback is not appropriate for this situation. Not knowing what else to use, they often do nothing.

This is an opportunity to be proactive by redirecting the employee toward good performance. This requires asking "What is the reason for the unacceptable performance?" Possibilities include insufficient training and coaching, the expectations were not clear, the expectation was not attainable, and unusual or unexpected circumstances prevented meeting the expectations. Understanding the root cause allows us to develop a plan to correct the problem, in this case unacceptable performance (or behavior).

Negative Feedback

Some of the time, as you carefully determine the cause of the unacceptable performance, you will determine that the employee's motivation, energy, focus, and concentration are the cause. In other words, the employee should have met the expectations – good performance was under his or her control.

In this situation, especially when you have already provided redirection feedback, negative feedback is warranted. Even here, though, neither you nor the employee should view negative feedback as a punishment. Rather it should be given as a choice:

- Make the change necessary for good performance.
- Incur the specified consequence.

Negative feedback is not easy to deliver. It is important, however, to keep in mind that the purpose of the feedback is still employee success.

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Motivating On-Farm Change

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▪ Take Home Messages

- Communication is one of the fundamental elements of a successful dairy business.
  - Prioritize communication and commit to being open, trustworthy, and transparent.
- Too often we assume that the best way to influence someone is by simply educating them.
  - We assume that once we provide someone with the information they will apply it in a rational way.
- We can be better influencers if we focus on understanding someone's mindset (e.g. attitudes, beliefs, values, etc.).
  - If we understand what someone knows and thinks, we can have a more appropriate discussion about how to change.
- Some of the best ways to motivate staff are through training and continuing education, goal setting, and recognition.
  - These practices help to develop your staff, allow them to have a voice, and ensure staff know they are valued.

▪ Introduction

I think most would agree that having a good team is one of the keys to success in business. Whether you're running a law firm, building a new start up tech company, or running a dairy farm, the one commonality you can bet on is the need for an effective group of individuals that are skilled, hard-working, and motivated to get the job done. Sounds great, right? It's usually easier said than done though.

So how do we get there? It's all about communication. The first step in ensuring that your farm and staff are operating efficiently is to focus on the communication methods you use. Communication plays a major role in employer-employee relationships on farms and is a key factor to your farms success. It also affects the relationships among family members on the management team. Good communication ensures you can successfully address issues of discipline, training, motivation, and implementing a new technology or practice.

Having an effective team takes commitment and a solid understanding of both your needs and your team's. Ultimately, this starts with asking questions of yourself, exploring your own mindset towards on-farm decisions. You must then start to explore the mindset of those you work with. It's not rocket science, but it does take time and effort to get it right. It's all about understanding the knowledge, attitudes, and assumptions each of you bring to a given problem and communicating to make sure the actions you take align with your goals.

Objectives

The first objective of this manuscript is to explore some of the key factors influencing on-farm behaviour, specifically highlighting the role of communication and mindset. The second objective is to review some of the qualities and practices that effective managers possess to motivate change.

■ Factors Influencing Behavioural Decisions

Simply put, change is difficult. Whether you're trying to make a change in your personal life or trying to introduce change to a specific management practice, strategy, or routine, changing behaviour is both challenging and complex. In many cases there are factors that you can control, and others you can't. This section will review some of these factors and explore their influence on on-farm behaviour and decision-making.

The Role of Knowledge and Awareness

When it comes to influencing someone to change their behaviour, one of the most common approaches is to educate or provide information. We often take the stance that educating someone will be the driver of change. Whether consciously or subconsciously, we tend to make the assumption that the reason someone isn't doing things a certain way is because they don't know the beneficial reasons behind it, and. that if we provide them with the information on what to do, they will take that knowledge and directly apply it in a rational way.

But think about it, is knowledge really the limiting factor for most people? Most individuals find introducing change, particularly health related behaviours, to their own lives difficult – and this is rarely because they don't know "what" to do. Think about smoking, eating healthy, sneezing into your arm. Most of us "know" what to do, yet we still engage in unhealthy behaviours or don't routinely practice healthier behaviours. Now apply this same thinking to farm-related tasks, such as biosecurity or udder health practices.

Change is difficult and complex, and most importantly, not solely governed by knowledge. There is a discrepancy between knowledge of a given practice and the actual level of implementation. This discrepancy is a well-known phenomenon (McKenzie-Mohr & Smith, 1999) and presents challenges when trying to influence on-farm change. Most importantly, if we provide information when it's seemingly not needed, it is often perceived as nagging, rather than educating, which often leads to a negative reaction from those we're trying to influence.

This is an important principle to understand when managing people and trying to influence change. Yes, knowledge and awareness of a given practice are important pieces of the puzzle, but they are only a small piece – a small piece that is often overlooked by agricultural extension specialist, researchers, and veterinarians. Traditionally, these groups were taught that agriculture was an activity executed by an individual farmer, based primarily on rational, technical, and economic considerations (Leeuwis, 2004; Burton, 2004). But, of course, we know that decisions are not solely made on these bases.

It's All About Mindset

Again, while knowledge and awareness play an important role in farm management, we have learned that on-farm decision making is governed by many other important social factors. A person's attitudes, beliefs, values, skills, personality, habits, and perceived ability to perform a given task (otherwise known as "self efficacy") all influence one's decision-making. These factors are often summarized as an individual's "mindset" (Jansen & Lam, 2012).

So how do we package these factors up in a meaningful way? A useful framework that can be applied to farm decisions is called the Health Belief Model (HBM) (Janz & Becker, 1984; Garcia & Mann, 2003). The idea is that when someone considers making a change, they consider (sometimes consciously, sometimes subconsciously) several questions. The answers to those questions determine whether they will make a change or not. Figure 1 summarizes the HBM questions and highlights a few additional factors that influence the likelihood of taking action (i.e. cues to action [e.g. external signals or attempts to influence you, such as a media campaign or veterinary advice] and modifiers [e.g. unique personal factors that will influence each person's perspective on the issue]).

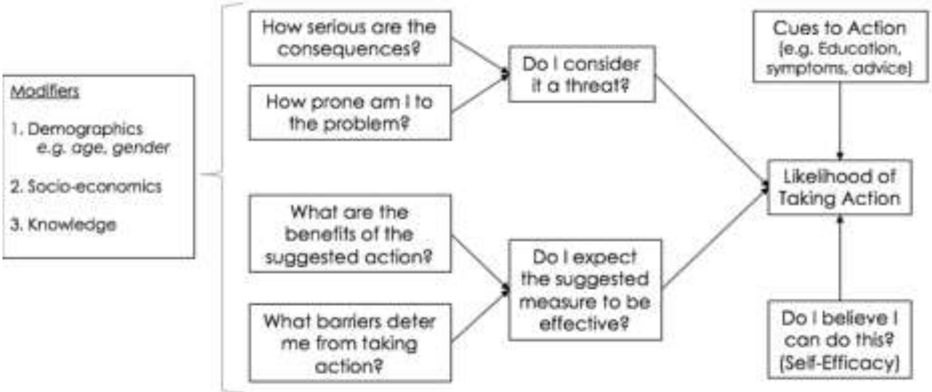

Figure 1: The Health Belief Model; a framework used to describe the factors influencing the likelihood of someone taking action.

To put this in perspective, let's look at the case of adding more bedding to help reduce hock injuries. Based on the HBM, a producer is most likely to adopt this change if:

a) they believe their cattle are at risk of having hock injuries,

b) they believe that a high number of hock injuries in the herd is serious and the consequences of these injuries are undesirable,

c) the risk of injuries will be reduced by adding more bedding,

d) the benefit of having fewer hock injuries will outweigh the cost (both real and perceived) of adding more bedding, and

e) they are confident that they can integrate this practice into their routine

That's a lot to consider! The point being, we need to understand someone's mindset towards a given issue or action before we go ahead and recommend or expect a change. So let's go ahead and look at how we can better understand someone's mindset and what we can do about it.

Communication and Mindset

Understanding mindset is all about communication. As managers and decision-makers you need to be open about what you do and why you do it. Your staff need to understand your mindset.

But it's not enough to simply convey your mindset to your staff, you also need to explore theirs. What do they think? What are their opinions and beliefs? What are their experiences?

Are you asking these questions of your staff?

Good managers ask open-ended questions (questions that don't end in a yes/no answer) and actively listen to responses. It's useful to ask questions that start with one of the 5 W's and H (who, what, where, when, why, how), which almost always result in someone having to explain their answer rather than just give a simple "yes" or "no" response. The idea is to get them talking and start to understand their mindset. Once you understand where things differ, you can start to discuss those specific issues and get on the same page.

It's important to note that communication doesn't just have value when it comes to understanding mindset, it also helps to build trusting relationships. As managers, keeping the lines of communication open helps show your staff that you value their opinion and you're open to discussing new ideas. Research has shown that staff value managers who demonstrate these qualities over and above other elements of the job, such as job security and flexible hours (Kolstrup, 2012). In fact, research has shown that employee engagement and satisfaction are higher among those who believe their manager is goal-oriented and trustworthy (Cho & Perry, 2011).

Open communication also makes it easier to deal with conflict. It's important not to duck conflict, but to deal with it directly. A calm and considerate approach is often the one that leads to a fair resolution, and while not always easy, open communication often makes dealing with conflict more manageable.

▪ From Mindset to Motivation

With better two-way communication between you and your staff (remember, this goes for working with your farm advisors as well!), and a better understanding of mindset, you can work on other managerial qualities that help to motivate on-farm change. Key one's worth discussing include: training and continuing education, goal setting, and recognition.

Training and Continuing Education

Proper training is essential for any staff member to perform their duties adequately. Training allows you to describe your approach to staff, and presents a perfect opportunity to get them to understand your mindset. It's not just about showing them how to perform a given task, it's about having them understand why it's done, and done your specific way. Use these opportunities to re-evaluate your methods, and provide opportunities for your staff to ask questions, and offer ideas and alternative approaches. Most importantly, use training opportunities to define roles and set expectations.

Create and communicate clear expectations of the job and what is required to successfully perform it.

Importantly, training shouldn't be viewed as a one-time thing. As new technologies become available, new science and ways of thinking are uncovered, and new problems arise, routine training and continuing education become paramount. Research has shown that education and training not only enhances farmers' ability to make successful changes to their management practices, but it also increases their willingness to do so (Kilpatric, 2000). Giving your staff continuing education opportunities also shows that you value them, you're investing in the success of your operation through them. These efforts have tangible value in not only helping to improve the efficiency of your operation, but also in staff engagement, motivation, and satisfaction.

Goal Setting

One of the best ways to engage and motivate your staff is to involve them in setting goals for themselves and your operation. Effective managers motivate their staff by creating an environment where the team works toward a predetermined goal or goals (Cho & Perry, 2011). Your job is to identify goals and focus your staff to work towards them.

The best place to start is with a brainstorming session, where everyone's thoughts and ideas are given equal value and consideration. Take this opportunity to hear the perspectives of your staff and re-think where your operation is currently. It's useful to track these ideas on a sheet of paper or chart paper. Then you and your team can work on prioritizing, identifying, and refining specific goals.

Once you've chosen a few of your top goals, set out to make them S.M.A.R.T: Specific, Measureable, Actionable, Realistic, and Time-bound. This helps to ensure your goals are clear and focused. Goals such as "improving production", or "reducing disease" are too broad. What specifically will you achieve and what specific steps will you take to get there? Most importantly, how will you know when you get there?

"SMART" goals help you articulate what you are striving for and how you'll get there. When it comes to planning, start simple and chunk it out. What's the first action you need to take? The old adage "how do you eat an elephant? One bite at a time" rings true here. Achieving your goals may take time and may require the achievement of several smaller tasks to get there. Be sure to stay positive and use these smaller steps to help identify measures of progress.

Recognition

Feedback from supervisors is routinely identified as one of the most important motivators for staff (Kolstrup, 2012). In fact, research has shown that staff recognition and achievement are not only the most frequent motivators, they also tend to have the longest impact on job satisfaction (Cho & Perry, 2011). Recognition doesn't have to be in the form of monetary incentive programs or tangible rewards. In fact, more money doesn't tend to equate to increased motivation and productivity (Cho & Perry, 2011). Recognition of a job well done or an appreciative remark ("thank you") can go a long way, and takes almost no effort at all. Feedback doesn't always have to be positive either, it just needs to be constructive. Taking the time to recognize someone's effort (even if misguided) should be your first priority. Then you can discuss the potential corrective measures you'd like to see put in place. Again, it's all about open communication and building a trusting relationship.

▪ Conclusion

Motivating staff and effective on-farm change happen when we understand one another's mindset. They require open communication and a commitment to staff. Training and continuing education, goal setting, and recognition are some of the best ways to help motivate your staff, and are a key part of successful dairy operations.

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What is Happening in Facility Design to Improve Cow Comfort and Health?

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Take Home Messages

- Deep bedding is much better for the cows than mattresses**.**
- Deep bedding requires an effective system of filling and daily management.
- Cows should rest at least 12h per day; sensors can measure this.
- Commercially available sensors will change the management of dry cows and transition.
- A Cuddle Box provides an essential infrastructure for calving pens, and for the optimal care of the newborn calf.

Comfortable Free-stalls: Introduction

In free-stall housing, the resting comfort and the amount of time cows spend lying down per day is decided by the design aspects and management of the free stalls. To assess this, a systems approach is necessary. In a systems approach, one takes the combination of multiple factors into account.

Vetvice/CowSignals uses the following approach to assess free-stalls. We articulate these as success factors. This means that we formulate the standard they should apply to. Comfortable free-stalls ensure that cows can lie down as much as they want, which is probable as well as good for them. When cows lie down their feet are not pressured; they rest and dry up.Lying cows are out of the way for the rest of the herd. This increases the social comfort in the walkways. And thus for all cows in the group it increases the effective access to feed, water, cowbrushes, etc.

Social research in the Netherlands indicates that public opinion about dairy farming is partly based on the perceived intentions of the whole sector

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regarding values such as “being respectful and caring for the animal”. Working together in the industry to ensure excellent resting facilities for all cows and young stock creates trust and appreciation amongst the public. The public does not want industrialization of dairy farming, as it is contrary to the perceived welfare of the animal. This judgement is also based on perceptions like ‘natural’ and ‘the cow not being a machine’.

▪ Construction and Management of Free-stalls

Please note that the dimensions are decided by the size of the cows in the herd. So all dimensions in this articles are starting points and are related to a bench mark cow. In practice, the starting point should be decided based on the dimensions of the cows in the herd. Measure a sample of the herd and decide the dimensions of the bench mark cow. This reference cow is used to establish all dimensions and positions of the free stall components at first installment.

When designing a new barn, it is wise to check that large size cows will also fit comfortably in the adjusted stalls, so that the farm has the flexibility to milk larger sized cows than it is milking at that moment.

After 2 to 4 weeks, the dimensions can be adjusted. Of course this can be done earlier, if there are strong reasons for it.

Dimensions of the bench mark cow used by Vetvice Barn Design in The Netherlands in 2018 are stated below. All stall dimensions stated in this review refer to the bench mark cow however should be adjusted if your cows are larger or smaller.

- Holstein Friesian
- body weight: 700 kg
- withers height 1.49 m
- nose to hook bones: 2.50 cm
- front shoulder joint to hook bones: 1.70 cm
- hookbone width: 61 cm
- width of abdomen: lactating: 79 cm, dry: 82 cm

Dimensions are based on measurement performed by Vetvice trainees on commercial dairy farms.

▪ Success Factors for Comfortable Free-stalls

The success factors are listed in order of priority. This means that this list can be used in the decision making process for improving existing free-stalls or designing new free-stalls.

Bedding

Bedding must be very soft for landing and lying, and should provide excellent grip for the hooves.

This is a subjective measurement. It can be tested by pushing your hock into the bedding, the knee-test and the back-of-hand rub.

The knee-test consists of letting yourself drop onto your knees on the bedding a couple of times. The landing should be soft and comfortable.

During the back-of-hand rub, you rub with the back of your hand over the surface of the bed in the area where the hocks of the lying cows touch the surface. Again, this should be a soft and comfortable experience.

Head Space

The front side of the free-stall should provide space for the cow to stick her head out forward and swing it up and down, while standing up and lying down.

For this, there must be no barriers between 10 cm and 90-100 cm in the front of the stall. When she swings her head, a mature cow will move her nose forward up to 75 cm, and perhaps more. The length of a mature 700 kg HF cow is about 2.50 m from her pin bones to her snout.

Double rows of free-stalls, head-to-head, should be at least 5.30 m long and optimally 5.50 m.

Standing and Lying Space

The position and design of the neck rail determines the standing space, and the position and height of a brisket locator determines the lying space.

About the neck rail: a curved neckrail is preferred. Position this at an angle of max. 45˚ with the horizon. Vertical distance to the bed: 1.25 m (open space). Diagonal distance to the curb: approximately 1.22 m.

Flexible Neckrail (even better): chain covered with a tylene hose, with a spring at one or both ends. Can be positioned at 1.15 m vertical distance from the bed. Diagonal distance to the curb: 1.25 m.

In free stalls that provide excellent grip to the feet of the cows and a soft landing, the cows are more capable of dealing with a neck rail that is positioned too far backwards or too low.

The brisket locator should be no higher than necessary to stimulate the cows to lie down in the back of the bed: 10 cm higher than the surface. The brisket locator should not have sharp edges because cows will put their legs on top of it. In free stalls with a head rail, often a brisket locator is not needed.

When a cow lies down, her front knees are resting about 30 cm in front of her shoulder. This means that for the bench mark cow the brisket locator should be located about 2.00 m in front of the curb.

Width

The free-stall should be wide enough for the cow to comfortably lie down. Dr. Neil Anderson (OMAFRA) set the standard of 2x the width of the pelvis measured at the hook bones. His standards come to about 1.22-1.25 m centre-to-centre width of a free-stall for lactating cows. Dry cows have bigger abdomens and need free-stalls that are 10 cm wider

Shape of the Divider

The head of the cow should be guided forward and the divider should not cause any injury.

When the dimensions and bedding are at standard, the shape of the divider is not much of an issue. It should position the cow straight in the free stall and it should stimulate the cow to swing out her head straight forward. When a cow swings her head to the side while she lies down, her back end will move to the opposite side and she will end up lying diagonally. Lying down diagonally is a major risk factor for developing injuries from the free stall divider.

Keep the fronts of free-stalls as open as possible; guiding the head movement forward is a subtle thing. As cows are social animals and prey animals, they want to see other cows and have an excellent overview of their surroundings. And as their noses are the point where they exhale humid air and want to inhale fresh air, excellent ventilation at the front of free-stalls is very important and should not be disturbed by any unnecessary construction.

Beside this, the dimensions of the divider are to a high extent decided by functionality: mounting the divider, keeping the free-stall together and bringing the neck rail in the right position. The preferable option is to mount each divider or set of dividers on a separate post. This construction doesn't require horizontal pipes for mounting purposes.

■ Management of Resting

Enough resting time is essential for confined dairy cattle. In general, 12 hours per day is regarded as the minimum for lactating cows, but more is better. For dry cows, a minimal threshold has not been established, but indications are that this is also 12 hours per day.

Commercially available sensors for automated heat detection can measure resting time and thus enable the farm manager to manage it. Scientific research on using sensors for this purpose has only started recently (discussed later in this review)

Data on resting behavior needs to be interpreted, as it changes during the lactation and over parities. In early lactation, cows spend more time eating and have less time available for resting. First lactation cows eat slower than adult cows, which also reduces the time they spend resting. Expectations are that this knowledge will develop rapidly over the coming years.

On farms with deep bedding, the daily resting time rapidly decreases when the level of the bedding is too low. So daily resting times provide a clear signal to the farmer: level of bedding is OK, or beds need to be filled up.

Bedding

Bedding needs to be dry, most certainly the top layer in the area where the udder rests.

Based on experience with our clients, deep bedding is better for cows than mattresses. Successful working with deep bedding requires:

1. Understanding of the principle and how to start up;
2. Keeping the level higher than the curb;
3. An easy way to perform daily maintenance, preferably mechanical;
4. An easy way to fill up bedding material, mechanically;
5. A cheap bedding material.

Common Issues and Problems in Dairy Facilities

Cows are put into a new facility where the free-stalls are dramatically changed

Cows need up to 4 weeks to get used to a different way of getting up and lying down and some cows may never adapt. In this adaptation period, cows can get stuck in the free stalls and end up in uncomfortable positions. There are common anecdotes from dairy farmers about cows standing up in an awkward way in pasture the first weeks after they are put into pasture again, following a long winter season in a barn with poorly dimensioned free-stalls.

Resting behavior in stalls with dividers that give the cows a lot of freedom, like plastic sticks, is also decided by the amount of cows compared to the amount of available free-stalls. In barns that have many more free-stalls than cows, the chances that a cow will enter a stall without a cow in one of the neighbouring stalls is quite great. So she can easily lie down diagonally. In barns where the free-stall to cow ratio is close to 1 to 1, very often there is at least one cow in a neighbouring stall and often there is a cow in both. In these situations, the neighbouring cows force the cow to lie down straight.

Cows in an Existing Barn

Too many cows lying diagonally

1. The neck rail is too far back, forcing the cow to stand diagonally before lying down. Bring the neck rail forward, and/or use a curved neck rail.
2. The brisket locator is too far back, forcing the cow to lie diagonally. Bring the brisket locator forward. Reduce the height when it is higher than 10 cm over the surface.
3. The cow cannot swing her head straight forward. When she swings her head to the side while lying down, her hind side will move to the other side and she will end up lying diagonally.

Thick hocks

The surface of the free stall is too hard. Make it softer. Weak cows, sick cows and cows with low BCS (Body Condition Score – no fat coverage and few muscles) are most at risk for this.

Bald hocks (hair loss)

The surface of the beds is too abrasive. Make is less abrasive by choosing softer bedding or using (much) more bedding material.

Bald and thick front knees

The surface in the front of the free-stall is too hard. Make it softer.

The neck rail is too low or too far back, forcing the cows to walk backwards on their front knees when they stand up. This is also a risky situation for cows getting caught up in the front of the free-stalls. Put the neck rail in the right position.

If cows have bumps and/or wounds on their back, the following may be happening:

1. cows are lying diagonally;
2. free-stalls are too narrow;
3. poor design of the free-stall divider;
4. all of the above

▪ The "Cuddlebox" Concept

Rule No. 1 for Effective Treatments (Hulsen) says "one person should be able to set one cow ready for treatment in one minute, and then treat her right in one go. A Cuddle box (Figure 1) provides the infrastructure for this in a calving pen".

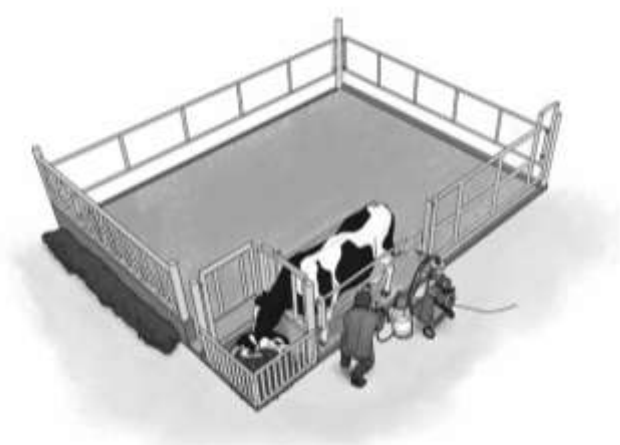

Figure 1: Cows Signals Cuddlebox

Catch and fixate a cow within one minute

The extendable swing gate enables a herdsperson to drive even a shy first calving heifer in a corner and fixate her with a chain behind her legs. This makes it very easy to quickly check the position of the calf and estimate whether it can be born spontaneously.

The urge to ‘get the calf out now that we have caught the heifer’ will be much less. This should bring down the amount of unnecessary and too-early events when assisting delivery. Assisting with briths is correlated with heavy calves, and that is a risk factor for disease and mortality of the calf. In addition it is a risk factor for trauma of the birth canal, ketosis and metritis of the dam.

Providing birth help itself is a risk factor for heavy birth: the birth canal might not be fully dilated when traction is applied, the birth process might be too heavy on the calf (continuously pulling for a long time span), the care taker might be causing trauma of the birth canal with his hands and arms, and not use adequate lubricant, etc. Too reduce these risks, there are two aspects to manage:

1. Tt must be very safe and easy for the care taker to fixate and catch the cow and to handle and treat her;

2. The care trainer must be well trained and using the most optimal procedures, tools and techniques.

Treat cow and calf together

Immediately after calving, the calf can be put on a layer of fresh feed in the box in front of the cuddle box. Fresh feed is a hygienic environment for the calf, as it does not contain manure. In the straw pen the calf will easily take in pathogens from manure, from the bedding and from the skin of the cow when it is searching for the udder.

Then the dam can be fixated in the cuddle box. This is an easy job, as she will want to go in to lick her calf. Now the cow can lick her calf, eat fresh feed and drink water that is provided.

This is the best moment to milk colostrum from the cow. Shortly after calving the dam is still a bit ‘high’ and very likely to accept to being milked. During calving the brain of the cow releases endorphins into the blood stream, which are hormones with an opioid-type of effect. Shortly after calving the effect of these endorphins is still present.

This is the best moment to feed fresh colostrum from the mother immediately to the calf. The quality of colostrum is the best when the cow is milked immediately after calving. A large interval between calving and milking colostrum is the main reason for suboptimal levels of antibodies in the colostrum, as measured with a refractometer or Bricks meter.

Fresh colostrum also contains living white blood cells, and leukocytes from the dam. When the calves drinks fresh colostrum, these leukocytes are still alive. They are absorbed and enter the blood stream of the calf. Both in the body of the calf and in the intestine, these leukocytes play a role in setting up the immune system and probably have an effect on the intestinal microflora (microbioma).

The calf can stay in the box as long as the herdsperson wants. It is in a safe environment, it cannot escape and the dam can still lick it. On many farms this reduces the amount of time needed to perform the complete standard operating procedure: “remove the calf, milk the cow and feed colostrum”. This makes it easier to do this job before finishing the rest of the work.

Farmers that work with the cuddle box are very positive about the concept but unfortunately there is very little research published about this topic. One probable reason for the success is that the herdsperson experiences better control, and he or she has a greater chance to milk the cow and feed the calf colostrum immediately after calving.

▪ Sensors in Transition Management

In the Netherlands, a multi-year/multi-farm field study was conducted by the Veterinary Faculty Utrecht, Wageningen University, Nedap and Vetvice, called ‘Sense of Sensors in Transition Management’. The aim of this study was to explore and develop the use of commercially available sensors in the management of dry cows and transition management.

Do sensors take over the work of people in taking care of the cows? No way. Sensors provide the possibility to better monitor and care for the individual cow. Furthermore, they add extra information on top of good observations and cow care skills.

Plus, as a stockperson you need to understand cows to be able to manage them well. Sensors and automation can be very helpful, but will never replace practical knowledge and skills.

Often, the first discussion point when talking about sensors in dairy cow management is the identification of sick cows. Yes, sensors can be of help in this process. But with good cow care, the sensors will not often identify a sick cow that the caretaker has not found.

Successful transition management is about ensuring that the cow keeps eating. And so eating is a control point. The care taker will check feed consumption by assessing the rumen fill and the activity of the cow. Sensors can be of help by showing the eating behavior during the first days after calving. And by giving an alarm when a cow has not been eating for say 6 hours in a row.

One of the management questions regarding fresh cow groups, is “when can a cow leave the fresh cow group?” A good answer to this question that can be provided with sensor data is, “when she has been eating well for at least the last 3 days”. The next question is how “eating well” is defined. The default setting for this can probably be 5.0 to 5.5 hours per day and at least 7 eating episodes. But it is relatively simple to work with farm-specific thresholds that are automatically calculated from the data collected from other cows in the herd. This is a better approach than working with default settings.

We know that cows that develop metritis after calving eat for shorter periods during the close up period compared to cows that stay healthy. Results from Sense of Sensors confirms this and shows that these cows already spend less time eating 6 weeks before calving. One of the many questions this study wanted to answer is “why do these cows spend less time eating?”

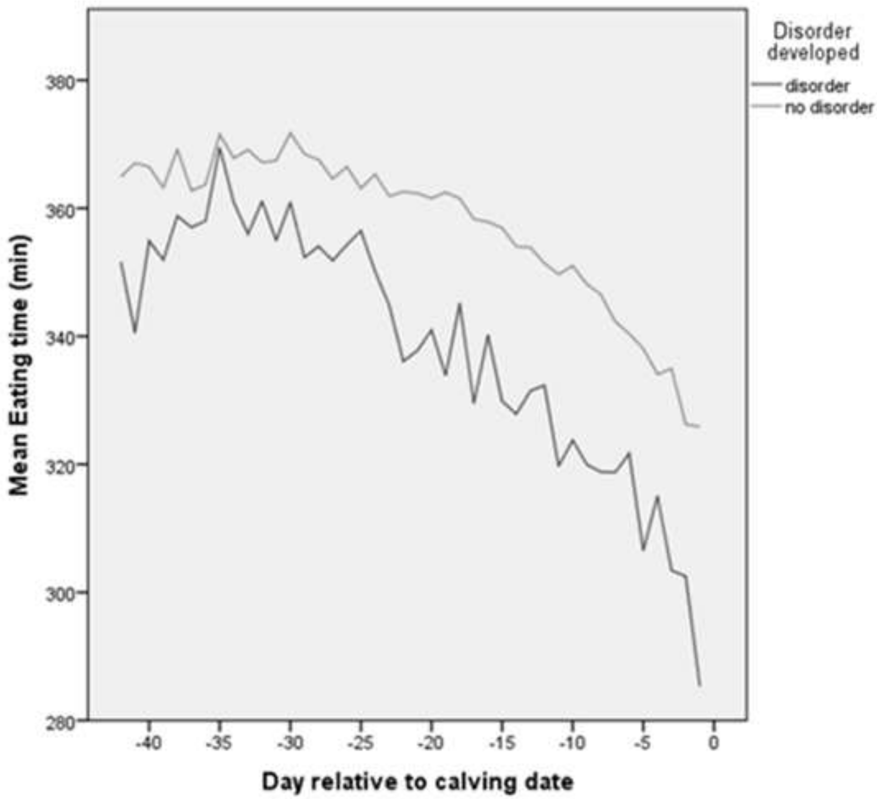

Figure 2. Eating time of cows that developed disorders in the transition period after calving. Cows that developed disorders already spend less time eating up to 8 weeks before calving. Source: Sense of sensors in transition management 2017 (unpublished data).

- Cows that develop disorders during the start of lactation show shorter eating time during the dry period
- Can we identify ‘at risk cows’ to give them supportive/preventive care?
- Can we prevent problems by ensuring that all cows achieve the target eating time?

The fact that these cows show significantly different behavior creates the option to identify at risk-animals. A farmer can give these at risk animals specific treatments and husbandry to prevent them from developing clinical problems.

One of the end goals is to define success factors for these periods as well as ways to measure them. When the farm has the success factors at level and under control, the health and vitality of transition cows is optimal.

Working with the concept of ‘success factors’ means that you define success, then you decide what you need to do to reach these goals. This you cluster into areas, or factors, that you can manage. These factors are then called ‘success factors’. When your success factors are OK, your results should be OK.

Examples of monitoring points that can be measured with sensors are:

1. Resting behavior
2. Eating and ruminating behavior
3. Behavioral patterns per day
4. Number of steps taken per day
5. Synchronization of behavior[1]
6. Behavior after introducing new animals

‘Synchronization of behavior’ represents the extent to which a group of animals show the same behavior at the same time (i.e. eating, resting). The idea is that animals that are at risk for ‘not eating enough-not resting enough-high social stress’, do not show the same behavior as the majority of the group (i.e. they are waiting while the others are eating, they are eating while the others are resting, etc). This is an area of research, so perhaps in future, insights will change.

The presentation and interpretation of this information is again ‘under development’. Essentially, it is management data, which means that the evaluation and interpretation is not done on a daily basis, but with longer intervals. Also, it is either done by the responsible manager or his boss, or by an advisor.

Does this make this data less valuable than data ‘for detecting a sick cow’? I think it is a lot more valuable, because it provides tools to prevent the cow from becoming sick.

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Benchmarking Health and Management across the Canadian Dairy Herd

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Take Home Messages

- The National Dairy Study 2015 represents the first successful attempt to benchmark health and management across the Canadian dairy industry, including herds from all 10 provinces.
- The majority of Canadian dairy farms purchase animals and add them to the herd with little in the way of pre-purchase screening, which poses a significant biosecurity risk on most farms.
- Based on bulk tank milk testing, over 85% of farms were positive for BLV, 45% were positive for Staph aureus and 20% were positive for Johne's Disease, indicating that the true prevalence of these diseases across Canada is likely even higher, and that the implementation of herd biosecurity needs to be improved.
- One in every 4 cows on Canadian dairy farms is lame, and one in 5 cows has a hock or knee injury, indicating that there is a need to improve animal care and welfare across the country.
- The adoption of best practices for milking cows is highly variable across the country and there may be opportunities to improve milk quality and improve udder health by increasing the adoption of these practices.

National Dairy Study 2015

The National Dairy Study (NDS) (http://www.nationaldairystudy.ca/) conducted in 2015 was the first attempt to benchmark the health and management on dairy farms in all 10 Canadian provinces. It was modeled after the National Animal Health Monitoring System (NAHMS) dairy studies in the USA (https://www.aphis.usda.gov/aphis/ourfocus/animalhealth/monitoring-and-surveillance/nahms/nahms_dairy_studies). Phase 1 consisted of an extensive questionnaire offered to all Canadian dairy producers, covering herd demographics and farm characteristics, biosecurity and infectious disease control, clinical disease estimates, calf health and management, animal care and welfare, udder health and milking hygiene, reproductive programs, and social media use. Phase 2 consisted of visits to 374 farms to collect more detailed health and management information, assess animal care based on selected animal-based measures, and to collect biological samples for testing. Farms participating in both phases were distributed across all 10 provinces and representative of the breadth of the Canadian dairy industry. The distribution of producers and phase I and II participants can be found in Table 1. NDS herds were housed in tie-stall (59%), free-stall (38%) or bedded pack (3%) facilities; 85% were enrolled in milk recording; 12% used robotic milking systems and 3% were certified organic.

Table 1. By province, the distribution of producers, and phase I and phase II participants in the National Dairy Study 2015.

Province	# Dairy producers	# Phase I participants	# Phase II participants
British Columbia	496	48	19
Alberta	549	57	20
Saskatchewan	156	13	10
Manitoba	299	45	10
Ontario	3 232	347	132
Quebec	5 660	508	122
New Brunswick	204	30	19
Nova Scotia	225	27	18
Prince Edward Island	177	27	20
Newfoundland	27	6	4
	11 025	1,108	374

▪ proAction

The proAction Initiative is a national on-farm customer assurance program developed by Dairy Farmers of Canada and implemented provincially by the respective milk boards (https://www.dairyfarmers.ca/what-we-do/programs/the-proaction-initiative-on-farm-excellence). Two of the six elements of proAction are Animal Care and Biosecurity. The Animal Care module includes an independent assessment of animal based-measures on a representative sample of cows in the herd. The Biosecurity element is focused on the introduction and within herd spread of infectious exotic and endemic diseases. Animal Care was implemented across the country in September 2017, while the target date for Biosecurity is September 2019. The NDS was developed to capture some key aspects of both of these components of proAction to serve as benchmarks for the dairy industry.

■ Biosecurity

A total of 1,373 dairy producers across Canada completed the Phase 1 survey between March 1 and April 30, 2015 and answered some or all of the biosecurity questions. Herds were classified as very small (< 45 cows; 21%), small (45 to 65 cows; 23%), medium (65 to 100 cows; 25%), and large (> 100 cows; 31%).

Animal Health Management

While 93% of the respondents kept an animal health record, only 45% reviewed the occurrence of diseases in their herd at least once a year. Respondents reported having protocols in place for lameness (49%), mastitis (93%), retained placenta and metritis (73%), respiratory disease (56%), pink eye (15%), and calf diarrhea (54%), but this varied substantially by geographical region. Infectious diseases that most respondents were trying to prevent from entering their herd were bovine viral diarrhea (BVD; 58%), and Johne's disease (51%). Infectious disease respondents wished to eliminate or control Staphylococcus aureus mastitis (69%) and digital dermatitis (48%). Forty percent of the respondents reported having at least one lactating cow that died or was euthanized for an unknown reason in 2014, and 24% of them reported having a post-mortem performed on that animal(s).

Animal Addition and Movement

Forty-one percent of the respondents indicated that they had a closed herd (no introduction or reintroduction of animals to the herd during the calendar year 2014). In herds where animals were added, 75% said they inquired about the disease status of the herd that the new animal originated from, but only 25% tested the new animal for diseases, mainly for contagious mastitis pathogens, Neospora, and bovine leucosis virus (BLV). Segregation and vaccination of a new animal was used, most of the time or always, by 24% and 40% of the respondents, respectively. Larger herds were more likely to use segregation and vaccination than smaller herds.

Sanitation

Eighty-three percent of the respondents ensured cow udders and lower legs were free of manure before calving, and 76% of them cleaned out, sanitized, and re-bedded the calving pen after each calving. Both were more common in smaller and tiestall operations than in larger and freestall operations, respectively. Sixty-four percent of the respondents never used the same equipment to handle both manure and cattle feed, and the 39% of the respondents sending their animals to pasture prevented their animals from grazing pasture where manure had been spread in the same growing season.

Human and Equipment Movement

There was very little effort to control who had access to their dairy farm: 2% of the operations had a gated main entrance, 14% had biosecurity signage, and 4% locked their doors when staff were not working in the barn. Employees were required to use boots and coveralls designated for the farm in 53%, and 37% of the operations, respectively. Consultants and visitors were required to use boots and coveralls designated for the farm, most of the time or always, in 62%, and 33% of the operations, respectively. Thirty-seven percent of the operations shared farm vehicles or equipment with a neighbor's farm, a practice which was more common on smaller operations than larger ones.

▪ Disease Testing

After the Phase 2 farm visits, bulk tank samples were collected from each of the 374 farms for disease testing. These bulk tank milk samples underwent testing at three different laboratories for bovine leukosis (Maritime Quality Milk Laboratory, Charlottetown, PE), four mastitis pathogens and Johne's disease (CanWEST DHI, Guelph, ON) and Salmonella Dublin (Laboratoire d'épidémiosurveillance animale, MAPAQ, Saint-Hyacinthe, QC).

Bovine Leukosis Results

Two bulk tank milk samples from each farm were tested one month apart using an indirect commercial ELISA (Nekouei et al., 2015) for leukosis antibodies, according to manufacturer's instructions. The cutoff for a positive test was >5. Herd-level prevalence was 87.2% with an average score of 59.4, indicating a high within herd prevalence in many of the positive herds.

Mastitis Results

One bulk tank milk sample from each farm was tested for Staphyloccocus aureus, Prototheca, Streptococcus agalactiae, and Mycoplasma bovis using the PathProof™ Mastitis Major 4 PCR Assay (Thermo Fisher Scientific Inc.Waltham, MA,US) according to manufacturer's instructions. The overall herd-level prevalence for S. aureus was 44.8% (Table 2) and using a logistic regression model the following variables were identified as risk factors for being a positive herd: tie-stall (odds ratio (OR) = 2.9), not visually tagging chronically infected cows (OR = 2.1), and not fore-stripping prior to milking (OR = 1.8). The herd-level prevalence for the remaining pathogens was 6.7% for Prototheca, and 0.3% for M. bovis and S. agalactiae.

Table 2. Bulk tank milk testing results for S. aureus and Prototheca by province for the National Dairy Study 2015.

Province	Number of farms visited	Number S. aureus Positives	Number Prototheca Positives
British Columbia	19 (5.1%)	2 (10.5%)	2 (10.5%)
Alberta	20 (5.3%)	5 (25.0%)	1 (5.0%)
Saskatchewan	10 (2.7%)	4 (40.0%)	0 (0.0%)
Manitoba	10 (2.7%)	4 (40.0%)	1(10.0%)
Ontario	132 (35.2%)	52 (39.3%)	8 (6.1%)
Québec	122 (32.5%)	76 (62.3%)	8 (6.6%)
New Brunswick	19 (5.1%)	12 (63.2%)	0 (0.0%)
Nova Scotia	18 (4.8%)	8 (44.4%)	0 (0.0%)
PEI	20 (5.3%)	8 (40.0%)	3 (15.0%)
Newfoundland	5 (1.3%)	2 (40.0%)	2 (40.0%)
Total	375	168 (44.8%)	25 (6.7%)

Johne's Disease Results

One bulk tank milk sample from each farm was tested for Johne's disease antibodies using the IDEXX indirect ELISA according to manufacturer's instructions. Herd-level prevalence was determined to be 15% (56 of 375 herd bulk tank samples were ELISA positive). Given that antibody ELISAs for Johne's disease have a low sensitivity, and that testing a bulk tank sample has a lower sensitivity than testing individual animals, this is clearly an underestimate and likely represents the proportion of herds with moderate to high within herd JD prevalence. By comparison, cultures of environmental samples collected from the lactating cow environment and the manure storage yielded positive results in one or more samples from 72 of 372 farms (19%).

Salmonella Dublin Results

One bulk tank milk sample from each farm was tested for Salmonella Dublin using a PCR-based test and a cutoff of ≥ 50 for a positive herd. The overall national herd-level prevalence was 1.1% with only 4 farms testing positive (one in Alberta and three in British Columbia). Environmental fecal samples from each farm were also cultured for Salmonella, but no farms tested positive for S. Dublin only. Salmonella species identified in the environmental samples included Cerro, Montevideo, Kentucky, and Rubislaw.

Lameness, Injury and Tail-Docking

During the Phase 2 farm visits a representative sample of cows was scored for lameness, hock injuries and body condition. The methods used were as described by the proAction program as of April, 2015. Lameness scoring in loose housing was based on the 5-point method described by Flower and Weary (2008), with cows scoring 3, 4 or 5 considered lame. Lameness in tie-stall housing was based on 4 behaviours described in detail in Gibbons et al. (2014), with cows exhibiting two or more of these behaviours categorized as lame. Results of the lameness evaluations, by housing type, are presented in Figure 1. Note that the lameness prevalence for loose housing conditions includes mildly lame cows (Score 3), which have recently been assigned to a 'monitor' category which is separate from the 'requires corrective action' (Score 4 and 5) in the proAction Animal Care program.

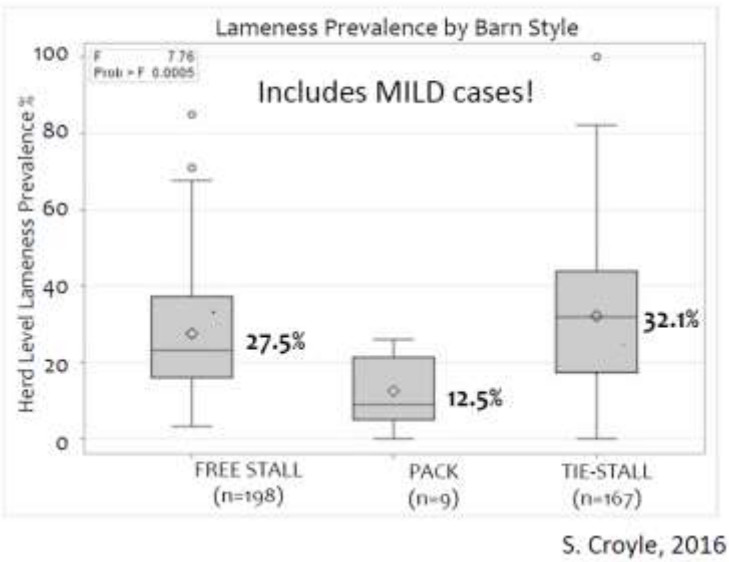
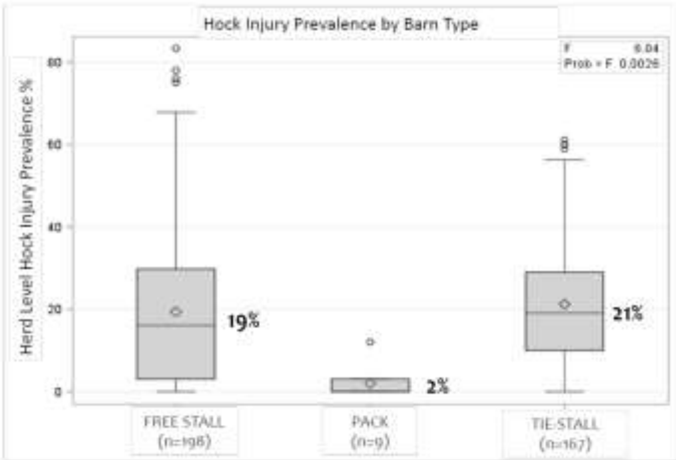


Figure 1. Herd level lameness prevalence by barn style for Phase 2 NDS herds.

Cows were also evaluated for hock injuries and body condition as described in the proAction manual. Hock injury prevalence by housing type is presented in Figure 2. Table 3 summarizes the prevalence of lameness, hock injury and body condition score on dairy farms across Canada, with benchmark ranges based on quartiles. One interesting and controversial practice across the dairy industry is the docking of tails for non-medical reasons. Although there are many industry and professional position statements opposing this practice, 8.5% of Canadian dairy producers indicated that they had cows with tails that were docked for non-medical reasons (Table 4).



S. Croyle, 2016

Figure 2. Herd level hock injury prevalence by barn type for NDS Phase 2 herds.

Table 3. Prevalence and benchmarks for animal-based measure evaluations on Canadian dairy farms during the Phase 2 NDS farm visits.

Animal Care Assessment Summary from National Dairy Study 2015 Herd Visits (n=375)						
Measure	**# Herds Scored**	**Excellent Target**	**Excellent**	**Green (Best 25%)**	**Yellow (Middle 50%)**	**Red (Worst 25%)**
		% of Cows Unacceptable	Met Target	% of Cows Unacceptable	% of Cows Unacceptable	% of Cows Unacceptable
Body Condition Score	372	<5%	369 herds (99.2%)	0% to 0%	0% to 0%	0% to 10%
Hock Injury	375	<10%	129 herds (34.3%)	0% to 5%	6% to 29%	30% to 83%
Lameness - Freestall	222	<10%	40 herds (18.1%)	0% to 13%	14% to 35%	35% to 100%
Lameness - Tiestall	156	<10%	4 herds (2.6%)	0% to 22%	23% to 50%	51% to 92%
Body Condition Score		A cow was deemed unacceptable if she had a body condition score less than or equal to 2 on the 5 point scale.				
Hock Injury		A cow's hock was considered to have an unacceptable injury if there was swelling of more than 1 cm and/or a bald area over the hock with a scab or broken skin.				
Lameness - Freestall		Cows were observed walking for at least 4 strides and scored as having a limp (unacceptable) or no limp (acceptable). A cow was deemed to have a limp if she was favouring one or more limbs.				
Lameness - Tiestall		Cows were scored in their stalls by observation for 1.5 minutes each. A cow was considered lame when she demonstrated 2 or more of the 4 behavioural indicators as described in the proAction manual.				

Table 4. Tail docking for non-medical reasons on Canadian dairy farms.

TAIL DOCK	AB	BC	MB	NB	NL	NS	ON	PEI	QC	SK	TOTAL
NO count	45	46	41	25	6	26	357	26	433	11	1016 **91.5%**
YES count	9	0	2	1	0	0	28	0	55	0	95 **8.5%**
% of **YES**	9.5	0	2	1	0	0	29.5	0	57.9	0	100%

▪ Udder Health and Milk Quality

Milking management

Nationally, 61% of farms required all milkers to wear gloves, 20% had only some of the milkers using gloves, and 19% of farms did not use gloves at all during milking. Of those wearing gloves, 73% indicated that milkers cleaned the gloves during milking, however 59% of these only cleaned them when dirty, 33% cleaned gloves regularly but not between each cow and only 8% cleaned them between each cow. Only 41% of the respondents cleaning gloves cleaned them with a disinfecting solution.

Nationally 61% of the respondents reported using a pre-milking teat disinfectant, and 81% of respondents fore-stripped prior to milking unit attachment. Over 95% of farms cleaned teats before attaching the unit (pre-dip, dry wipe, udder wash, or water wash). The majority of respondents used one disposable paper towel to dry the teats of each cow prior to milking (54%), 23% used a new reusable cloth towel for each cow, 8% used the same towel to dry teats of multiple cows and 13% stated that they did not dry teats prior to milking. Overall 70% of respondents used automatic take-offs with all of their cows, while 21% did not use automatic take-offs at all. Finally, 97% of respondents reported using a post-milking teat disinfectant.

The adoption of recommended milking practices varied across farms, with markedly different adoption rates for different practices. Some of the practices, most notably the use of a post milking teat disinfectant, were reported to be widely adopted. Other practices, including cleaning gloves with disinfectant and use of a pre milking teat disinfectant are much less widely in use.

Acknowledgements

The results presented in this paper are the combined work of a large team of veterinarians from across Canada who conducted the National Dairy Study in 2015. Contributors include H. Barkema (U of Calgary), C. Bauman (U of Guelph), E Belage (U of Guelph), M. Cameron (U of PEI), S Croyle (U of Guelph), J. Denis-Robichaud (U of Guelph), J Dubuc (U of Montreal), and G. Keefe (U of PEI).

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Adapting Current Practices for Automatic Milking Systems: Pros and Cons

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Take Home Messages

- Milking cows using automatic milking systems (AMS) goes against some basic behavioral drives of cattle: gregarious and crepuscular feeding activity.
- The most commonly recommended way of milking cows with an AMS is using free-traffic and investing in labor to fetch cows during times of the day when the waiting area is less cluttered.
- If possible, try to separate primiparous from multiparous cows in order to maximize the number of daily milkings of primiparous cows.
- Using large feed allowances in the AMS does not seem to be an effective strategy to improve milking frequency. Palatability of the feed may be more important than its actual nutrient composition.
- Delivering PMR twice daily or more and limiting concentrate allowance in the AMS to 3-4 kg/d seems to be the optimal strategy to maximize consistency of milkings.
- A combination of multiple concentrates (both in terms of total amount and proportion) to precisely meet nutrient requirements of each cow in the herd is an effective strategy to improve economic returns in herds with AMS

Introduction

The first commercial automatic milking system (AMS) was installed in 1992, and today there are more than 12,000 units installed worldwide. However, the installation of AMS in a dairy herd not only implies a change in the milking parlor, it also entails drastic changes in management, feeding, and even the layout of the facilities. Cows in herds equipped with conventional milking parlors are kept under a structured, consistent, and social milking and feeding routine, whereas in herds equipped with AMS cows are milked at different times every day and at different milking intervals. Furthermore, in most cases of herds with conventional milking parlors, cows obtain all their nutrients from a TMR. Conversely, in herds equipped with AMS, a fraction of their nutrients is provided during milking, mainly as a means to attract cows to the milking system, whereas the remaining fraction is supplied in the feed bunk through a partial mixed ration (PMR). Because of these two aspects, the AMS presents both a challenge and an opportunity for feeding cows. The main challenge resides in that milking frequency in the AMS is dependent not only on the nutritional offer (in terms of both composition and amount) at the AMS (Bach et al., 2007) but also on many other aspects including the social structure of the herd (Bach et al., 2006a), the farm layout design (Thune et al., 2002), the type of traffic imposed to cows (Hermans et al., 2003), and the health condition of the cow, especially lameness (Bach et al., 2006b; Borderas et al., 2008). This article summarizes and discusses behavioral, feeding, and economic aspects when milking cows with AMS in an attempt to overcome challenges and seize opportunities, and contains several excerpts from a review article by Bach and Cabrera (2017).

■ Behavioral Considerations

In herds equipped with an AMS, cows need to attend the milking system individually, which is an unnatural behavior because dairy cows are gregarious and show marked synchronized behaviors (Benham, 1992). Furthermore, diurnal patterns of feeding and lying behaviors of cattle are quite marked with fewer cows feeding and more cows lying down during the night (DeVries et al., 2011; Jacobs, 2011). This behavior tends to be present in both conventional herds and herds equipped with AMS, which typically results in cluttering of the waiting area early and late in the day in herds with AMS. Forcing the cows to break these inherent social behaviors represents one of the most challenging aspects of AMS. Although, it is not difficult to find herds with an average number of milkings per cow and day of about 2.5 (Wagner-Storch et al., 2003; Bach et al. 2009; Deming et al., 2013), in some instances, individual variation in the number of milkings can be high. Most (67%) cows milked in AMS have milking intervals between 6 to 12 h, with 11% of intervals <6 h and 21.5% surpassing the 12 h (Gygax et al., 2007). However, these figures do not represent voluntary milking visits, as they include some cows that had to be fetched and brought to the AMS because their milking interval was excessively long. Uneven and extended milking frequency has been associated with increased risk of mastitis (Stefanowska et al., 2000) and decreased daily milk yield, especially in multiparous cows (Bach and Busto, 2005). Furthermore, after an omitted or a failed milking, cows stand longer in cubicles and lay less than cows that are successfully milked (Stefanowska et al., 2000), which may potentially increase the risk of lameness, the latter of which may affect the number of visits to the AMS (Bach et al., 2006b).

Another social aspect to consider with AMS is the social structure of herd or pen. Cows tend to form a hierarchy among individuals to prioritize access to limiting resources. As a result, dominant cows spend less time in the waiting area than subordinate cows (Melin et al., 2005), and thus milking frequency of subordinate cows is typically lower than that of dominant cows (Halachmi, 2009). Furthermore, experiencing negative social interactions at the waiting area of the AMS may reduce the motivation of cows to revisit the AMS a second time (Jacobs et al., 2012), and thus, subordinate cows are likely to progressively visit the AMS less frequently.

Ironically, all these negative aspects stemming from social behavior of cows milked in AMS could present a great opportunity of AMS because if overcome, it would allow dairy herds to assign different milking frequencies to different cows consistently day after day.

To minimize the variation in milking frequency in cows milked using AMS due to social dominance, gregarious behavior, and crepuscular behavior, it has been proposed to entice cows using feed in the AMS (as discussed later) or imposing cows to what is known as forced or guided traffic, which mainly consists of forcing the cows to visit the AMS before they can reach the feed bunk, or less commonly the resting area. However, both strategies attempt to address a social or behavioral challenge by providing a solution based directly (when feeding in the AMS) or indirectly (when using guided traffic) on nutrition.

Forced or guided traffic consists of controlling access of cows to precious resources (i.e., water, feed, resting) before reaching the AMS. Imposing a forced or guided traffic to cows milked in an AMS improves milking frequency and reduces variation in milking intervals, but it has been reported to also reduce the time that cows have access to the feed bunk (Melin et al., 2007) and it ultimately compromises feed intake (Bach et al., 2009). On the other hand, the negative repercussions of social hierarchy seem to be more relevant under guided- than under free-traffic conditions (Rodenburg, 2012), and guided traffic may compromise the resting times of cows (Thune et al., 2002). It is likely that both the reduction of time access to the feed bunk and lying time with guided traffic situations are the main reasons for the reported decrease in milk production compared with free traffic conditions in a multivariate analysis of field data conducted by Tremblay et al. (2016). Thus, today, the most effective way of milking cows in an AMS is using free-traffic and investing in labor to fetch cows during times of the day when the waiting area is less cluttered.

Lastly, the number of daily visits per cow to the AMS is also dependent on stage of lactation and parity. For instance, primiparous cows visit the AMS more often than multiparous cows (Bach et al., 2006a), and the number of visits to an AMS seems to reach a maximum plateau around 100 DIM (Clark et al., 2014). Addressing the different behavior of primiparous compared with multiparous cows is relatively easy if the herd has several AMS; in that situation the solution consists of grouping all primiparous cows in a single AMS (Figure 1). A more challenging pitfall is the stage of lactation, because cows that are advanced in the lactation curve not only produce less milk and show less visits to the AMS, but they will also be less attracted by the offer of feed in the AMS, which makes it difficult to maintain an adequate milking interval without human intervention.

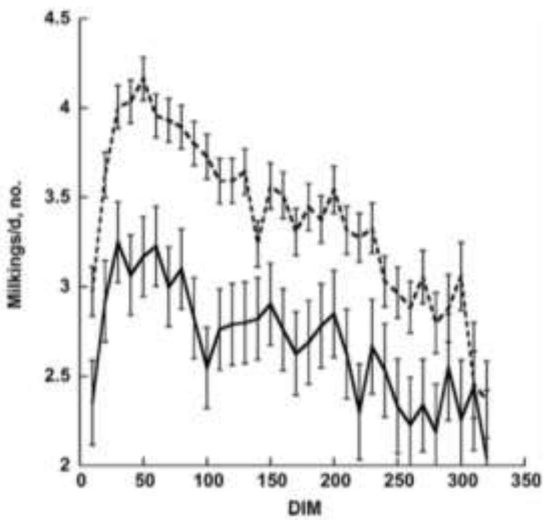

Figure 1. Number of daily milkings of primiparous cows as affected by stage of lactation and grouping strategy. Solid line represents number of daily milkings of primiparous cows housed with multiparous cows; dashed lines represent the number of daily milkings of primiparous cows housed alone (Adapted from Bach et al., 2006a).

■ Feeding Considerations

Concentrate feeding at the AMS is commonly recommended as a means of attracting cows to milking and minimize fetching because cows, if given a choice, will choose feeding over milking (Prescott et al., 1998). A common feeding strategy on many dairy farms equipped with AMS is to start with a low level of concentrates at calving, followed by a linear increase during the first weeks of lactation (Kokkonen et al., 2004). Around lactation peak, from week 3 until weeks 10–14, concentrate supply increases as milk yield increases, and after that, concentrate allowance is lowered following the decline in milk yield (André et al., 2010). But, in addition to the progressive decline in milk yield and subsequent appetite, a challenge to overcome is the relatively large variation in the number and frequency of visits to the AMS. These deviations in feed intake between days may carry some negative consequences beyond those associated with inconsistent milking frequency. Variation in nutrient supply, per se, has been shown to negatively affect milk production. For example, Sova et al. (2014) described a negative relationship between the coefficient of variation of NEl content of a TMR and milk production across 22 surveyed dairy herds. On the other hand, it has been shown that cows subjected to 4 and 6 h feeding periods were able to learn each routine and adapt the timing of their movement to and from the feed bunk to match the duration of the feeding period (Livshin et al., 1995). Thus, if feed is provided during milking, in a conventional herd, cows could anticipate they would be fed in the parlor and thus they could adapt their eating pattern to accommodate that meal. In an AMS, however, the fluctuations in milking and eating patterns make it difficult for the cow to maintain a constant intake of PMR and concentrate and keep the proportion of forage to concentrate in the total diet constant.

Cows do not typically consume all their concentrate allowance in the AMS, especially when concentrate offer is high (i.e., > 4 kg/d) and the amount of unconsumed concentrate seems to increase as concentrate allowance increases (Bach and Cabrera, 2017). In addition, large concentrate allowances in the AMS are typically coupled with feeding a PMR with a low nutrient density, and thus if cows do not consume all concentrate allocated in the AMS their nutrient supply is compromised, which could hamper milk production and profits. In fact, Tremblay et al. (2016) found a negative association between concentrate allowance in the AMS and milk yield. Interestingly, Halachmi et al. (2005) compared milking frequency when limiting concentrate delivery at each milking to 1.2 kg vs. a maximum allowance of 7 kg/d, and reported no difference in the number of voluntary visits to the AMS. Similarly, Bach et al. (2007) compared a concentrate allowance of 3 to 8 kg/d and reported no differences in the number of daily visits to the AMS. Thus, using large amounts of feed to improve milking frequency does not seem to be an effective strategy, as evidenced by some authors successfully milking cows on pasture with as little as 300 g of concentrate per visit (Scott et al. 2014) or even without supplementing concentrate in an AMS (Jago et al., 2007).

Another reason for limiting concentrate supply in the AMS is the time constraint that cows face when attempting to consume their entire concentrate allowance. Cows typically consume TMR and PMR at a rate ranging between 50-150 g/min (Bach et al., 2007; Bach et al., 2009; DeVries et al., 2009) and pellet concentrates between 250 and 400 g/min (Kertz et al., 1981). Considering an average time spent in the AMS per milking of about 7 min (Castro et al., 2012), cows could consume at most an average of about 2.8 kg of concentrate per milking. Because in most occasions the average number of visits to an AMS is < 3/d (Wagner-Storch et al., 2003; Bach et al., 2009; Deming et al., 2013) a cow could consume a theoretical maximum average of 8.4 kg of concentrate per day. Therefore, using concentrate allowances > 8 kg/d are likely to fail, and to take advantage of precision feeding approaches (as discussed later) in AMS, the amount of concentrate allowance should be kept low (i.e., < 4 kg/d). However, an interesting approach to increase the motivation to visit the AMS may consist of offering the PMR more frequently. Deming et al. (2013) reported that cows fed a PMR twice daily visited the AMS about 2 h closer to each feed delivery time than cows fed once a day, which would indicate that delivering PMR is a strong motivating stimulus for cows to visit the AMS (under free traffic conditions).

Taking into account the nutritional composition of the concentrate offered in the AMS is also important. For example, feeding concentrates with a high content of starch may not only affect the appetite and feeding behavior of the cows, but also the rate and extent of NDF digestibility and rumen pH, which may in turn alter milk composition and production, as well as increase the risk of lameness (Oba and Wertz-Lutz, 2010) – all of which may decrease the frequency of visits to the AMS (Bach et al., 2006b; Borderas et al., 2008). Regarding milk production and composition, Miron et al. (2004) reported that feeding concentrates high in starch content increased milk protein content and feeding concentrates rich in digestible fibre (e.g., soybean hulls) increased milk fat content. On the other hand, Halachmi et al. (2006) compared 2 concentrates (25 vs 49% starch) and reported similar numbers of voluntary milkings (3.31 vs. 3.39 visits/cow.d), milk yield, and milk components. The difference in these 2 studies was mainly that Miron et al. (2004) used 8 kg/d of concentrate allowance, whereas Halachmi et al. (2006) limited concentrate allowance to 3 kg/d. Thus, it can be inferred that if concentrate allowance is kept low (i.e., 3 kg/d) nutrient composition of the concentrate at the AMS has minor repercussions on yield, milk composition, and number of visits to the AMS. Therefore, more than the provision of nutrients, it seems that offering palatable feed is what drives cows to visit the AMS. Madsen et al. (2010) concluded that cows prefer concentrates based on a mixture of barley and oat, and that cows prefer wheat over corn or barley. Regarding the physical form of the concentrate offered at the AMS, a pellet form is preferred over mash or meal form (Spörndly and Åsberg, 2006). Also, the hardness of the pellet should be high as crumbles and fines diminish the intake of dairy cows (Rodenburg et al., 2004).

Lastly, the supply of minerals and vitamins with AMS should also be considered. Typically, these components are thought to have poor acceptability by cows and are commonly excluded from the concentrate used in AMS and are only supplied through the PMR. However, as milk yield increases and concentrate allowance at the AMS is also increased, the amount of minerals that the cow will consume might be limited because the increase in DMI is mainly driven by an increase in concentrate intake rather than PMR intake. For instance, Bach et al. (2007) evaluated milk and intake responses in cows milked using an AMS and offered either 3 or 8 kg of concentrate/d, and calculated that for every unit of increase in concentrate intake at the AMS, there was a concomitant reduction in PMR consumption equivalent to 1.15 units.

■ Social and Economic Considerations

Many producers install AMS because they either have difficulties hiring labour or want to minimize external labour on the farm. However, AMS systems reduce the need for milkers but do not necessarily reduce the labour needed, for instance, fetching cows. The number of cows needed to be fetched into the AMS bears important economic costs both from a labour and a loss of production stand point, and it typically voids the expected profits (i.e., reduced labor and increased milk yield) behind the decision of installing an AMS. A Canadian survey reported that 4 to 25% of the cows had to be fetched to the AMS for milking (Rodenburg and House, 2007). Further, a study conducted in the Netherlands (Steeneveld et al., 2012) concluded that herds with AMS have greater capital costs per unit of milk produced over conventional herds, but both types of herds have similar labour costs (thus, the apparent labour savings associated with AMS were not realized in practice).

Nevertheless, maximum return on the investment of an AMS is attained, in theory, when cows adapt their own daily routine and traffic around the system, resulting in full utilization of the AMS with little or no human intervention. This can be achieved, as discussed above, by addressing behavioral and nutritional aspects. But, AMS systems offer an interesting opportunity to feed cows using a precision feeding approach. Precision feeding has the potential to improve productivity, and most importantly, efficiency of production by meeting each individual cow's nutrient requirements accurately. The AMS technology bears the appealing opportunity to overcome the inefficiencies linked to TMR or PMR feeding, where cows are fed to an average production and some cows receive either less or more nutrients than what they need. Furthermore, cows need to consume the right amount of a balanced-nutrient meal. In other words, because intake is variable between and within cows, depending on stage of lactation, BW, etc..., a "balanced" mouthful of TMR for one cow may be an "imbalanced" mouthful for another cow in the same pen. As a result, both energy and protein balance progressively differ at different proportions as milk production deviates from the one the ration was originally balanced for (Figure 2).

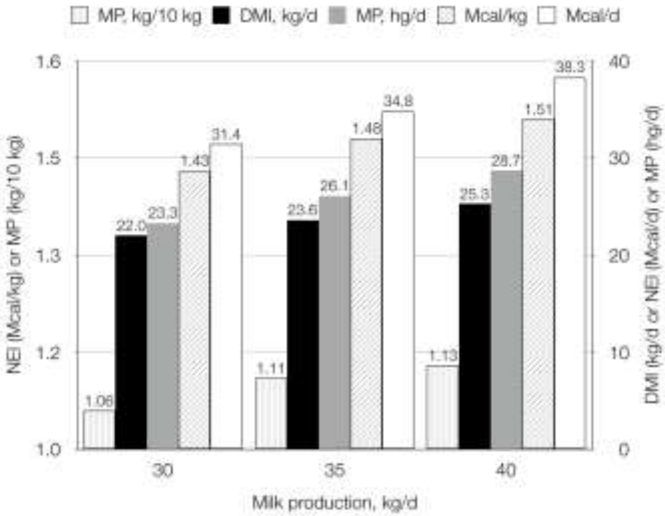

Figure 2. Dry matter intake, metabolizable protein (MP) and net energy (NEl) for different milk yields according to NRC (2001). The proportion of MP and NEl in the total diet is not constant and increases at different rates for MP and NEl as milk yield increases (Adapted from Bach and Cabrera, 2017).

Implementing precision feeding strategies with AMS (and in other situations such as parlor feeding) bears the challenge of estimating (and monitoring) the expected milk response obtained for any given concentrate supplementation. The efficiency at which the concentrate will be used to produce milk is a driver for profit, and thus, if milk yield response is below expectations, supplementing concentrates may not be a profitable decision, especially if milk prices are low and feed costs are high. Most AMS systems are equipped with one single bin for delivering concentrate to cows. Under this situation, as it would occur with TMRs, the AMS offers a feed with a fixed chemical and nutritional composition with the only variable in the system being the amount of concentrate that each cow is entitled to consume on a daily basis. Thus, depending on the nutrient density of the PMR, the stage of lactation and milk production, cows receive different amounts of feed. But, as described above, the composition of the pellet or mash offered is the same regardless of the amount of milk produced, and thus nutrient supply progressively becomes imbalanced as milk yield deviates from the one used to formulate the feed supplement. An interesting opportunity to maximize returns from an AMS is through using a combination of feeds (e.g., an energy source and a protein source) fed to cows at different proportions and quantities according to milk yield, BW, stage of lactation, and even, with some milking systems, milk components.

Lastly, milk harvested per cow and milking is related to the time elapsed since the previous milking – a relationship which is more or less linear until 16 h and constant thereafter (Delamaire and Guinard-Flament, 2006). Tremblay et al. (2016) showed that as the number of cows per AMS increases, the number of milkings is reduced (i.e., milking interval increases), and the time that cows occupy the AMS is increased. Despite the fact that both milking frequency and time spent in the AMS per milking increase milk production, these 2 aspects rarely increase simultaneously (Tremblay et al., 2016). It is commonly recommended that the number of animals per AMS should be around 60-70 cows. But, results from the literature suggest that to attain maximum milk harvesting capacity of an AMS, the goal should be maximizing milk yield per cow instead of increasing the number of cows. Typically, decreasing the number of cows per AMS decreases the time cows spend waiting in the pre-milking area, particularly for low socially ranked or less experienced cows (Halachmi, 2009). Moreover, small reductions in cow numbers are commonly compensated for by increases in milk production from the remaining cows because the number of milkings increases and time spent milking decreases (Tremblay et al., 2016).

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Nutritional Management of Fresh Cows: Helping for Smooth Take Off

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▪ Take Home Messages

- It is recommended to prepare a different TMR for fresh cows, if possible, to address their specific needs.
- Animal responses to supplemental fat vary depending on stage of lactation; more variable and sometimes negative during the fresh period compared with peak lactation. Fresh cows, mobilizing their fat reserves, have limited capacity to metabolize additional fatty acids supplied from diets. Fat supplementation requires caution during the fresh period.
- Increasing dietary starch content does not always increase milk production of fresh cows. Cows fed high-starch close-up diets may respond better to high starch diets postpartum, but cows fed low-starch controlled-energy diets before calving likely respond better to low starch diets during the fresh period. The fresh period is a part of the calving transition period, and optimum postpartum nutritional management is likely affected by nutritional management before calving.
- Cows with sub-acute rumen acidosis alter their feed preference, and attempt to consume more long forage. We should provide fresh cows with top-dressed long hay in addition to TMR to allow them to consume more physically effective fibre, as needed, to attenuate rumen acidosis.
- Increasing metabolizable protein supply in the fresh diets may lead to greater milk production.
- Feeding *Saccharomyces cerevisiae* fermentation products may increase DMI during the peripaturient period and improve health of fresh cows.

■ Introduction

The calving transition period can be defined as a period from 3 weeks prior to calving to 3 weeks after calving. Nutritional management during the calving transition period is critically important as it affects health, milk production, and reproductive performance of dairy cows. Nutritional management during the pre-partum phase of this transition period (i.e., close-up period) has been extensively studied over the last few decades, but only limited data exist for the nutritional management of the post-partum phase of the transition period (i.e., fresh period). As fresh cows usually experience a negative energy balance, some nutritionists try to maximize their energy intake by increasing the energy density of diets, but this effort does not necessarily increase energy intake if DMI is reduced. For example, feeding high starch diets or high fat diets increases energy density of diets, but their effects on energy intake, energy balance, and overall productivity of dairy cows are not very consistent. The objectives of this paper are to review several recent research publications that evaluated the nutritional management of fresh cows and to discuss how to optimize their performance.

■ Should We Feed High Fat Diets to Fresh Cows?

Generally speaking, fat supplementation is a useful approach to increase milk production and improve reproductive performance of high producing dairy cows, but it is important to note that high fat diets do not always work positively for fresh cows. Animal responses to high fat diets during the fresh period are not consistent in the literature. Sklan et al. (1991) fed Ca salts of fatty acids (48.1% palmitic acid, 4.4% stearic acid, 40.2% oleic acid, and 7.4% linoleic acid) during the first 120 d after calving and reported positive effects on overall milk production and reproductive performance. However, the fat supplementation increased BW loss during the first few weeks after calving.

Beam and Butler (1998) fed prilled fatty acids (Energy Booster-100®; Milk Specialties Co., Dundee, IL) to increase dietary fat content from 4.8 to 7.0%. They found that cows fed the high fat diet decreased DMI during the first 4 week after calving (15.5 vs. 17.3 vs. kg/d), and reported a tendency for diet x week interaction where cows fed the high fat diet decreased milk yield during the first 3 week after calving, but increased milk yield starting 5 week after calving.

Piantoni et al. (2015) fed saturated fatty acids (46.2% stearic acid and 37.0% palmitic acid) to fresh cows from d 1 to 29 after calving, and reported that the fat supplementation increased DMI (23.6 vs. 22.2 kg/d) and decreased BW loss (-96 vs. -118 kg). However, in their study, the diet high in saturated free fatty acids tended to decrease milk yield (46.6 vs 49.7 kg/d).

More recently, de Souza and Lock (2017) fed a high fat diet supplemented with palmitic acid either during the fresh period (until 24 days in milk) or peak period (25 to 67 days in milk). The high fat diet did not affect milk yield and decreased BW (668 vs. 709 kg) in the fresh period, but increased milk yield (58.0 vs. 54.6 kg/d) without affecting BW during peak lactation.

These studies collectively indicate that animal responses to high fat diets are highly variable during the fresh period, and less positive – or sometimes even negative – compared to the peak lactation period. Variable animal responses reported in the literature are partly attributed to different type of fatty acids evaluated in the studies, but it is apparent that fresh cows respond to fat supplementation differently than cows in peak lactation.

A variable lipolytic state is a possible reason for inconsistent animal responses to fat supplementation during the fresh period. Cows have limited capacity to metabolize fat, and supplemental fat during the fresh period may exceed the capability to metabolize fat if cows excessively mobilize their body reserve (Palmquist, 1994). Some cows may lose more body condition than others depending on cow comfort, management during the transition period, and BCS at calving. Feeding high fat diets is not recommended in herds where cows excessively lose body condition because fat supplementation may delay recovery of DMI, thereby making the situation even worse. However, in dairies with good transition management, where the postpartum increase in feed intake is smooth, cows do not mobilize their own fat excessively and as such they have the metabolic capacity to deal with fat supplied from diets. In such herds, it is likely that animals respond to fat supplementation more positively and sooner after calving.

▪ Should We Feed High Starch Diets to Fresh Cows?

Another approach to increase diet energy density is to increase starch content of diets. Increasing dietary starch content generally improves the energy status of animals indicated by blood metabolites. Penner and Oba (2009) and McCarthy et al. (2015b) reported that increasing starch content of fresh diets increased blood glucose concentration and decreased plasma concentrations of NEFA and BHB. However, it is noteworthy that animal responses to high starch diets in milk production have not been consistent in the literature.

McCarthy et al. (2015a) compared the effects of feeding TMR differing in dietary starch content during the fresh period (26.2 vs. 21.5%) and reported starch content x week interactions for DMI and milk yield, indicating that cows fed the high starch diet had faster increase in DMI (15.6 vs. 14.8 kg/d) and milk yield (31.0 vs. 29.8 kg/d) during the first 3 weeks after calving. In addition, cows fed the high starch diet decreased BCS to a lesser extent (-0.21 vs. -0.33) and experienced less negative energy balance (-6.8 vs. -11.8 Mcal/d) during the fresh period compared with those fed the low starch diet.

Similarly, Piantoni et al. (2015) compared fresh diets differing in dietary forage NDF content, which also differed in dietary starch content (24.0 vs. 17.5%), and reported that cows fed the high-starch fresh diets increased DMI compared with those fed the low starch diet (23.9 vs. 21.9 kg/d), although milk yield was not affected.

Contrarily, a recent Dutch study (Dieho et al., 2016) reported that milk yield was greater for cows fed low starch diets during the fresh period. Dieho et al. (2016) evaluated two different rates of increase in concentrate allowance after calving. After cows were fed concentrate at 0.9 kg/d for 3 d immediately after calving, they were assigned to treatment of either rapid (RAP; a 1.0-kg increase per day over a 10-d period to reach the maximum allowance of 10.9 kg/d on d 13) or gradual increase in concentrate allowance (GRAD; a 0.25-kg increase per day over a 40-d period to reach the maximum allowance of 10.9 kg/d on d 43). The starch contents were 13.9 and 24.8%, respectively, for basal TMR and concentrate. Although dietary starch contents have changed throughout the experimental period depending on the treatments and actual intake of the basal TMR, cows on the RAP treatment were obviously fed more starch during the fresh period. Although total DMI was not affected by treatment, milk yield tended to be lower for RAP than GRAD treatment (i.e., for cows fed high starch diets; 33.2 vs. 37.6 kg/d).

Dieho et al. (2016) reported negative responses to high-starch fresh diets, while McCarthy et al. (2015a) and Piantoni et al. (2015) reported positive responses to high-starch fresh diets. These discrepancies may be attributed to different starch contents of close-up diets that animals were fed before calving. Dann (2016) made similar observations as Dieho et al. (2016) and speculated that cows fed high-starch close-up diets would respond better to high-starch fresh diets while cows fed low-starch controlled-energy diets before calving would respond better to low-starch fresh diets. Consistent with this speculation, in the studies of McCarthy et al. (2015a) and Piantoni et al. (2015), starch contents of close-up diets were relatively high (17.4 and 18.1%, respectively) while Dieho et al. (2016) fed a low-starch close-up diet (9.0%). Fresh cows might need to be metabolically ready, by being fed high-starch close-up diets, to benefit from highly fermentable diets after calving.

More and more dairies are feeding controlled-energy diets before calving (feeding straw at approximately 30% of dietary DM) to avoid excess energy intake before calving and reduce metabolic complications after calving (Mann et al., 2015). It is important to check what diet is being fed to close-up cows when the nutritional management of fresh cows is discussed. The optimum starch content of fresh diets is likely affected by the starch content of close-up diets, and high starch diets may not always work during the fresh period. The fresh period should not be considered as a stand-alone period, but rather as a part of the whole calving transition period.

Several other studies conducted at U of A evaluated the effects of starch content of fresh diets. Penner and Oba (2009) replaced corn grain with sucrose in a diet for fresh cows to increase dietary sugar content from 4.5 to 8.7% and to decrease dietary starch content from 20.6 to 18.5%. They reported that the high sugar diet (i.e., low starch diet) increased DMI (18.3 vs. 17.2 kg/d) and tended to increase mean rumen pH (6.21 vs. 6.06) and milk fat yield (1.44 vs. 1.35 kg/d), although milk yield was not affected by treatment. Dyck et al. (2011) replaced a part of barley silage with corn starch in a diet for cows in early lactation (from calving to 70 days in milk) to increase dietary starch content from 23.3 to 26.7%, but reported that the high starch diet did not increase DMI, milk production, or energy balance. Sun and Oba (2014) fed high vs. low starch diets (29.2 vs. 19.1%; rolled barley grain was replaced by wheat DDGS for the low starch diet) to cows in early lactation (from calving to 12 weeks in lactation) and reported no difference in milk yield, even with a 10%-unit difference in dietary starch content.

Both Penner and Oba (2009) and Sun and Oba (2014) reported that energy balance, indicated by plasma NEFA concentration, was better for cows fed the high starch diets, but that cows fed the high starch diets did not increase milk yield. These observations indicate that high starch diets may not always increase milk yield of fresh cows, and other energy sources, such as sugar or digestible fibre, are at least as effective as starch to maintain milk production during the fresh period. Interestingly, both Dyck et al. (2011) and Subramaniam et al. (2016) reported that high starch diets increased the incidence of multiple ovulations compared with those fed the low starch diets, although dietary starch content did not affect overall reproductive performance in their studies.

▪ Should We Feed More Physically Effective Fibre to Fresh Cows?

It is also important to note that fresh cows have a greater risk of sub-acute rumen acidosis (SARA; Penner et al., 2007), and appropriate management actions should be taken to reduce the severity of SARA. Keunen et al. (2002) reported that cows with SARA altered feed preference when given a choice of feeds; they decreased intake of alfalfa pellet and increased intake of long alfalfa hay, which provides more effective fibre to stimulate chewing and salivary buffer secretion, thereby attenuating SARA. However, Keunen et al. (2003) reported in a follow-up study that SARA cows did not increase their intake of sodium bicarbonate, indicating that long hay is a preferred feedstuff for cows experiencing SARA.

Maulfair et al. (2013) made similar observations. They prepared a TMR with long-particle forage and dry cracked corn (slowly-fermenting starch) and a TMR with short-particle forage and fine ground corn (faster-fermenting starch). They offered both of them side by side to animals before and after SARA was induced. Although animals preferred the TMR with short-particle forage during the baseline period, they altered feed preference after SARA was induced. The relative intake of TMR containing long-particle forage increased on the day of SARA and the following day (i.e., recovery day), then decreased to the baseline level. These observations indicate that cows with SARA attempt to increase consumption of long-particle forage to mitigate the severity of SARA.

Considering the greater risk of SARA in fresh cows (Penner et al., 2007), it may be wise to consider formulating a different TMR for fresh cows, and feed less starch and more physically-effective highly-digestible forage fibre. Alternatively, if it is difficult to prepare a different TMR for fresh cows, we should at least consider offering fresh cows top-dressed long hay in addition to a common TMR for lactating cows. This approach allows fresh cows to consume additional hay, as needed, to attenuate SARA that they likely experience after calving.

■ Should We Feed High Protein Diets to Fresh Cows?

Fresh cows do not only mobilize their fat reserves, but also their protein reserves to support milk production. As such, it is important to consider specific nutrient needs on the protein side as well. Carder and Weiss (2017; Table 1) recently evaluated three diets differing in supply of metabolizable protein (MP) and amino acid profile during the fresh period (d 3 to 23 after calving); MP-allowable milk yield was 25 and 30 kg/d for the low MP diet and the high MP diets, respectively, assuming 17 kg/d of DMI. One of the high MP diets was balanced for the optimum amino acid profile (+AA; containing Met and Lys at 2.60 and 7.20 % of MP, respectively) while the other high MP diet was not (-AA; containing Met and Lys at 1.83 and 6.33 % of MP, respectively). They showed that feeding the high MP diets increased energy-corrected milk yield and decreased plasma concentration of 3-methylhistidine, which is an indicator of muscle protein turnover. Although the long-term carryover effects of reduced muscle protein mobilization on milk production were not observed in their study, these findings suggest that greater MP supply to fresh cows has beneficial effects.

Table 1. Effects of dietary starch content on milk yield of fresh cows (adapted from Carder and Weiss, 2017)

	Low	High MP		P values*	
	MP	- AA	+ AA	MP	AA
DMI, kg/d	17.8	18.0	18.5	NS	NS
Milk yield, kg/d	33.6	34.7	33.2	NS	NS
Milk fat, %	3.80	4.21	4.51	< 0.01	NS
Milk protein, %	3.17	3.17	3.30	NS	0.04
Energy-corrected milk yield, kg/d	35.3	38.6	38.4	0.05	NS
Plasma 3-methylhistidine, µM	5.80	4.50	4.55	0.03	NS

* MP = contrast between low MP diet vs. two high MP diets; AA = contrast between -AA vs. +AA.

▪ Recent University of Alberta Study

We recently completed a study evaluating nutritional management during the calving transition at the University of Alberta (Shi et al., unpublished). In this study, we evaluated the effects of supplementing a novel *Saccharomyces cerevisiae* fermentation product (SCFP; NutriTek; Diamond V Mills Inc., Cedar Rapids, IA) during the periparturient period and dietary starch content during the first three weeks immediately after calving. The SCFP was mixed in TMR to provide 19 g/d assuming DMI of 11 and 20 kg/d for prepartum and postpartum cows, respectively. Experimental diets were fed from 4 weeks prior to the expected calving date to 6 weeks after calving. All animals were fed a common basal close-up diet (13.9% starch, 15.3% CP, 1.43 Mcal of NEL/kg DM), and fed either a high starch (28.3% starch, 17.2% CP, 1.64 Mcal of NEL/kg DM) or a low starch diet (22.0% starch, 17.2% CP, 1.61 Mcal of NEL/kg DM) during the first three weeks after calving. All cows were fed the high starch diets from week 4 after calving.

Cows fed the low starch diets had greater milk yield compared with those fed the high starch diets during the first 3 week after calving (34.1 vs. 32.1 kg/d; Table 2). Moreover, they tended to have greater milk yield even after they were switched to the high starch diets (Week 4 to 6 after calving; 42.3 vs. 40.3 kg/d). These are consistent with the findings of Dieho et al. (2016), as discussed in the previous section. It is noteworthy that both Dieho et al. (2016) and the current study fed low-starch controlled-energy diets before calving, and observed greater milk yield in cows fed low starch diets during the fresh period.

Table 2. Effects of starch content of fresh diets and supplementation of a novel *Saccharomyces cerevisiae* fermentation product (SCFP) during the periparturient period on postpartum DMI and milk production

	Low Starch		High Starch		P values		
	CON	SCFP	CON	SCFP	Starch	SCFP	INT
Week 1-3							
DMI, kg/d	16.2	17.2	16.4	17.5	0.57	0.22	0.36
Milk yield, kg/d	34.4	33.8	31.1	33.0	0.05	0.54	0.24
Milk fat, kg/d	1.48	1.61	1.53	1.53	0.73	0.22	0.21
FCM / DMI	2.54	2.51	2.52	2.49	0.79	0.72	0.98
Week 4-6							
DMI, kg/d	20.7	19.9	20.6	19.8	0.77	0.10	0.98
Milk yield, kg/d	42.6	41.9	39.4	41.2	0.09	0.60	0.27
Milk fat, kg/d	1.56	1.66	1.60	1.63	0.92	0.21	0.46
FCM / DMI	2.12	2.29	2.14	2.26	0.91	0.01	0.62

The greater milk yield for cows fed the low-starch fresh diets observed in the recent U of A study cannot be attributed to greater energy intake because DMI and total tract OM digestibility were not affected by dietary starch concentration. In addition, energy status indicated by plasma metabolites was better for cows fed the high starch diets (Table 3). Furthermore, cows fed the low starch diets tended to lose more BCS during the first 3 weeks after calving (-0.42 vs. -0.35 /21d). As such, the reasons for greater milk production for cows fed the low starch diets are not clear; however, cows fed the low starch diets had greater apparent total tract NDF digestibility compared with those fed the high starch diets on d 7 ± 3 after calving (40.7 vs. 35.3%), indicating that the low-starch fresh diets provided more energy from fibre fermentation in the rumen, which can supply energy to animals more consistently over time, and indicate that how energy is supplied might be an important factor affecting productivity of fresh cows. However, further research is warranted to evaluate this speculation.

Table 3. Effects of starch content of fresh diets and supplementation of a novel *Saccharomyces cerevisiae* fermentation product (SCFP) during the periparturient period on plasma metabolite concentrations

	Low Starch		High Starch		P values		
	CON	SCFP	CON	SCFP	Starch	SCFP	INT
d 7 ± 3 after calving							
Glucose, mg/dL	58.5	56.2	61.0	59.6	0.05	0.23	0.75
NEFA, mEq/L	568[a]	423[b]	386[b]	463[ab]	0.16	0.50	0.03
BHB, mg/dL	9.34	8.44	9.23	8.51	0.98	0.20	0.90
d 21 ± 3 after calving							
Glucose, mg/dL	58.2	59.4	64.6	63.2	< 0.01	0.96	0.43
NEFA, mEq/L	416[a]	331[ab]	274[b]	368[ab]	0.23	0.91	0.04
BHB, mg/dL	9.66	10.2	8.30	8.01	0.01	0.83	0.54
d 42 ± 3 after calving							
Glucose, mg/dL	59.0	65.0	62.6	67.9	0.06	< 0.01	0.75
NEFA, mEq/L	360[a]	207[b]	250[ab]	345[a]	0.73	0.47	< 0.01
BHB, mg/dL	8.43[ab]	8.57[ab]	10.1[a]	7.55[b]	0.59	0.05	0.03

[ab] Superscripts differ if treatment means in a row differ significantly ($P < 0.05$)

Another interesting observation made in the recent U of A study is the effect of SCFP on periparturient DMI. Cows fed SCFP had greater DMI on d 1 and 5 after calving (Figure 1). In this study, reductions in DMI during a 7-d period immediately before calving were minimal regardless of treatment, possibly because all cows were fed a controlled-energy close-up diet containing straw at approximately 30% of diet DM. However, cows fed SCFP had greater DMI on d 1 when cows were switched to lactation diets regardless of dietary starch content. In addition, on d 5 after calving, when cows on the control diets slightly decreased DMI, cows fed SCFP continued to increase DMI.

In addition, serum concentration of haptoglobin, an acute phase protein, was lower for cows fed SCFP supplementation on d 7 after calving (Figure 2), which might indicate that the cows had less subclinical disease, tissue damage, or infections. Supplementation of SCFP might have contributed to a more stable rumen fermentation environment (Li et al., 2013) or altered some inflammatory mediators (Zaworski et al., 2014; Li et al., 2016), leading to greater DMI during the periparturient period.

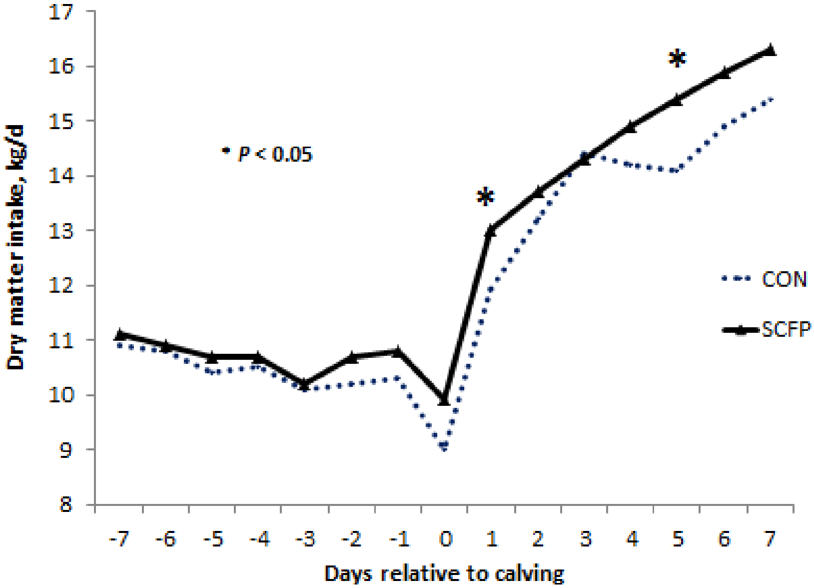

Figure 1. Effects of supplementation of a novel *Saccharomyces cerevisiae* fermentation product (SCFP) during the periparturient period on DMI (kg/d) from 7 d before calving to 7 d after calving

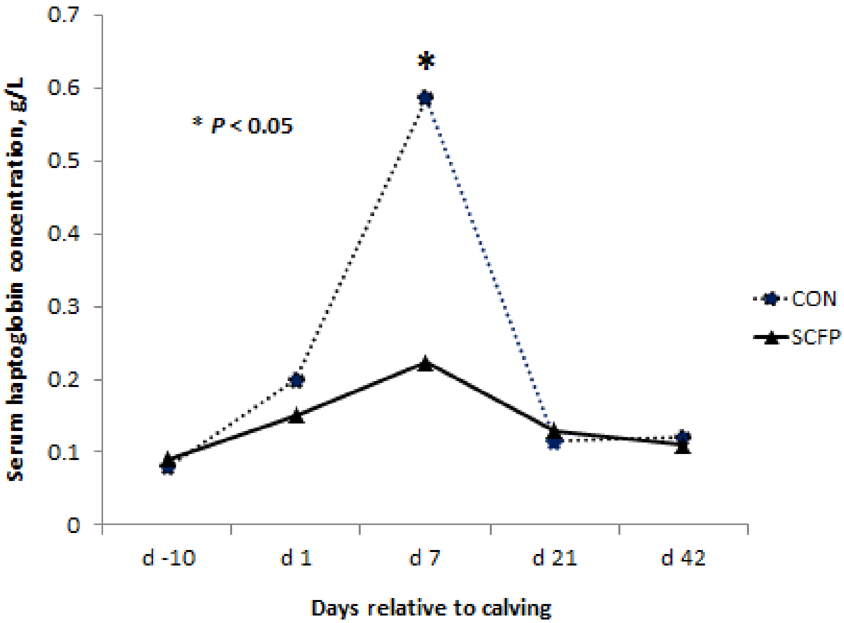

Figure 2. Effects of supplementation of a novel *Saccharomyces cerevisiae* fermentation product (SCFP) during the periparturient period on serum haptoglobin concentration (g/L) from 10 d before calving to 42 d after calving

▪ Conclusion

Increasing dietary fat and starch contents is a common approach to maximize energy intake and milk production for cows in peak lactation. However, fresh cows are under a unique physiological state and their responses are often different from cows in peak lactation. For example, some fresh cows, especially in a lipolytic state, do not respond positively to fat supplementation. Similarly, feeding high starch diets during the fresh period may decrease milk production, particularly if a low-starch controlled-energy diet is fed during the close-up period. As such, it is recommended to feed a different diet just for fresh cows to address their specific needs. This approach would also allow us to include some expensive supplements in their diets in a cost-effective manner because a small number of animals, who would show greater responses than the others, can be targeted. If it is difficult to prepare a different TMR for fresh cows, thus offering top-dressed long hay along with a common lactating cow TMR should be considered to allow fresh cows to consume more physically-effective fibre to mitigate the risk of SARA.

Optimizing nutritional management of fresh cows helps enable a smooth take off for successful lactation performance.

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Recent Advances in Our Understanding of Fatty Acid Digestion and Metabolism in Lactating Dairy Cows

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Take Home Messages

- Identify what you are trying to achieve, then design your nutritional program (including fatty acid [FA] supplementation) around those objectives. Evaluate the effects of individual FA and commercial FA supplements on production performance and tangible factors not measured daily in the tank.
- Important to consider the possible effects of FA in the rumen, in the small intestine, in the mammary gland, and energy partitioning between tissues.
- Not all FA or fat sources are the same. Know what FA are in the supplement you are using. The profile of supplemental FA is key in determining production responses and energy partitioning.
- Digestibility appears to be a good indicator of inclusion or not of a FA in the diet, assuming that this source of FA does not markedly affect DMI.
- Use of supplemental FA in the fresh period should be considered; new research suggests that FA supplementation increases performance in fresh cows.

Introduction

Recently, the effects of individual fatty acids (FA) on digestibility, metabolism, and production responses of dairy cows has received renewed attention. The addition of supplemental FA sources to diets is a common practice in dairy nutrition to increase dietary energy density and to support milk production. The ability to understand and model FA, the effects of individual FA, and different FA supplements on production parameters has direct impact on dairy industry recommendations and the usefulness of FA supplementation strategies. In fresh cows, the high metabolic demand of lactation and reduced DMI during the immediate postpartum period result in a state of negative energy balance. Approaches to increase the energy intake of postpartum cows include increasing starch content of the diet and supplementing FA to increase the energy density of the diet. However, feeding high starch diets that promote greater ruminal propionate production during early lactation could be hypophagic and therefore further reduce DMI and increase the risk of ruminal acidosis and displaced abomasum (Allen and Piantoni, 2013). Regarding supplemental FA, some authors suggest that caution should be exercised when using dietary FA to increase the caloric density of diets in early lactation dairy cows since a high lipid load may affect the endocrine system, feed intake, and increase the risk for metabolic disorders (Kuhla et al., 2016). However, just as we recognize that not all protein sources are the same, it is important to remember that not all FA or FA supplements are the same. We will briefly review the biological processes and quantitative changes during the metabolism of FA, the digestibility of these FA, and their overall impact on performance. Our emphasis in the current paper is on recent research supplementing palmitic (C16:0), stearic (C18:0), oleic (*cis*-9 C18:1), omega-3, and omega-6 acids on feed intake, nutrient digestibility, milk production and milk composition, health, and reproduction.

▪ C16:0, C18:0, and *Cis*-9 C18:1 Effects on FA Digestibility

Our recent FA digestibility research utilized and focused on C16:0, C18:0, and *cis*-9 C18:1. Of particular importance, Boerman et al. (2017) fed increasing levels of a C18:0-enriched supplement (93% C18:0) to mid-lactation dairy cows and observed no positive effect on production responses, which was likely associated with the pronounced decrease in total FA digestibility as FA intake increased (Figure 1A). Similarly, Rico et al. (2017) fed increasing levels of a C16:0-enriched supplement (87% C16:0) to mid-lactation dairy cows and even though a positive effect was observed on production response up to 1.5% diet DM, a decrease in total FA digestibility with increasing FA intake was observed (Figure 1B). However, considering that the range in FA intake was similar across both studies, the decrease in total FA digestibility was more pronounced when there was increased intake/rumen outflow of C18:0 rather than C16:0. This is supported by our meta-analysis, in which a negative relationship between the total flow and digestibility of FA was observed, with the decrease in total FA digestibility driven by the digestibility of C18:0 because of the negative relationship between duodenal flow and digestibility of C18:0 (Boerman et al., 2015). The exact mechanisms for these differences in digestibility are not understood; however, potential causes include the lower solubility of C18:0 compared to C16:0, which would be more dependent on emulsification for absorption (Drackey, 2000). Additionally, results have shown that *cis*-9 C18:1 has greater digestibility than C16:0 and C18:0 (Boerman et al., 2015).

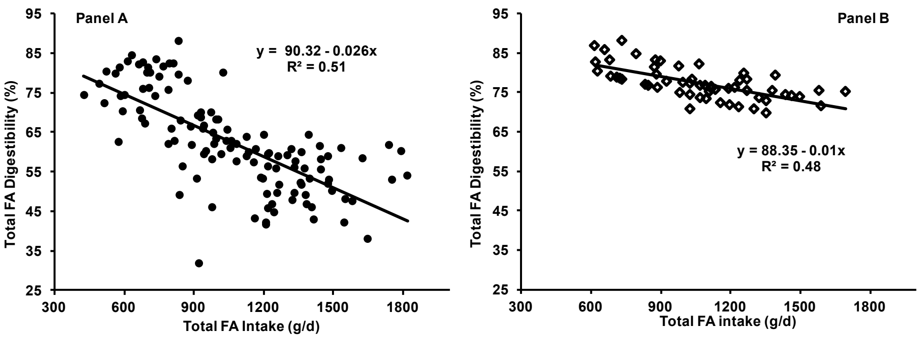

Figure 1. Relationship between total FA intake and apparent total-tract FA digestibility of dairy cows supplemented with either a C18:0-enriched supplement (Panel A) or a C16:0-enriched supplement (Panel B). Results in Panel A utilized 32 mid-lactation cows receiving diets with increasing levels (0 to 2.3% dry matter) of a C18:0-enriched supplement (93% C18:0) in a 4 X 4 Latin square design with 21-d periods (Boerman et al., 2017). Results in Panel B utilized 16 mid-lactation cows receiving diets with increasing levels (0 to 2.25% dry matter) of a C16:0-enriched supplement (87% C16:0) in a 4 X 4 Latin square design with 14-d periods (Rico et al., 2017).

Freeman (1969) examined the amphiphilic properties of polar lipid solutes and found that *cis*-9 C18:1 had a positive effect on the micellar solubility of C18:0. To further understand what factors influence FA digestibility, we utilized a random regression model to analyze available individual cow data from 5 studies that fed a C16:0-enriched supplement to dairy cows. We observed that total FA digestibility was negatively impacted by total FA intake, but positively influenced by the intake of *cis*-9 C18:1 (unpublished results). Finally, we recently evaluated the effects of varying the ratio of dietary C16:0, C18:0, and *cis*-9 C18:1 in basal diets containing soyhulls or whole cottonseed on FA digestibility. We observed that feeding a supplement containing C16:0 and *cis*-9 C18:1 increased FA digestibility compared with a supplement containing C16:0, a mixture C16:0 and C18:0, and a non-fat control diet. The supplement containing a mixture C16:0 and C18:0 reduced 16-, 18-carbon, and total FA digestibility compared with the other treatments (de Souza et al., 2018). This is displayed in Figure 2 by using a Lucas test to estimate the apparent digestibility of the supplemental FA blends. The slopes (i.e., digestibility of the supplemental FA blends) in soyhulls based diets were 0.64, 0.55 and 0.75 and in cottonseed diets were 0.70, 0.56 and 0.81 for supplements containing C16:0, a mixture C16:0 and C18:0, and a mixture of C16:0 and *cis*-9 C18:1, respectively. This supports the concept that a combination of 16-carbon and unsaturated 18-carbon FA may improve FA digestibility, but reasons for this need to be determined.

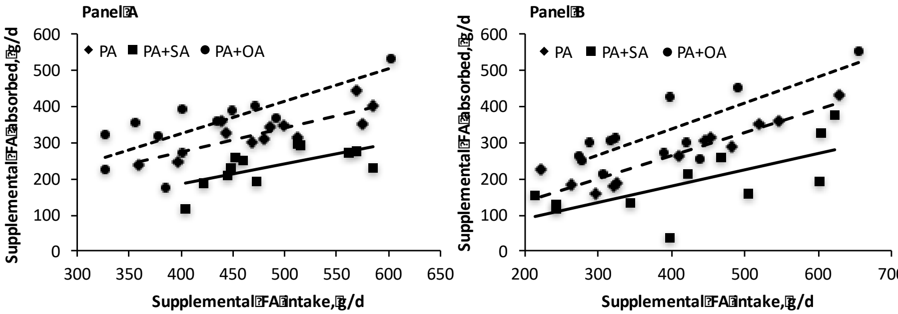

Figure 2. Lucas test to estimate total FA digestibility of supplemental FA treatments when cows received either a soyhulls basal diet (Panel A) or a cottonseed basal diet (Panel B). PA (Palmitic Acid; C16:0) long-dashed line (1.5% of FA supplement blend to provide ~ 80% of C16:0); PA+SA (Stearic Acid; C18:0) solid line (1.5% of FA supplement blend to provide ~ 40% of C16:0 + 40% of C18:0); and PA+OA short-dashed line (1.5% of FA supplement blend to provide ~ 45% of C16:0 + 35% of C18:1 cis-9). Digestibility of supplemental FA was estimated by regressing intake of supplemental FA on intake of digestible supplemental FA. The mean intakes of FA and digestible FA when cows were fed the control diet were subtracted from the actual intakes of total FA and digestible FA for each observation. From de Souza et al. (2018).

In fresh cows, there is scarce information about the effects of supplemental FA on FA digestibility. We recently conducted a study to evaluate the effects of timing of C16:0 supplementation on performance of early lactation dairy cows (de Souza and Lock, 2017b). We observed a treatment by time interaction for C16:0 supplementation during the fresh period (1 – 24 DIM); although C16:0 reduced total FA digestibility compared with control, the magnitude of difference reduced over time (Figure 3). Interestingly, we also observed an interaction between time of supplementation and C16:0 supplementation during the peak period (25 – 67 DIM), due to C16:0 only reducing FA digestibility in cows that received the control diet in the fresh period. This may suggest an adaptive mechanism in the intestine when C16:0 is fed long-term. Understanding the mechanisms responsible for this effect deserves future attention, as does the impact of other supplemental FA during early post-partum on FA digestibility and nutrient digestibility.

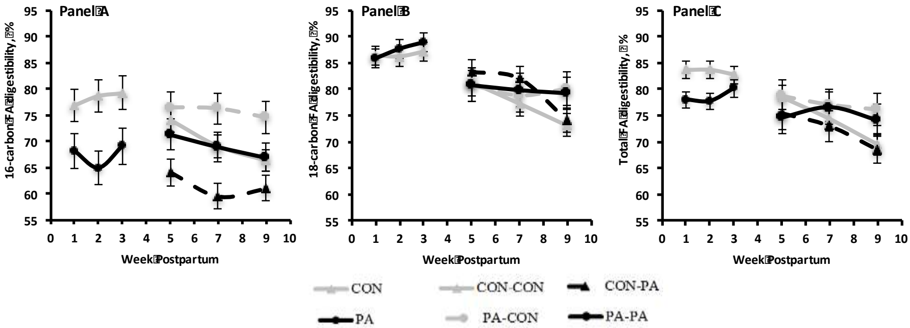

Figure 3. The effects of C16:0-enriched supplementation for early lactation cows on digestibility of 16-carbon (Panel A), 18-carbon (Panel B), and total FA (Panel C). Results utilized 52 early-lactation cows receiving the following diets: no supplemental fat (CON) or a C16:0 supplemented diet (PA) that was fed either from calving (1 to 24 DIM; fresh period FR) or from 25 to 67 DIM (peak period). From de Souza and Lock (2017b).

■ Effect of Fatty Acids on NDF Digestibility

Changes in intake and digestibility of other nutrients, such as NDF, due to FA supplementation may affect positively or negatively the digestible energy value of any FA supplement. Weld and Armentano (2017) performed a meta-analysis to evaluate the effects of FA supplementation on DMI and NDF digestibility of dairy cows. Supplementation of supplements high in medium chain FA (12 and 14-carbons) decreased both DMI and NDF digestibility. Addition of vegetable oil decreased NDF digestibility by 2.1 percentage units, but did not affect DMI. Also, feeding saturated prilled supplements (combinations of C16:0 and C18:0) did not affect DMI, but increased NDF digestibility by 0.22 percentage units. Overall, the authors concluded that the addition of a fat supplement, in which the FA are 16-carbon or greater in length, has minimal effects on NDF digestibility, but the effect of C16:0-enriched supplements were not evaluated.

We recently utilized a random regression model to analyze available individual cow data from 6 studies that fed C16:0-enriched supplements to dairy cows (de Souza et al., 2016). We observed that NDF digestibility was positively impacted by total C16:0 intake (Figure 4A) and DMI was not affected. This suggests that that the increase in NDF digestibility when C16:0-enriched supplements are fed to dairy cows is not explained through a decrease in DMI. Additionally, when comparing combinations of C16:0, C18:0, and *cis*-9 C18:1 in supplemental fat, we observed that feeding supplements containing C16:0 or C16:0 and *cis*-9 C18:1 increased NDF digestibility compared with a supplement containing C16:0 and C18:0 (de Souza et al., 2018).

With early lactation cows, Piantoni et al. (2015b) fed a saturated fat supplement (~ 40% C16:0 and 40% C18:0) and observed that fat supplementation increased NDF digestibility by 3.9% units in the low forage diet (20% fNDF), but had no effect in the high forage diet (26% fNDF). In our recent study that evaluated the effects of timing of C16:0 supplementation (PA) on performance of early lactation dairy cows (de Souza and Lock, 2017b), we observed that C16:0 supplementation consistently increased NDF digestibility ~ 5% units over the 10 weeks of treatment compared with control (Figure 4B).

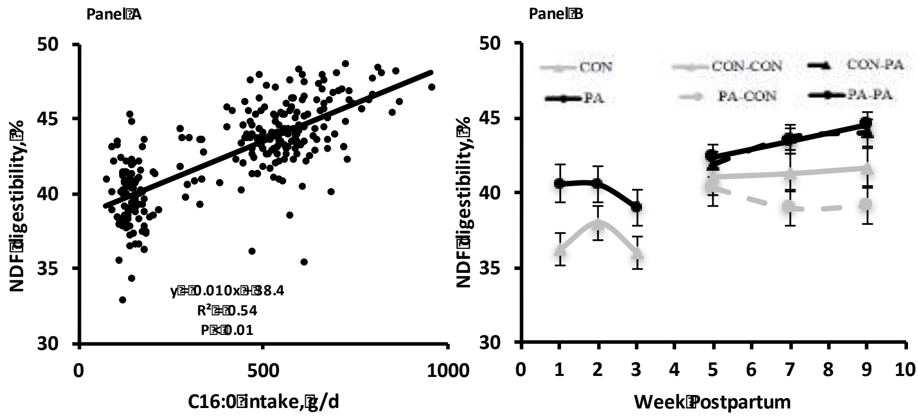

Figure 4. Panel A: Relationship between C16:0 intake and NDF digestibility of dairy cows fed C16:0-enriched FA supplements. Panel B: The effects of C16:0-enriched supplementation in early lactation cows on NDF digestibility. Results in Panel A represent a combined data set evaluated using a random regression model from 6 studies feeding C16:0-enriched supplements on NDF digestibility of post-peak cows (de Souza et al., 2016). Results in Panel B utilized 52 early-lactation cows receiving the following diets: no supplemental fat (CON) or a C16:0 supplemented diet (PA) that was fed either from calving (1 to 24 DIM; fresh period) or from 25 to 67 DIM (peak period). From de Souza and Lock (2017b).

▪ Effects of C16:0, C18:0, and *Cis*-9 C18:1 on Production Responses

We have recently carried out a series of studies examining the effect of individual saturated FA on production and metabolic responses of lactating cows. Piantoni et al. (2015a) reported that C18:0 increased DMI and yields of milk and milk components, with increases more evident in cows with higher milk yields, but the response occurred only in one of the two periods of the crossover design. Reasons why only higher yielding cows responded more positively to C18:0 supplementation and only in one period remains to be determined. Additionally, in a recent dose response study with mid lactation cows, feeding a C18:0-enriched supplement (93% C18:0) increased DMI but had no effect on the yields of milk or milk components when compared to a non-FA supplemented control diet, which was probably associated with the decrease in FA digestibility (Figure 1A, Boerman et al., 2017). Our results, and those of others, indicate that C16:0 supplementation has the potential to increase yields of ECM and milk fat as well as the conversion of feed to milk, independent of production level when it was included in the diet for soyhulls or C18:0 (Piantoni et al., 2013; Rico et al., 2014). We recently utilized a random regression model to analyze available individual cow data from 10 studies that fed C16:0-enriched supplements to post peak dairy cows (de Souza et al., 2016). We observed that energy partitioning toward milk was increased linearly with C16:0 intake as a result of a linear increase in milk fat yield and ECM with increasing intake of C16:0.

When we compared combinations of C16:0, C18:0, and *cis*-9 C18:1 in FA supplements, a supplement containing more C16:0 increased energy partitioning toward milk due to the greater milk fat yield response compared with the other treatments (de Souza et al., 2018). In contrast, a FA supplement containing C16:0 and *cis*-9 C18:1 increased energy allocated to body reserves compared with other treatments. The FA supplement containing a combination of C16:0 and C18:0 reduced nutrient digestibility, which most likely explains the lower production responses observed compared with the other treatments. Interestingly, in a follow up study we compared different ratios of C16:0 and *cis*-9 C18:1 in FA supplements fed to post-peak cows and observed that supplements with more C16:0 favored energy partitioning to milk in cows producing less than 45 kg/d, while supplements with more *cis*-9 C18:1 favored energy partitioning to milk in cows producing great than 60 kg/d (de Souza and Lock, 2017a). Also, regardless of production level, supplements with more *cis*-9 C18:1 increased BW change. This may suggest that C16:0 and *cis*-9 C18:1 are able to alter energy partitioning between the mammary gland and adipose tissue, which may allow for different FA supplements to be fed in specific situations according to the metabolic priority and needs of dairy cows. Further research is needed to confirm these results in cows at different stages of lactation or other physiological conditions.

In early lactation cows, Beam and Butler (1998) fed a saturated FA supplement (~ 40% C16:0 and 40% C18:0) and observed that FA supplementation decreased DMI and did not affect yields of milk and ECM in the first 4 weeks after calving. Piantoni et al. (2015b) fed a similar saturated FA supplement (~ 40% C16:0 and 40% C18:0) and observed that FA supplementation during the immediate postpartum (1-29 DIM) favored energy partitioning to body reserves rather than milk yield, especially in the lower forage diet. The high forage diet with supplemental FA increased DMI and tended to decrease BCS loss compared with the same diet without FA supplementation. Also, regardless of forage level, feeding supplemental FA increased DMI, decreased BCS loss, but tended to decrease milk yield. When cows were fed a common diet during the carryover period, the low forage diet with FA supplementation fed during the immediate postpartum continued to decrease milk yield and maintained higher BCS compared with the other treatments. On the other hand, Weiss and Pinos-Rodriguez (2009) fed a similar saturated FA supplement (~ 40% C16:0 and 40% C18:0) to early-lactation cows (21 to 126 DIM) and observed that when high-forage diets were supplemented with FA, the increased NE_L intake went toward body energy reserves as measured by higher BCS with no change in milk yield. However, when low-forage diets were supplemented with FA, milk yield increased (2.6 kg/d) with no change in BCS.

In a recent study, we evaluated the effects of timing of C16:0 supplementation on the performance of early lactation dairy cows (de Souza and Lock, 2017b). During the fresh period (1-24 DIM), we did not observe treatment differences for DMI or milk yield (Figure 5A), but compared with control, C16:0 increased the yield of ECM by 4.70 kg/d consistently over time (Figure 5B). However, C16:0 reduced body weight by 21 kg (Figure 6), and body condition score by 0.09 units, and tended to increase body weight loss by 0.76 kg/d compared with CON. Feeding C16:0 during the peak period (25 to 67 DIM) increased the yield of milk by 3.45 kg/d, ECM yield by 4.60 kg/d, and tended to reduce body weight by 10 kg compared with control (Figure 6).

Interestingly, Greco et al. (2015) observed that decreasing the ratio of omega-6 to omega-3 FA in the diet of lactating dairy cows while maintaining similar dietary concentrations of total FA improved productive performance in early lactation. A dietary omega-6 to omega-3 ratio of approximately 4:1 increased DMI and production of milk and milk components compared with a 6:1 ratio. Approximately 1.3 kg of milk response could not be accounted for by differences in nutrient intake, which suggests that reducing the dietary FA ratio from 6:1 to 4:1 can influence nutrient partitioning to favor an increased proportion of the total net energy consumed being allocated to milk synthesis.

Further studies focusing on altering the ratio of dietary FA are warranted, especially in early lactation cows.

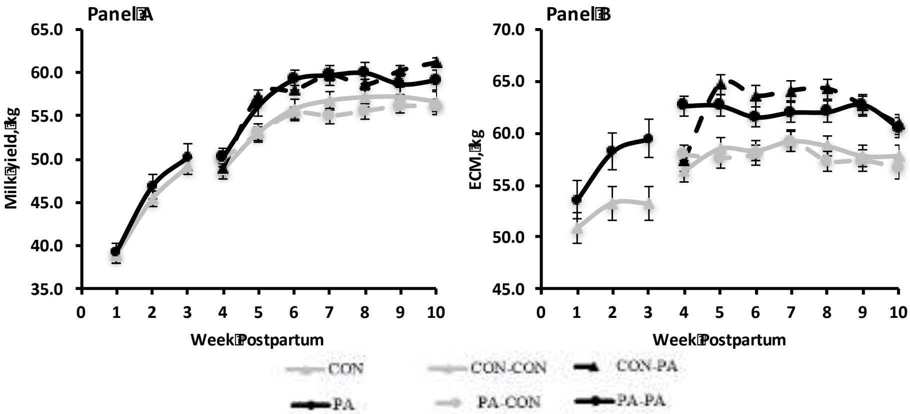

Figure 5. The effects of C16:0-enriched supplementation in early lactation cows on the yield of milk (Panel A) and ECM (Panel B). Results from 52 early-lactation cows receiving the following diets: no supplemental fat (CON) or a C16:0 supplemented diet (PA) that was fed either from calving (1 to 24 DIM; fresh period FR) or from 25 to 67 DIM (peak period). From de Souza and Lock (2017b).

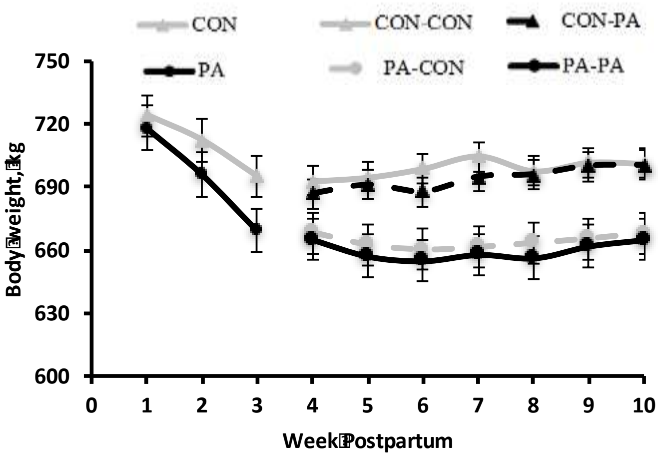

Figure 6. The effects of C16:0-enriched supplementation in early lactation cows on body weight. Results from 52 early-lactation cows receiving the following diets: no supplemental fat (CON) or a C16:0 supplemented diet (PA) that was fed either from calving (1 to 24 DIM; fresh period) or from 25 to 67 DIM (peak period). From de Souza and Lock (2017b).

▪ Conclusion

The addition of supplemental FA to diets is a common practice in dairy nutrition to increase dietary energy density and to support milk production. Although in general FA supplementation has been shown to increase milk yield, milk fat yield, and improve reproduction performance, great variation has been reported in production performance for different FA supplements, and indeed the same supplement across different diets and studies. Results are contradictory about the benefits of FA supplementation to early lactation dairy cows. We propose that this is a result of differences in FA profile of supplements used and the time at which FA supplementation starts. Further work is required to characterize the sources of variation in response to FA supplementation. Just as we recognize that not all protein sources are the same it is important to remember that not all FA sources and FA supplements are the same. The key is to know what FA are present in the supplement, particularly FA chain length and their degree of unsaturation. Once this information is known it is important to consider the possible effects of these FA on DMI, rumen metabolism, small intestine digestibility, milk component synthesis in the mammary gland, energy partitioning between the mammary gland and other tissues, body condition, and their effects on immune and reproductive function. The extent of these simultaneous changes along with the goal of the nutritional strategy employed will ultimately determine the overall effect of the FA supplementation and the associated decision regarding their inclusion in diets for lactating dairy cows.

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Keys to Producing High Quality Corn Silage in Western Canada

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Take Home Message

- Corn grown in western Canada has potential for high silage yield with high digestible energy content. However, the potential is not always achieved due to the limited growing season.
- Select a hybrid with a corn heat unit rating that matches the long-term rating of the growing location to maximize starch content before frost occurs.
- Corn should be harvested for silage when the whole plant contains 32 to 38% dry matter content. Later maturing hybrids may not reach this target before frost occurs.
- Kernel processing should be conducted at the time of harvest to maximize starch availability in the rumen.

Introduction

With the relatively recent availability of short-season corn hybrids that fit within the prairie maturity zone, corn silage acreages in western Canada continue to expand, reaching 16,200 seeded hectares in Alberta in 2015. Corn silage can be a good alternative to small grain silage for dairy cows because of its high dry matter (DM) yield and high digestible energy content. We believe that about 50% of dairy producers in Alberta are currently growing or have tried to grow corn for silage. However, corn grown in western Canada does not always achieve its potential due to the limited growing season. Many recommendations for producing high quality corn silage originate from studies conducted in the USA, with limited applicability in areas with shorter growing season. Thus, the purpose of our paper is to discuss results from recent studies conducted in western Canada that highlight important factors to consider when producing high quality corn silage for dairy cows in short season areas.

▪ Getting the Agronomics Right

Consult with seed companies and experienced growers to find out what works best in your area. Because corn makes use of the entire growing season, early seeding to take advantage of all available Corn Heat Units (CHU) is necessary despite the risk of spring frost. Usually, corn is seeded at a depth of 3.5 mm (1.5 in) or deeper. Recommended seeding rates are 64,000 to 89,000 seeds/ha (26,000 to 36,000 seeds/ac) with row spacing about 75 cm (30 in) apart. Planting density is greater relative to the cornbelt area of the USA because short season corn plants are smaller. Corn requires at least 500 mm of water per growing season; however, most of the corn grown on the prairies is not grown under irrigation. Corn grown in drier areas needs to be grown at plant densities as low as 45,000 to 50,000 plants/ha. Further, as plant densities increase, silking date, grain and silage maturity may be delayed, having subsequent effects on silage quality (Cusicanqui and Lauer, 1999; Baron et al., 2006).

Pests and diseases can cause large economic losses, with infections of Fusarium being the greatest threat. Specialized equipment requiring substantial investment is needed to seed and harvest corn. A kernel processor on the silage chopper is highly recommended because short season hybrids can have very hard kernels that resist degradation in the rumen unless processed.

▪ Corn Heat Unit (CHU) System

Corn hybrids marketed in Canada are rated for maturity using the CHU system (Brown and Bootsma, 1993). CHUs indicate the number of accumulated thermal units from planting to grain maturity. Hybrids used for silage can have grain maturity ratings 100 to 200 CHU less than those used for grain because they are harvested at a lower DM content before the grain is fully mature. CHU zones in Canada are mapped according to the growing season and long-term weather data. Hybrids are then selected such that their CHU rating fits within the CHU rating of the location in which they are grown. In the USA, the Minnesota relative maturity rating (RM) system is used, which provides a hybrid rating in days. A very early corn hybrid used in western Canada rated at 2000 CHU would have a RM of 52 days and one with 2600 CHU would have an RM of 78 days.

In contrast to barley silage, which can be planted at several dates and still mature within the growing season, there is much less flexibility for corn grown in short-season regions. Corn development, in particular kernel filling, will be limited if the CHU accumulation from planting to harvest is less than the CHU rating of the hybrid. In regions very suited to corn production grain fills rapidly and linearly over a 3 to 4 week period at a rate of 3 to 4% of maximum grain yield per day. Grain filling begins about 14 days after silking. In short season areas, frost can occur before the plant reaches the ideal maturity and as a result starch content will be low and kernel moisture will be above 50%.

■ The Research Study

Corn hybrids were grown for silage in 3 years (2013, 2014 and 2015) in 4 different locations (Lacombe, AB; Lethbridge, AB; Vauxhall, AB; Elm Creek, MB) representing various environmental conditions in western Canada. Long term average CHU received at these locations versus the CHU received during the study are shown in Table 1. At each location, 6 hybrids were planted in replicated plots. Given that each location has a different CHU rating, hybrids grown in each location differed and were selected such that the CHU rating of the hybrids overlapped with the rating of the zone. The CHU ratings of the hybrids used in the study were: Lacombe, 2000 to 2200; Lethbridge, 2000 to 2600; Vauxhall, 2175 to 2650; and Elm Creek, 2175 to 2650. The plants were harvested before and after frost. The results demonstrate the pre-ensiling potential of the forages as harvested.

Table 1. Seeding and harvest information for the corn hybrid study.

Location (long term CHU rating)	Year	Seeding date	Before Frost		After Frost		Water supply (mm)*
			Harvest date	CHU received	Harvest date	CHU received	
Lacombe, AB	2013	10/05	18/09	2113	01/10	2113	276
(CHU=1955)	2014	16/05	16/09	1780	22/09	1780	231
	2015	05/05	15/09	1837	23/09	1842	279
Lethbridge, AB	2013	08/05	22/09	2631	07/10	2692	572
(CHU=2448)	2014	22/05	22/09	2205	27/09	2293	480
	2015	06/05	18/09	2263	29/09	2418	284
Vauxhall, AB	2013	13/05	24/09	2458	01/10	2500	445
(CHU=2538)	2014	19/05	21/09	2168	27/09	2269	354
	2015	07/05	18/09	2182	29/09	2306	283
Elm Creek, MB	2013	17/05	17/09	2292	08/10	2521	313
(CHU=2463)	2014	29/05	08/09	2178	23/10	2178	317
	2015	03/06**	24/09	2308	06/10	2413	253

*Precipitation and irrigation; **Late seeding because of delayed spring.

■ Maximizing Silage Yield

Whole plant DM yield of the corn hybrids during the 3-year study are shown by growing location in Table 2. Yield was highly variable within location from year-to-year and among hybrids. These effects were especially evident in Lacombe in 2014 and 2015. In those years, less than 2100 CHUs were received from planting to harvest causing DM yield of all hybrids to be severely negatively affected. In addition, the 2015 May and June rainfall was 50% of normal. In contrast, in 2013, a good year for growing corn in Lacombe, the average yield was 14.5 t DM/ha. The operating cost of corn silage production is 50% greater than for barley (Baron et al., 2014). If the expected barley silage yield is 10 t DM/ha and the yield of corn silage is ≥14 t/ha, then corn would be an appropriate choice because the energy content of corn silage is about 10-15% greater than that of barley silage. However, in CHU zones less than 2200 the risk of not achieving adequate yield of corn is high.

Table 2. Whole plant dry matter (tonnes/ha) yield of corn hybrids grown in 4 locations in 3 years in western Canada. Only hybrids harvested with 28 to 40% DM content are shown (n = 288).

Location	Average	Minimum	Maximum
Lacombe, AB	9.4	3.5	17.6
Lethbridge, AB	15.4	4.8	23.4
Vauxhall, AB	12.5	6.3	22.4
Elm Creek, MB	19.2	12.1	24.2

▪ Hybrid Selection

Dry matter yield and nutritional value of corn silage is mainly determined by CHUs received from planting to harvest versus the CHU rating of the hybrid. While later maturing hybrids have the potential to maximize yield, kernel development can be challenged by the short growing season and the onset of frost at harvest. In all four locations, differences in yield among hybrids were significantly less than differences in yield from year-to-year caused by variability in weather. However, in general, later maturing corn hybrids had greater yields than earlier maturing hybrids. Thus, producers may be tempted to use a later maturing hybrid to maximize silage yield. However, later maturing hybrids may not reach the desired DM content before the first frost even though yield is high. It may be necessary to sacrifice yield to ensure quality by selecting a hybrid that is rated at or below the CHU zone of the growing location.

▪ Dry Matter Content

Corn should be harvested for silage when the whole plant is 32 to 38% DM. It is important to seed a hybrid that will reach the ideal DM content before frost. A recommendation from USA corn experts is to harvest corn silage when the milk line in the kernel is 1/2 to 2/3 down from the kernel crown; however, in western Canada that recommendation does not hold true because there is a poor relationship between whole plant DM content and kernel milk line. To monitor whole plant DM, cut 5 corn plants/row from 2 rows in different locations in the field. Put the material in a large plastic bag until it can be chopped through a yard or brush shredder. Take several representative samples and determine moisture content using a microwave or Koster moisture tester. Standing corn plants dry down at a rate of about 0.5 percentage units per day (faster in dry and hot weather and after frost), so it may be necessary to start the harvest at a lower DM and end at a higher DM. It is important to avoid silages that are too wet (< 28% DM), as these will cause seepage from the silo and excessive fermentation resulting in high concentrations of total silage acids that reduce dry matter intake (DMI) of cows. It is also important to avoid silages that are too dry (> 40% DM), as these are difficult to pack and are poorly fermented in the silo.

■ Nutrient Content

The overall nutrient content of the hybrids harvested in our study is presented in Table 2. Chemical composition and digestibility were extremely variable, which would have large impact on expected milk production from cows. It is important to understand the factors affecting this variability.

Table 2. Nutritional composition of corn hybrids from a 3-year study conducted in western Canada (DM basis). Only samples harvested 28 to 40% DM content are shown (n=255).

	DM %	TDN %DM	DMD %DM	CP %DM	Starch %DM	NDF %DM	NDFD %NDF	ADF %DM	ADL %DM
Mean	34.1	65.1	66.5	7.9	24.0	54.0	54.3	28.6	3.1
Min	28.0	54.1	55.5	5.1	3.4	39.6	39.5	19.0	1.0
Max	39.9	73.4	74.4	10.0	47.3	75.1	69.6	39.8	10.4

DM, dry matter; TDN, calculated total digestible nutrient content (NRC, 2001); DMD, DM digestibility (48 h in vitro); CP, crude protein; NDF, neutral detergent fiber; NDFD, NDF digestibility (48 h in vitro); ADF, acid detergent fiber; ADL, acid detergent lignin.

■ Maximizing Digestibility and Energy Content

Corn silage can be a major source of digestible energy in the diet of dairy cows. Average total digestible nutrient (TDN) content of hybrids in our study was 65% DM, ranging from 54% to 73%. The low TDN forages were those with very low starch content, which affected estimated milk yield (Fig. 2).

There are two distinct components to corn silage: forage (fiber) and grain (starch). As the corn plant matures, its digestible energy content increases, unlike legumes and grasses. Increased energy content with maturity is due to the increase in starch content in the grain portion, despite increased maturity of the fiber in the forage fraction. Starch is almost twice as digestible as fiber, so maximizing energy content of corn silage is mainly achieved by maximizing starch content. Generally speaking, starch content increases in concert with advancement in kernel maturity, which occurs at about 35% grain moisture, depending on location and expected CHU accumulation. Lower mature-kernel moisture percentages occur in regions with higher CHU accumulation.

Interestingly, DMD measured in vitro (48 h) gave a very similar estimate of digestible nutrients, as did TDN, which was calculated from the individual nutrient components. DMD was positively associated with starch content (r = 0.36), negatively associated with NDF content (r = -0.46), and positively associated (r = 0.43) with NDF digestibility (NDFD, measured at 48 h in vitro). Thus, in addition to maximizing starch content, hybrids with low NDF content and high NDFD are desirable. Because starch, NDF and NDFD contents are highly variable in short season hybrids, lab predictions of energy content (TDN or NE_L) from equations developed in eastern Canada or the USA may be highly inaccurate for western Canada, unless these three components are measured.

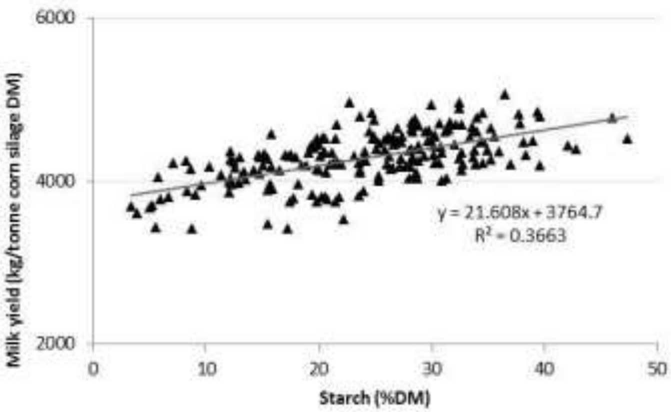

Fig. 2. Effects of starch content of corn hybrids on estimated milk yield using the Milk2006 model. Data from a 3-year study conducted in western Canada. Only samples harvested 28 to 40% DM content are shown (n = 255).

■ Maximizing Starch Content

High starch content can be difficult to achieve in western Canada due to the short growing season. **Choosing a hybrid with a CHU rating that matches the long-term CHU average of the growing location will allow for adequate kernel development and high starch content in most years.** In the USA, starch content of corn silage almost always exceeds 30% DM. The mean (±SD) starch content of corn silage from 3 labs in the U.S. was 32.6% ± 6.95 (169,620 samples; NASEM, 2016). In our study starch content averaged 24% DM, but there was tremendous variability (range: 3 to 47% DM; Table 2). Starch content of the plant increases with maturity; as the cob is formed starch is laid into kernels. We observed a strong positive correlation between starch content and whole plant DM at harvest (r = 0.68; Fig. 3). Thus, if the hybrid CHU rating exceeds the CHU received in a given year, starch content will be low in the same way that DM content will be low.

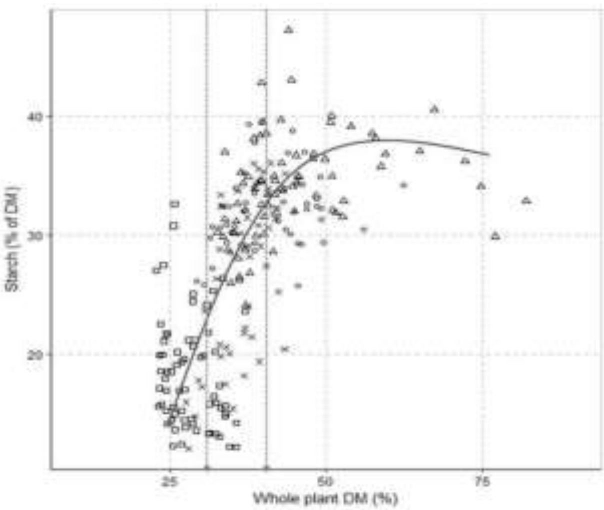

Fig. 3. Starch content as a function of whole plant dry matter (DM) content. Dotted lines with arrows indicate optimum range of DM content at ensiling.

For hybrids grown in Lacombe, characterized by a very short growing season, there was a strong negative relationship (r = -68) between starch content and CHU rating of the hybrids. When the growing season is short, hybrid selection becomes more critical for maximizing starch and consequently energy content of the silage. In the warmest location, Vauxhall, starch content was mainly a function of the CHU received, with smaller differences among hybrids.

To a certain extent starch content can be managed, but these practices may negatively impact silage or DM yield. Choosing an early corn hybrid for a lower CHU zone may sacrifice yield for kernel maturity, but result in more milk per tonne of silage produced. Growing corn at lower plant populations may increase grain yield and starch yield per plant, thereby increasing milk yield per tonne over milk yield per ha. Finally increasing cutting height should increase grain and starch content of silage, but the degree of impact depends on stage of maturity at cutting and hybrid type (Lewis et al., 2004). None of these practices have been thoroughly investigated in the Prairie environment.

■ Kernel Hardness

Hybrids differ in kernel hardness due to moisture content, starch content, and properties of the endosperm. As kernel DM content increases, so does kernel hardness. Short-season corn hybrids grown in western Canada are of both flint and dent origin. Use of genetic populations of flint heritage in short-season corn breeding programs can confer early silking dates, cool temperature and drought tolerance, and resistance to kernel damage during combining. Flint-endosperm hybrids contain a greater proportion of vitreous endosperm in the kernel making the starch harder to degrade because it is protected by a thick protein matrix. Hybrids with greater proportion of floury endosperm (dent hybrids) have more digestible starch because the granules are loosely packed and the surrounding protein matrix is thinner. Hybrids vary in their proportion of vitreous starch. To maximize digestibility of starch in the rumen and minimize the limitations of kernel hardness, **kernel processing should be conducted at the time of harvest**. This is especially needed when corn is harvested relatively dry, and for hybrids with low CHU ratings, as they tend to have more vitreous starch.

We conducted a study to determine whether kernel hardness of short season hybrids affects availability of starch in the rumen, and whether processing can overcome any potentially negative effects. We selected kernels from hybrids grown in Lacombe and subjected them to (median size): coarse (2.3 mm), medium (1.3 mm), and fine (0.7) processing. The processed kernels were incubated in the rumen over time. Examples of two hybrids with higher and lower ruminal starch degradabilities grown at Lacombe are shown in Fig. 4. Processing had a much greater impact on starch availability for the hybrid (39F44) with less degradable starch. However, fine processing did not overcome the limited starch availability, as the starch from the finely processed kernels was still only as degradable as the coarse material from the hybrid (PS226RR) with greater starch availability.

Starch digestibility will increase by about 5 percentage units during the first 60 days in the silo (Der Bedrosian et al., 2012), but even after fermentation in the silo, the starch may not be fully digestible. As a result, a significant fraction of the corn kernels will pass through the cow undigested. The calculation of TDN content of silage assumes starch digestibility in the rumen is 96.7% (NRC, 2001). With unprocessed corn and hybrids with high starch vitreousness, energy content of the silage will be highly overestimated. When fed these silages, cows may increase their intakes to meet energy demands; however, this may not be possible if intake is limited by rumen fill. Thus, milk production will be less than expected.

The bottom-line is that kernel processing is needed for short season hybrids to ensure the starch in the kernels is available for rumen digestion. Degree of kernel processing can be checked by separating kernels from forage in a bucket of water (L. Kung, University of Delaware; personal communication). The heavier kernel pieces will sink, while the lighter forage material will float. Remove the long particles, pour off the water and examine the remaining kernels. Adequate processing is when 90 to 95% of the kernels are cracked, with 65 to 75% equal to or smaller than 1/3 to 1/4 kernel size. Cobs should be more than quartered.

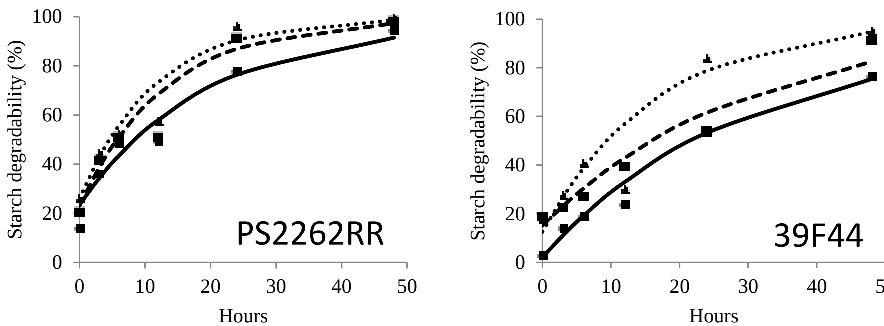

Fig. 4. Starch degradability in the rumen of 2 hybrids grown in Lacombe (39F44, CHU rating = 2000, Pioneer Hi-Bred, Johnson, IA; PS2262RR, CHU rating = 2175, Pickseed, Lindsay, ON). Kernels were processed – coarse, - - medium, and ··· fine.

▪ NDF and NDF Digestibility (NDFD)

The concentration of NDF and its digestibility determine the maximum amount of forage that a cow can consume. Increased NDFD of forage increases DMI and milk yield (Fig. 5). Summarizing a number of studies that used non brown mid-rib corn silage, Owens (2014) reported that daily DMI and milk production increased by 0.034 and 0.111 kg/d, respectively, for each one-percentage unit increase in NDFD of forage. Oba and Allen (1999) reported an even larger increase in intake and milk yield per unit increase in NDFD for a range of forages (0.168 and 0.245 kg/d, respectively; Oba and Allen, 1999).

As starch content increases, the NDF content in the stalk, leaves, husk and cobs is diluted out, and thus NDF content of the whole plant decreases. Overall, we observed a correlation between starch content and NDF content of -0.71 (for plants harvested before frost). The NDF content in our study averaged 54%, but ranged from 40 to 75% DM (Table 2). The NDFD (% of

NDF, 48 h) averaged 54% and ranged from 40 to 70%. The NDF content was poorly correlated to NDFD (r = 0.22) meaning that NDFD cannot be predicted from NDF content. Similarly, in a study of 32 corn hybrids grown in Michigan, NDFD-48h ranged from 25 to 60% (Allen et al., 2003), and NDFD was also not related to NDF content. Hybrids with higher NDFD may be more leafy with more husk, shank and cobs, as the NDFD of these portions is typically > 60% in contrast to stalk with NDFD < 38% (Owens, 2014).

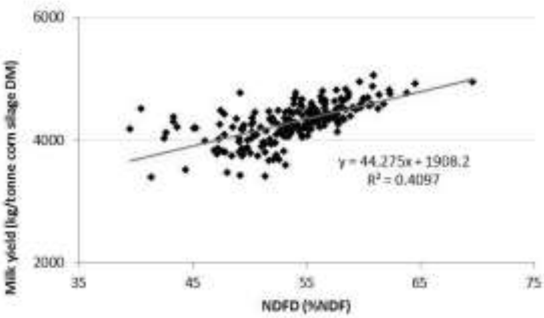

Fig. 5. Effect of variation in NDF digestibility (NDFD) of corn hybrids on estimated milk yield using Milk2006 model. Data from a 3-year study conducted in western Canada (DM basis). Only samples harvested 28 to 40% DM content are shown (n = 255).

▪ Harvesting After Frost

If corn plants are immature at the time of frost (< 30% DM), they are often left standing in the field to extend the growing season. Subjecting the plant to frost increases its DM content, which can have beneficial effects for fermentation in the silo and DMI. However, standing corn subjected to frost will dry down very rapidly. Monitoring silage DM percentage is important because ensiling right after frost may be necessary. Kernel processing is a must for frozen corn silage because kernels can dry and harden more rapidly than expected when subjected to frost. After a hard frost, little moisture enters the kernel; husks dry and loosen, reducing the resistance to moisture evaporation from the kernel. Drying winds speed up the kernel dry-down rate.

▪ Particle Size Recommendations

In addition to chemical composition, particle size affects fermentation in the silo and DMI of cows. It is recommended to use a theoretical length of cut of 3/8 to 1/2 inch for unprocessed corn silage and 3/4 inch for processed silage. It is important to check actual particle size during harvest because the feed roll speed determines actual particle length. Using a Penn State Forage Separator (3 sieves plus pan), 3 to 8% of the weight should be retained on the top screen to ensure optimum levels of physically effective fiber in the diet. More than 8% will increase sorting and will make packing of the silage difficult. The middle screen should have 45 to 65% of the particles, the lower screen should have 20 to 30% of the weight, and the pan should collect <10%.

■ Fermentation in the Silo

The keys to making good quality and palatable silage in western Canada are the same as elsewhere, and have been covered previously at this conference (Kung, 2009). It is critical to rapidly exclude air from the forage mass during ensiling by packing tightly to promote rapid production of lactic acid and reduction in silage pH. Silos should be sealed rapidly after filling and penetration of air into the silage during storage should be avoided. Use a proven inoculant with supportive research data for corn silage to help improve storage and feed-out.

■ Milk2006 Model

Milk 2006 is a software tool developed at the University of Wisconsin to help dairy producers predict the potential amount of milk that can be produced accounting for corn silage nutritive value (Schwab et al., 2003; https://shaverlab.dysci.wisc.edu/spreadsheets/). Inputs into the calculation include chemical composition, NDFD, and whether corn is processed. The potential DMI and TDN content of corn silage are estimated, and then used to predict milk production. We used the Milk2006 model to compare the hybrids grown in our study (Table 3). The variation in estimated DMI from the corn silages was due to NDF content and NDFD, while differences in estimated milk yield per tonne of silage reflected differences in TDN and DMI. The estimated energy content was then combined with DM yield to estimate milk yield per hectare of silage.

Table 3. Estimated energy content, corn silage intake, and milk yield from a 3-year study conducted in western Canada based on the Milk2006 model. Only samples harvested 28 to 40% DM content are shown.

Location	Est. NE_L (Mcal/kg DM)	Max. CS DMI (kg/d)	Estimated milk yield (tonne/tonne DM of CS)	Estimated milk yield (tonne/ha of CS)
Lacombe, AB (n = 89)				
Mean	1.46	10.3	3.45	32.43
Min	1.21	8.4	3.00	13.74
Max	1.71	13.5	4.29	66.06
Lethbridge, AB (n=48)				
Mean	1.53	11.6	3.66	69.21
Min	1.39	8.6	3.15	43.96
Max	1.64	14.2	4.06	81.26
Vauxhall, AB (n = 85)				
Mean	1.46	10.2	3.44	47.37
Min	1.21	7.1	2.53	28.95
Max	1.68	14.0	4.18	67.17
Elm Creek, MB (n=33)				
Mean	1.49	10.5	3.51	67.38
Min	1.40	9.2	3.17	43.88
Max	1.64	12.2	4.04	86.57

▪ Conclusions

Chemical composition and digestibility of corn silage grown in western Canada are highly variable, which will affect intake and milk production of cows. At the very minimum, it is important to analyze corn silage for starch, NDF, and NDFD content, as these components will determine intake potential and energy (TDN and NE_L) content. It is important to harvest silage at the optimum DM content to promote fermentation in the silo. Because later maturing hybrids may not reach the desired DM content before the first frost occurs, it may be necessary to sacrifice yield to ensure quality by selecting a hybrid that is adapted to the local growing environment. Furthermore, to maximize the energy content of the silage, the starch in the silage needs to be available, and thus kernel processing is needed.

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Setting the Stage for the Future: Managing and Rearing During Early Life

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▪ Take Home Messages

- The cost of each kilogram of calf feed (either starter concentrate or milk replacer) is often the greatest among the feeds found on a farm. However, this does not directly imply that feed costs associated with pre-weaned calves are the greatest.
- The high efficiency of conversion of nutrients at early ages offsets their high costs; thus, growing fast during the 2 months is more economically advantageous than attempting to put these on kilograms during the last phase of the rearing period.
- There is empirical evidence that providing high planes of nutrition (both in the form of solid or liquid feeds) in calves results in positive long-term effects on production.
- An "ideal" feeding program for calves could probably consist of feeding 6 l/d at 15% (900 g/d of solids) along with a highly palatable starter feed and some chopped high-fiber forage.
- Chopped forage should be about 2.5 cm in length, and despite the fact that it must be high in fiber (>60%NDF), it must also be of high nutritional quality (i.e. free of molds, mycotoxins).
- Fostering solid feed intake should be a pivotal objective for any rearing program mainly because: 1) it will help improve nutrient supply and growth, 2) it will contribute to increase milk production in the future, 3) it will enhance rumen development, and 4) it will facilitate the weaning process.
- Socializing calves way before weaning increases solid feed intake and diminishes the severity of disease around weaning.

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■ Introduction

Most dairy producers (and dairy consultants) are focused on feeding and managing the lactating herd. This practice often results in less than desirable attention to calves, heifers, and dry cows. This less-than-desirable attention to calves and heifers is likely one the most important reasons behind the astonishing failure rate of new products (i.e. heifers after first calving). Several studies report that between 9 and 17% of the heifers that reach first calving do not finish the first lactation (Bach, 2011; Sherwin et al., 2016). This figure is due to many aspects, but basically it is related to a combination of inadequate nutrition and rearing practices, coupled with a lack of sufficient information to properly manage young stock. Contrary to lactating cows, where management is based on records of milk yield, milk composition, feed intake, body condition, etc..., the most common situation in heifer rearing is that management is based on “feeling” rather than on methodic data collection and record keeping. Thus, ensuring that adequate feeding and management practices are implemented in the rearing of calves is difficult. This article will review several nutritional aspects aimed at improving performance of calves through nutrition and management, with special emphasis on potential long-term effects on productivity and health.

■ Economics of the First Stages of Life

Raising dairy replacements properly may represent some additional economic savings and a reduced environmental impact of the dairy enterprise. For example, the number of required heifers to maintain the cow numbers of a dairy operation can be calculated with the following equation:

Number of cows x replacement rate / [(1-mortality) x (1-culling rate of heifers)] x 2x (age at first calving (months)/24)

From this equation, and assuming a 100 dairy cow herd with 30% replacement rate for lactating cows, 3% mortality of calves and heifers, and a 1% culling rate for heifers, it can be determined that if age at first calving (**AFC**) is 22, 24, or 28, the number of heifers needed is 57, 63, and 73, respectively. This means that, assuming an average daily feeding cost for heifers of CAN$2, producers with an AFC at 22 save more than CAN$10,000/year compared with AFC at 28 months (73 – 57 = 16; 16 x 2 x 365 = CAN$11,680). These relatively large savings are due to the combination of both a lower number of heifers (positive for the environment) and the fact that they are fed for a shorter period of time (22 vs 28 months). However, it is important to ensure that heifers calve with an adequate body weight (**BW**). Evidence from the literature (Hoffman and Funk, 1992) and our own field data (Bach and Ahedo, 2008) suggest that age at first calving has little correlation with milk production during the first lactation, provided the age is above 22 months, and BW seems to have a larger effect on milk production than age. Bach and Ahedo (2008) concluded that for every 70 kg of BW at calving, an increase of 1,000 kg of milk yield during the first 305 d of the first lactation could be, on average, expected. Therefore, a reasonable target for raising dairy heifers under intensive conditions would be a first calving between 22 and 24 months with a BW about 650 kg, or assuming an 11.1% loss in BW after parturition, a BW after calving of about 580 kg. Thus, the question becomes, what is the best growth curve to achieve this target BW at 22 months? Most producers believe that the most expensive rearing period of calves is between birth and weaning (due to high feed costs and labor intensive procedures). This is partly true: the cost of each kilogram of feed (either starter concentrate or milk replacer) is in many cases the greatest among the feeds on a farm. However, this does not directly imply that feed costs associated with pre-weaned calves are the greatest. The goal when rearing calves is to achieve 650 kg at 22 months of age; thus, calves need to put about 540 kg (580 kg of final BW minus 40 kg of BW at birth) of true BW (not accounting for the placenta and the baby calf they will carry during the last 9 months). Ironically, and despite the fact that a unit cost of starter feed and milk replacer (**MR**) is very high, every kilogram of BW achieved during the first 2 months of life is less expensive than a kilogram deposited when the heifer is 18 to 20 months of age. The reason for this is that feed efficiency (the proportion of feed that is converted into BW) is greatest (about 60%) during the first 2 months and lowest (about 7%) during the last months of pregnancy. Thus, the high efficiency of conversion of MR and starter feeds offsets their high costs, and growing fast during the 2 months is more economically advantageous than attempting to put these kilograms during the last phase of the rearing period (despite unitary feed cost being fairly low). More important, the most economically efficient growth during the rearing process occurs after weaning, when calves can utilize solid feed (relatively inexpensive at that age) with feed efficiencies around 30% (Bach et al., 2017b), and it turns out that ADG during the late phase of transition (between 160 and 230 d of age) is also positively correlated with future milk production (Bach and Ahedo, 2008).

▪ Feeding the Calf

Potential Long-term Consequences of Plane of Nutrition Early in Life

It is well established that nutrition represents one of the greatest environmental determinants of an individual's health and metabolic activity, and that it is likely that today's cow, with high milk yield but also reproductive and metabolic challenges, is not only a consequence of genetic selection, but also the result of the way both her and her dam were fed early after birth (Bach, 2012). However, the mechanisms involved in orchestrating the interaction of nutrition with genetic and epigenetic modifications is fairly unknown, and thus the potential long-term effects of nutrition through modifications of gene expression are often overlooked.

There is evidence that providing high planes of nutrition in calves results in positive long-term effects on production (Bach, 2012; Soberon et al, 2012; Gelsinger et al., 2016). Furthermore, two prospective studies indicated that growth rate early in life is positively correlated with survivability to second lactation (Bach, 2011; Heinrichs and Heinrichs, 2011). However, whether these changes are due to epigenetic modifications is currently unknown. It is likely that supplementation of methyl donors may have an influence in regulating epigenetic marks. Some recent evidence (Bach et al., 2017a) shows that supplementation of methyldonors (vitamin B_{12} and folic acid) during pregnancy has an effect of the epigenome of the offspring, and the changes in methylation pattern of the offspring differs between daughters to heifers or daughters to lactating cows (Figure 1). However, we do not yet know whether these changes are positive or negative. Nevertheless, Jacometo et al. (2016) reported that supplementing lactating dams with methionine (a methyl-donor) resulted in calves that underwent a faster maturation of gluconeogenesis and fatty acid oxidation in the liver, which would be advantageous for adapting to the metabolic demands of extra-uterine life. On the other hand, the long-term effects associated with greater planes of nutrition could also be mediated by non-epigenetic changes. For instance, feeding a MR rich in linolenic acid (1.5% of the total DM) compared with a regular MR (providing 0.45% of linolenic acid) modified the expression of hepatic genes, including genes predicted to decrease infections and to increase lipid utilization and protein synthesis (Garcia et al, 2016). However, whether these changes were a result of differences in metabolic pathways or consequence of epigenetic changes (which would then have a sustained response) was not determined in that study. It is likely though that the observed effects were the result of both metabolic activity and some changes in the epigenome. Furthermore, Geifer et al. (2017) hypothesized that increased planes of nutrition during the pre-weaning period enhanced the responsiveness of the mammary tissue to mammogenic stimulus, as they reported an increase in the expression of estrogen receptors in the mammary gland of animals fed increased planes of nutrition compared with traditionally-fed calves.

Liquid Feeding

Based on economic arguments and empirical evidence of increased longevity and productivity associated with improved growth rates early in life, the industry is now providing larger amounts nutrients to sustain rapid growth rates (>850 g/d) during the first 2 months by mainly offering larger volumes of milk or MR.

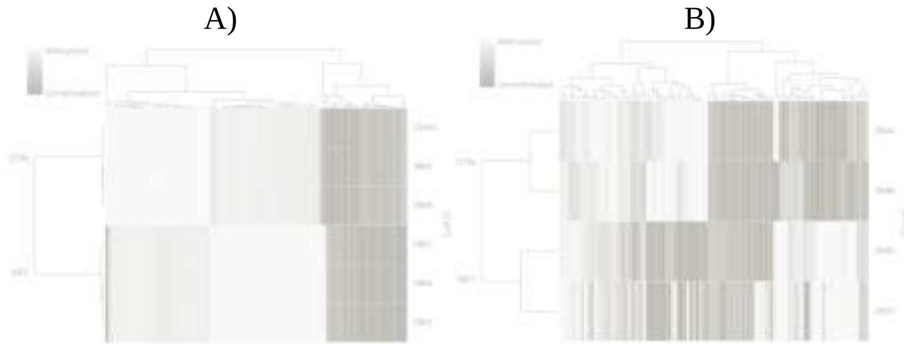

Figure 1. Cluster analysis of CpG sites differentially methylated ($P < 0.01$) in the offspring born to lactating (A) dams or heifers (B) that received a supplementation of methyl donors or a placebo during early pregnancy. Control lactating dams received a placebo, whereas MET dams received weekly administrations of 200 mg of folic acid and 20 mg of vitamin B_{12}. Control heifers received a placebo, whereas MET dams received weekly administrations of 100 mg of folic acid and 10 mg of vitamin B_{12}. (Adapted from Bach et al., 2017a)

Right after birth, we must ensure that the newborn calf receives an adequate amount of antibodies and nutrients to avoid illness during the early stages of life. Most emphasis in colostrum has been placed on immunity and we have often forgotten that colostrum provides a large amount of nutrients (mainly protein and fat). Figure 2 shows the evolution of nutrient content of milk following calving. Calves only receive colostrum 2 or 3 times and then they are moved to whole milk or MR with a substantial reduction in nutrient supply. To partially compensate for this difference, some producers are increasing the DM of MRs by using dilution rates of 15% rather than the traditional 12.5% (similar to the solid contents of milk). However, the relative proportion of nutrients offered in MR still differs quite drastically from that found in whole milk and there is some controversy about the optimal relative proportion of nutrients in MR.

For instance, Hill et al. (2006) concluded optimal concentration of protein and fat in MR should be approximately 26% CP and 17% fat, which was later corroborated by Hill et al. (2009b), who reported a linear decrease in ADG as the CP of MR decreased from 27 to 25 and 23% while maintaining fat content fixed at 17%. However, Daniels et al. (2009) reported no differences in growth rate between 5 and 9 weeks of calves offered 950 g/d of a MR containing either 28% CP and 20% fat or 28% CP and 25% fat, although calves offered the 27:28 MR tended to grow more between weeks 5 and 7 than those fed the 28:20 MR. Similarly, Morrison et al. (2009) compared one MR providing 21% CP and 18% with one providing 27% CP and 17% fat and reported no difference in ADG between calves fed either 5 or 10 l/d of each MR. Hill et al. (2009a) reported no differences between calves fed a MR containing 27% CP and 20% fat or 27% CP and 17% fat. A potential reason for the lack of response to increased fat or protein supply through the MR could be, in part, changes in solid feed intake (other reasons could include inadequate amino acid or fatty acid profile, or poor digestibility of the ingredients used). But Hill et al. (2009a) reported that calves fed a MR containing 27% CP and 31% fat achieved equivalent solid feed intakes as calves consuming a MR containing 27% CP and 17% fat, but surprisingly, calves fed the high-fat MR had a lower ADG compared with those fed the one containing 17% fat. In a former study, Hill et al. (2007) had already reported that adding energy in MR via lactose or CP, but not via fat, improved ADG. However, offering MR with about 27% MR and about 17% fat results in an oversupply of lactose (>45%). Lactose, differently from fat, is vigorously fermented by intestinal bacteria and may represent a risk for diarrhea.

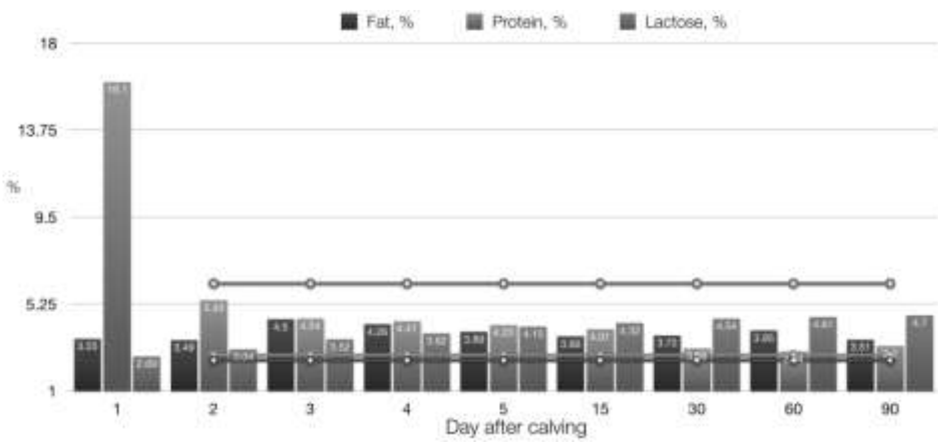

Figure 2. Evolution of nutrient composition of milk following calving (bars) compared with the nutrient composition of a typical milk replacer (lines).

An “ideal” feeding program for calves would probably consist of feeding 6 l/d at 15% (900 g/d of solids) along with a highly palatable starter feed and some chopped high-fiber forage (see below). Offering 8 l/d may foster increased growth rates early in life, but is likely to compromise intake of starter (Bach et al., 2013b; Figure 3), and if fed twice daily may foster insulin resistance in calves (Bach et al., 2013a). However, concerns about incurring long-lasting detrimental effects due to insulin resistance seem unlikely, as Yunta et al. (2015) showed that 20 d after weaning there were no differences in insulin sensitivity among calves fed 4, 6, o 8 L/d of MR during the first 2 months of life.

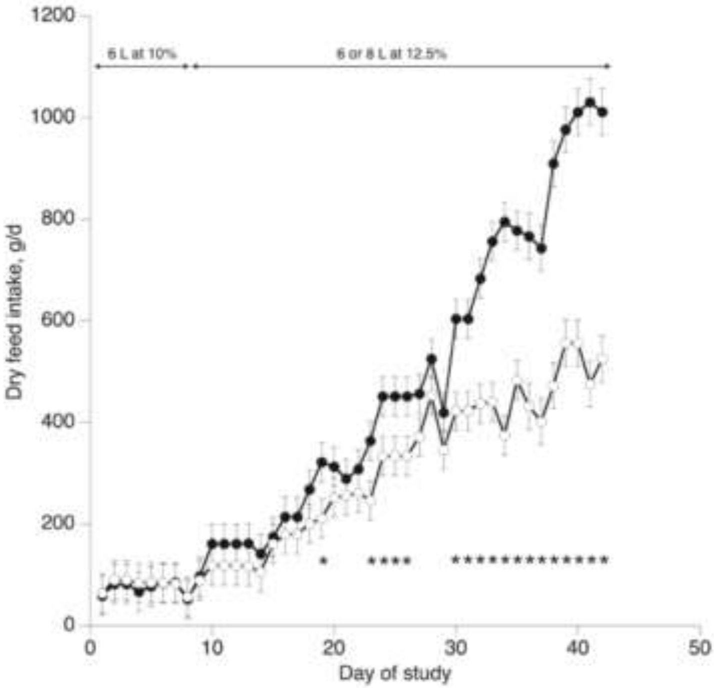

Figure 3. Evolution of dry feed intake during the first 42 d of the study as affected by the level of milk replacer (MR). Open circles denote 8 L of MR/d and solid circles depict 6 L of MR/d. Asterisks indicate days of study when dry feed consumption differed ($P < 0.05$) between MR allowances. Adapted from Bach et al. (2013b).

Solid Feeding

Some schools of thought have proposed that the positive effects on future milk production observed when providing high planes of nutrition in early life could only be achieved by providing increased amounts of MR (Soberon et al., 2012). However, Bach et al. (2012), and more recently (Gelsinger et al., 2016), showed that nutrients supplied from liquid or solid feeding are equally effective in inducing positive long-term effects in milk production. Thus, fostering solid feed intake should be a pivotal objective for any rearing program mainly because: 1) it will help in improving nutrient supply and growth, 2) it will contribute to increase milk production in the future, 3) it will enhance rumen development, and 4) it will facilitate the weaning process. Calves fed high milk allowances tend to struggle during transition onto solid feed, and part of the growth advantage achieved before weaning may be lost due to: 1) diminished consumption of nutrients, and 2) reduced digestibility. Early dry feed consumption fosters early rumen microbial development, resulting in a greater rumen metabolic activity (Anderson et al., 1987). Thus, the high level of MR in calves following an enhanced growth feeding program may delay the start of dry feed consumption, and consequently, it may delay rumen development, making it difficult to wean calves and maintain rapid growth rates.

There are several strategies to improve starter feed intake and support greater ADG early in life. One strategy consists of including 'palatable' ingredients in the formulation of the starter. Miller-Cushon et al. (2014) evaluated the palatability of several energy and protein ingredients and concluded that corn gluten feed and corn gluten meal should be avoided, whereas wheat, sorghum, corn, soybean meal should be prioritized to increase palatability of starters. Oats, which are commonly included in starters, were found to have low palatability, and thus their inclusion in the formulation of starter should not be forced, and if possible, it should be avoided. In terms of nutrients, a good starter should contain 18% CP and 3.2 Mcal/kg of metabolizable energy, although starters containing 20% or more CP may have some benefits right after weaning when rearing calves in intensified milk regimes to provide sufficient metabolizable protein and ensure amino acids do not limit growth. In fact, Stamey et al. (2012) reported increased solid feed intake around weaning (with ~300 g difference in DM intake at weaning) when comparing calves fed ~900 g/d of solids from a MR with 28.5% CP and 15% fat and a starter feed containing 25.5% CP with one containing 20% CP. However, when offering restricted amounts of milk, feeding starter feeds with >22% CP (DM basis) provides no additional advantage in growth (Akayezu et al., 1994). Thus, it seems that with large milk allowances, calves may benefit from increased CP supply via starter feed. Lastly, it may seem logical to limit starch content to avoid acidosis, but the calf actually needs starch, not only for rumen development (as its fermentation will generate large amounts of VFA that stimulate papillae growth), but also to provide energy to sustain growth. Thus, inclusion of low levels of starch in starter feeds is not recommended. In general, feeding starter feeds containing between 25 and 35% starch should be adequate (Bach et al., 2017b).

Several studies (Khan et al. 2011; Castells et al., 2012, Castells et al., 2013; Montoro et al., 2013) have shown that an effective method to foster solid feed intake of calves, contrary to what it has been traditionally recommended, is to provide ad libitum access to poor quality (nutritionally) chopped straw or chopped grass hay. In the last century, it was believed that feeding a fiber source to young dairy calves was necessary because it improved rumen health, and that if no forage was provided to calves, low fiber content of the complete starter should be avoided (Jahn et al., 1970; Thomas and Hinks, 1982). But in the 70's, the concept of textured starter was introduced (Warner et al., 1973). It was then assumed that with textured starters no additional feeding of forage was needed. However, several authors (Kincaid, 1980; Thomas and Hinks, 1992; Phillips 2004; Suárez et al., 2007; Castells et al.,

2012) have reported either an increase in starter intake or no effect on total feed consumption with the inclusion of dietary forage. Castells et al. (2012) offered an 18% NDF and 19.5% CP pelleted starter in conjunction with different sources of chopped forage to young dairy calves, and reported that feeding chopped grass hay or straw improved total dry feed intake and rate of growth, without impairing nutrient digestibility and gain to feed ratio. In contrast, when the forage was alfalfa hay, these benefits were not observed. Several studies (Hill et al., 2008) have argued that feeding forage (hay and straw) to pre-weaned dairy heifers reduced starter and overall dry matter consumption. It is important to note that in the studies by Castells et al. (2012, 2013), when calves were fed ad libitum chopped alfalfa hay, forage intake was 14% of total solid feed intake, whereas when calves were offered chopped oats hay, forage consumption did not surpass 4% of total solid feed intake. Nevertheless, some nutrition consultants do not advocate for forage feeding and propose feeding texturized starter feeds; however, their success will depend on: 1) the scraping ability of the starter feed, and 2) the amount of solid feed consumed by the calf. If calves consume large amounts of starter feed, even a texturized starter feed may fail to provide sufficient scraping activity in the rumen. Thus, from a practical point of view and to remove uncertainty, feeding high-fiber (>60 %NDF) chopped forage along with a starter feed is likely to result in a consistently adequate growing performance. Lastly, when feeding chopped forage to calves, it needs to be well and consistently chopped at about 2.5 cm in length, and despite the fact that it must be high in fiber (>60%NDF), it must also be of high quality (i.e., free of molds, mycotoxins and other impurities).

▪ Weaning Calves

With the introduction of enhanced feeding programs, which consist of feeding large volumes of milk or even providing milk ad libitum, calves depend less on starter feed intake to meet their nutrient needs, and solid feed intake generally represents about <60% of total feed intake the week preceding weaning. In other words, with some enhanced feeding programs, calves are weaned with solid feed intakes around 500 g/d (Terré et al., 2007), which makes it impossible for the calf to maintain adequate ADG during the first weeks of transition. This growth slump has 3 main consequences: 1) potential reduction of milking performance at adulthood; 2) increased risk for disease, especially bovine respiratory disease (**BRD**); and 3) economic loss. Heinrichs and Heinrichs (2011) reported that milk yield during first lactation was positively correlated with the amount of solid feed consumed by calves at weaning (among other factors), and Ollivett et al. (2012) reported that fecal scores improved faster among calves challenged with *Cryptosporidium parvum* and receiving a high plane of nutrition compared with calves on a low plane of nutrition. Lastly, given that feed efficiency and growth potential are high and feed cost is relatively low during the transition, this represents the most profitable period to foster BW accretion and development. The aim should be achieving an ADG in the week following weaning greater >1.0 kg/d, and thus calves should not be weaned until they are consuming at least 1.8 kg/d of starter feed (Figure 4).

Lastly, an important aspect of weaning calves is the way they are socialized. Dairy calves have traditionally been reared individually, mainly to stem the spread of disease, but a growing body of literature suggests several benefits of social housing (in which two or more calves are housed together). Social housing allows for normal social development of the calf, and calves reared in groups respond to novel social situations with less fear and reactivity (de Paula Vieira et al., 2012). Social housing has been shown to encourage greater solid feed meal frequency and intake before and during weaning (Bach et al., 2010; de Paula Vieira et al., 2010), may support greater ADG and reduce stress (de Paula Vieira et al., 2010) through weaning, and might reduce the severity of BRD (Bach et al., 2010). Similarly, grouping calves either at weaning time or during preweaning (Bach et al., 2010), when milk offer is reduced, can result in increased feed intakes and performance. Similarly, social housing at 1 week of age has been reported (Costa et al., 2015) to support greater intake and growth compared with calves grouped at 6 weeks of age; other studies also report similar results when providing social contact to calves before 3 weeks of age when feeding relatively large amounts (<1.0 kg/d) of milk (Jensen et al., 2015).

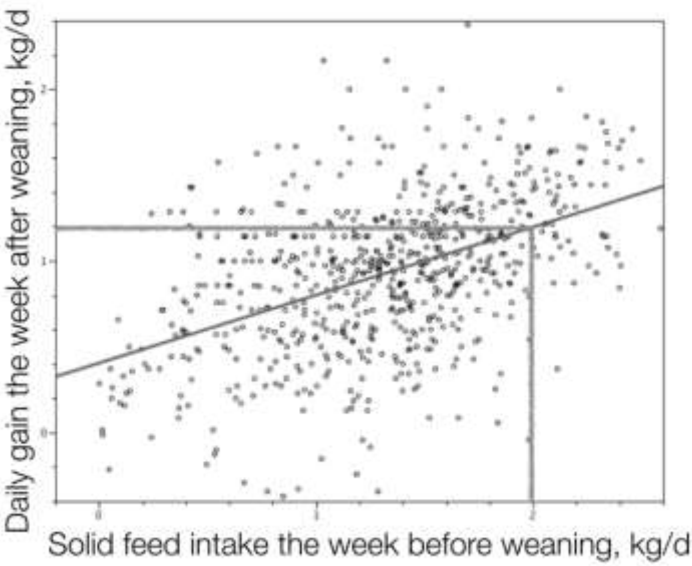

Figure 4. Relationship between solid feed intake the week preceding weaning and average daily gain the week after weaning (Adapted from Bach et al., 2017b).

Summary

Rearing costs represent a large investment for dairy producers. Implementing adequate rearing programs should not only result in optimal rearing costs, but it should also ensure maximum return on investment through improved productivity and longevity.

There exists substantial evidence that generous growth during the first 2 months of life results in improved milk performance at adulthood, and ironically, calves that grow faster early in life are commonly less expensive at first calving than those that grow more slowly. This rapid growth can be achieved by providing about ~1 kg of milk powder per day along with a highly palatable pelleted starter feed and free access to a chopped (~2.5 cm) high-fiber (>60% NDF) grass hay or straw.

Fostering growth right after weaning is highly desirable to lower rearing costs. For this reason, the weaning program must avoid the common growth slump that occurs when feeding generous amounts of milk. Thus, calves should not be weaned until they consume at least 2 kg of starter feed. Also, calves benefit from being weaned in groups rather than in individual hutches.

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What you need to know before, during and after transitioning to group housing of calves: Key considerations

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Take Home Messages

- Benefits of group housing for the calf: improved social skills, more adaptable animals, faster behavioral development, and improved feed intake and weight gains.
- Benefits of group housing for the farm: easy delivery of an enhanced diet of milk or milk replacer, individualized feeding behaviour data, and an improved consumer perception of the industry.
- Before beginning to group house there must be: proper colostrum management (failure of passive transfer < 5% of calves) and minimal health problems in the pre-weaning period (morbidity < 10%, and mortality < 5% of calves)
- Calves raised in a group require a high milk allowance and a gradual or step-down weaning program, ideally providing more than one teat.
- Other important factors for successful group housing include: appropriate group size, all-in-all-out grouping, regular cleaning of bedding and feeding equipment, and monitoring for illness.
- Before going big, we recommend to start small. Producers interested in trying group housing on their farm should start with pairs or triplets, using animals that are most similar in age. This can often be done by removing the partitions between individual pens or hutches. If this works well, groups can easily be expanded to 12 calves if needed.

Introduction

Most farmed mammals such as sheep, pigs, horses, and beef cattle are housed with their dam during the milk-feeding period, and the young normally have contact with other young of a similar age. Dairy cattle production is the exception; standard practice in the North American dairy industry is to separate the calf and dam immediately after birth and raise calves in individual pens during the milk-feeding period, or even after weaning. This limited maternal and social contact contrasts with the evolutionary nature of cattle where young would remain with the mother and interact with other young calves in the herd.

There is a growing number of farms, however, that are moving toward housing calves in groups, in part due to the availability of automatic feeders and the potential of reducing labour requirements per head. While separation from the dam and individual housing remains the norm in the USA (78% of producers), a significant fraction of producers (22%) are converting to some form of group housing (NAHMS, 2014). Recent research has shown that group housing can provide many advantages to both the calves and the farmer if managed well. Moreover, there is recent pressure from consumers and policy-makers to transition to group housing. Here we outline the positive outcomes, but also the common pitfalls, of adopting group housing, and provide suggestions for how management practices can mitigate some of these key issues. We end with a discussion of the future of group housing, and the exciting opportunities that farmers can take advantage of now and in the future.

▪ Why group house calves?

There is a growing evidence showing the negative effects of social isolation in many species, including dairy calves. These include impaired social behavior development, the ability to cope with novelty and stressors, and cognitive development (reviewed by Costa et al., 2016). A few studies have shown how these impairments carry over to adulthood, such as high reactivity to isolation and difficulty integrating into the lactating herd (Wagner et al., 2015). Therefore, it is critical to raise a calf that can effectively and successfully cope with the many management practices on a typical commercial farm.

Group housing is an alternative to individual housing that more closely resembles the natural social grouping of calves and has been shown to mitigate the negative impacts of isolation in early life. For instance, group-housed calves were shown to be less reactive toward an unfamiliar calf (De Paula Vieira et al., 2012), approached a novel object and human quicker (Meagher et al., 2015), and were more likely to consume a novel food (Costa et al., 2014) compared to calves raised individually. Group-housed calves were also more flexible when they had to re-learn a cognitive task (Gaillard et al., 2014), indicating these animals were better at adapting to changes in their environment. It is these types of calves that are best able to cope with transitions (e.g. changes in diet, feeding or lying equipment, introduction to the milking parlor) that farmers should target for their herds.

Another important benefit of housing calves in groups is an increase in weight gain and feed intake compared to calves housed individually (Costa et al., 2015). This is thought to be related to the presence of one or more social companions that facilitate attention toward and subsequently increase manipulation and intake of feed, especially when others are also feeding. Increased dry matter intake and weight gain occurs during the pre-weaning period, as early as 41 days of age, and can persist after weaning (Bernal-Rigoli et al., 2012; Jensen et al., 2015). Early onset of rumination has also been reported in group-housed compared to individually-housed calves (Babu et al., 2004).

These benefits are not just restricted to grouping with multiple calves. Many of these benefits have been seen even when calves are paired, although the age that calves are paired or grouped is important. Research has shown that there is a critical period when calves should be socially housed in order to gain the benefits of this housing system, sometime between 3 and 6 weeks of age (Costa et al., 2015). However, we recommend pairing or grouping as early as possible (at birth or shortly after) to maximize the opportunity for calves to learn from their social companions and achieve high intakes and weight gains.

▪ What do farmers, consumers and policy-makers think of group housing?

Individual housing is one of the main animal welfare concerns in the dairy industry and likely one of the areas that will experience increased criticism of animal agriculture practices with respect to animal welfare, particularly the issues of cow-calf separation and extended social isolation of calves. These practices have been indicated as a key concern by consumers (Ventura et al., 2016) and thus are likely to become more and more important in driving policies that require specific standards in the dairy industry.

Group housing of calves in part addresses some of these concerns, and is likely to increase consumer acceptability and the image of the dairy industry, although this requires further research (Ventura et al., 2016). The Canadian Code of Practice for the Care and Handling of Dairy Cattle recently included a recommendation for housing calves in groups, which can become a requirement in the near future. This follows in the footsteps of several countries who have mandated that calves must be housed in a social group from an early age.

When investigating what dairy farmers think, a recent survey of dairy farmers in Canada (Medrano-Galarza et al., 2017) showed that farmers who moved from individual to group housing with automated feeders did so based on the following 4 reasons: to raise better calves, offer more milk to calves, reduce labour, and improve working conditions. Those farmers who remained with individual housing reported that manual feeding of calves had an advantage for lowering the transmission of disease and the identification of sick calves was easier.

While the reasons to move to group housing are enticing, the transition from individual to group housing is not without its challenges. To rear calves in groups, an understanding of the practical benefits and constraints of social housing is essential. We address these issues in the following section.

▪ Common pitfalls and solutions while transitioning to group housing

What is your rate of morbidity and mortality? It needs to be low.

The risk of horizontal transmission of disease in group housed calves is inevitably greater than when calves are individually housed. Thus it is not surprising that health is one of the most commonly cited concerns associated with group housing. These concerns are certainly valid given that morbidity and mortality rates of calves on farms across the globe remain high, even when calves are individually housed. For instance, yearly mortality of heifers in the United States has been reported to be 6.9% and 7.8% on calf ranches and dairy farms, respectively (Walker et al., 2012). If health is not managed well in individual housing, the problem is likely to be exacerbated in group housing.

Van Amburgh et al. (2011) suggests that dairy farms should use key targets to assess the efficacy of their calf management program. These measures include: failure of passive transfer (FPT) below 5%, calf morbidity rate under 10% (based on number of treatments) and calf mortality rate under 5%. We suggest that farms that are over these thresholds should first assess and address other aspects of management that are critically associated with illness and mortality before the transition to group-housing. Many of the problems associated with health of pre-weaned calves can be traced back to colostrum management, cleanliness of the pen and feeding equipment, or ventilation, which are issues independent of housing system. Therefore, it is critical to ensure that issues with management associated with morbidity and mortality are corrected first before changing to a group housing system.

How is your colostrum management? It needs to be measured.

Passive transfer of immunity from colostrum is one of the most important factors influencing calf health. Failure of passive transfer is highly related to increased morbidity and mortality in calves, which is associated with lower productivity and increased risk of culling later in life. Therefore, it is critical to have a successful colostrum management program in place before moving to group housing. This includes optimal quality and quantity of colostrum and appropriate timing of delivery.

An easy cow-side test for quality of colostrum is to use a digital or optical refractometer or hydrometer (colostrometer) to ensure colostrum contains at least 50 mg/mL of immunoglobulins. When 4 L of high-quality colostrum is fed to all calves within 6 hours after birth, the producer is most likely to ensure a high rate of passive transfer in calves. To confirm passive transfer, the immunoglobulin content can be estimated by measuring the protein in the serum of the blood using a digital or optical refractometer. Calves that are under 5.2 g/dL of serum total protein are considered to have failure of passive transfer (McGuirk and Collins, 2004).

As with morbidity rate, farms that have more than 5% of FPT should not move to group housing until this issue is corrected. Farms with higher than average rates of morbidity or mortality should work with their veterinarian, consultant or extension agent to set up a colostrum management program, ensuring that colostrum quality and passive transfer are directly measured and that protocols for quantity and timing of colostrum delivery are in place. Setting proactive goals and measuring results are keys to a successful calf program, regardless of the type of housing.

How much are you feeding? More milk and gradual weaning is key.

Traditionally, calves have been fed restricted amounts of milk to encourage early consumption of grain and to accelerate rumen development so that weaning can be completed early. This milk-feeding strategy is still prevalent today, where calves are fed approximately 10% of their body weight (around 4 to 6 L of milk / day) on most farms. However, this feeding practice not only limits growth but also leaves calves experiencing prolonged hunger compared to feeding higher amounts of milk (De Paula Vieira et al., 2008; Khan et al., 2011). Consequently, calves that are fed restricted amounts of milk show more abnormal oral behaviors, such as sucking on fixtures in the pen. In group housing, this behavior can also be directed at other calves in the form of cross-sucking (Nielsen et al., 2008).

Therefore to achieve the benefits of social housing, such as higher intakes and weight gains, while minimizing abnormal behaviors, it is essential to feed higher amounts of milk. Recent research provides evidence for what may be considered a ‘high’ amount of milk. Calves that were offered 10 or 12 L of milk had the greatest weight gains, grain intakes and had the least number of visits to the milk feeder when milk was unavailable (a measure of hunger) compared to calves receiving 6 L of milk (Rosenberger et al., 2017).

When feeding higher amounts of milk, a gradual weaning program is critical to ensure calves gain familiarity with solid feeds before weaning and thereby maintain weight gains during the pre-weaning period and decrease the feeling of hunger associated with removal of milk (Khan et al., 2016). One type of gradual weaning program includes a step-down technique where milk is reduced to an intermediate level (e.g. from 12 L to 6 L/day) at about one month of age and maintained until a final milk reduction at the targeted weaning age (e.g. from 6 L to 0 L/day). This type of weaning program can be easily implemented for group housed calves using an automated milk feeder.

Can competition and cross-sucking be limited? Provide sucking opportunities.

An obvious advantage of individual housing is that competition, aggression, and cross-sucking are prevented. Nonetheless, several strategies can be employed to reduce these cases during feeding time in group housing. More than one teat should be provided when calves are housed in groups of more than 12 and free access to solid feed should be provided. Even in smaller groups, multiple teats will limit competition. Barriers that protect the calf’s head and shoulders, or even the full body, are a good option that will limit or altogether prevent displacements during feeding. When milk is offered in fewer and larger portions, competition for access to teats will also be lowered. As a rule of thumb, there should not be more than 1 month of age difference between calves in a single group so that younger and smaller animals are able to access feed.

Once groups are formed, introduction or removal of individuals should be avoided since calves establish social relationships as early as 30 days of age that may negatively impact the individual if these bonds are disrupted. Therefore, to limit aggressive behavior, calves should be maintained in stable groups of a similar age.

Cross-sucking in group housed calves is another commonly cited problem but there are studies that have reported little to no cross-sucking in groups (e.g. Chua et al., 2002), suggesting that the problem can be managed. Cross-sucking often becomes a problem when the ability to engage in natural suckling behaviour is prevented or limited, which is often related to poor milk-feeding practices. Solutions include providing enough milk and teats so that the motivation to suckle can be satisfied.

Can disease transmission be minimized? Small groups, clean, and monitor.

One common reason for individually housing young calves is to limit disease transmission and to facilitate the identification of illness in individuals. On the contrary, there is little evidence of improved calf health in individual compared to small group sizes. Some studies have indeed reported more health problems in group-reared calves while others have found no health advantage of individual housing compared with small groups (reviewed in Costa et al., 2016). Furthermore, diarrhea and respiratory illness, the most common diseases in young calves, are not consistently associated with group housing (e.g. Hänninen et al., 2003). Nonetheless, we caution that many management practices can influence the risk of disease transmission and should be considered where comparing housing systems, such as the amount of milk fed and bedding management.

Group size and method of grouping are two key practices that can help to minimize disease spread. Groups of less than 12 calves are easiest to manage and reportedly have reduced respiratory illness and severe diarrhea compared to larger groups. Groups of 2 up to 8 made no difference in terms of disease incidence (Abdelfattah et al., 2013). An ‘all-in-all-out’ grouping system should be used whenever possible to minimize the spread of disease between groups. In this system, calves remain in a stable environment together instead of moving in and out of pens. This form of management helps to prevent the spread of infections between groups of animals raised in the same unit by allowing for cleaning and disinfection between groups.

Clean milk feeding equipment and bedding are also essential to maintaining good calf health. This includes disinfection of tubing and nipples on a regular basis to prevent bacteria build-up and soured milk. Bedding should also be changed, or at the very least topped up, regularly, and ammonia levels should be closely monitored.

We have described just a few of the important variables that must be managed to minimize health problems in group housed calves. However, there are many other factors including ventilation, bedding type, nutrition plan, stocking density, and space allowance that are related with health issues. Farms that are experiencing health problems in calves should first address and manage these factors before transitioning to group housing. However, even when each of these factors are managed well, some calves will inevitably still fall ill and thus monitoring of illness should remain a priority. Close monitoring of individuals and early detection of illness becomes easier in smaller groups.

In summary, while group housing has its benefits, it is not without its challenges, requiring careful attention and specialized management. Farms should avoid transitioning to group housing until pre-existing issues are addressed, such as high morbidity or mortality rates and poor colostrum management. Group housing is most successful when calves are fed high amounts of milk, which prevents periods of hunger and limits competition and cross-sucking. Consideration for group size and all-in-all-out group strategies will also address problems with competition and disease transmission. Finally, regular cleaning of feeding equipment and bedding is essential to minimize illness among grouped calves. Although ‘reduced labour’ was a top-cited reason for farmers to move to group housing, the points addressed above indicate that the time previously spent individually feeding calves should be shifted to cleaning of equipment and bedding, and monitoring grouped calves for early signs of illness.

▪ The future of group housing: automated technologies

Once a farm has successfully implemented a group housing program, the dairy has another large opportunity especially when using automated milk feeders. The data recorded by these feeders can be used to identify calves that may be ill and to track overall performance and success of the pre-weaning period – all with very little additional labour. Data management and data-informed management decisions are some of the biggest opportunities for the agriculture sector, and these data management techniques and automation are expected to become more sophisticated in the near future.

The automated milk feeding system is one of the most common precision technology used to detect disease development such as bovine respiratory disease and diarrhea. For instance, the Forster Technik (Engen, Germany) software collects data on individual calf daily milk intake, drinking speed and visits to the feeder. It also can be programmed to “alarm” the farmer when a calf deviates from its normal feeding pattern or trajectory. These deviations may reflect sickness behaviours, allowing for early treatment of illness. One study reported that the automated feeder detected deviations from normal milk intake and drinking speed 2 days before diagnosis of illness, and deviations from normal unrewarded visits were noted as early as 4 days before diagnosis (Knauer et al., 2017). This example highlights a crucial opportunity for farms to utilize data collection from the feeders to identify sickness and provide treatment earlier, thus limiting the negative impacts of reduced feed intake and illness on the welfare of the individual. Calves that are detected as deviants can be placed on a ‘watch’ list that notifies the farmer outside of the facility, making it a convenient and efficient method for monitoring illness in grouped calves. However, we caution that the automated milk feeder should not be used as a replacement for direct assessment of calf health, but rather as a guideline for which calves may require additional attention.

In addition to using the automated milk feeder to determine which calves require further health assessments, the feeder can monitor the overall success of the pre-weaning program. The program can estimate weight gains by using the initial weight and calculating a current weight based on the calf's milk intake. These systems are thus capable of tracking the growth of individuals within groups of calves during the pre-weaning period, offering immediate feedback on the success of the milk-feeding program. Similar to feeding behaviour, deviations in growth can also be set to send an 'alarm' indicating a possible case of illness or a poor transition during weaning.

In addition, provided the calf was not sick, grain consumption can be calculated as the crude difference in weights from the automated milk feeder software and the actual weight of the calf. This can be used to calculate feed efficiency, variability in feeding patterns and many other factors that can inform culling decisions and feeding strategies. Alternatively, an automated grain feeder can be integrated with the milk feeder to report true grain intake. This option provides the opportunity to wean calves based upon individual grain consumption (de Passillé and Rushen, 2016).

In the long-term, this data has the potential to inform farmers of how the pre-weaning program is linked with later performance in the milking herd. Given that high milk consumption early in life has been associated with higher milk production and greater parenchymal mass (udder development) compared to restricted-fed calves (Geiger et al., 2016), records of a cow's early-life feeding patterns and growth will provide critical information to aid in our understanding of the long-term impacts of early-life rearing and nutrition on future productivity. Furthermore, with the advancement of technologies for monitoring other behavioural and physiological measures in calves, such as activity, rumination and body temperature, we can expect many more possibilities allowing for the automated collection, analysis and application of feeding behaviour and intake data of grouped calves.

▪ Conclusions

The detrimental effects of social isolation are now recognized in a range of species, and we have highlighted newer work on dairy calves showing that individually-raised calves have deficient social skills, difficulties coping with novel situations, and poor learning abilities. Social housing for calves improves pre-weaning solid feed intake and overall weight gain during the transition from milk to solid feed. The challenges associated with group housing include disease transmission, competition at the feeder and cross-sucking, but we have presented research suggesting that calves can be grouped in good health with minimal abnormal behaviours if housing is properly managed.

Grouping calves from an early age will have returns. The long-term effects of early-life social rearing are beginning to show that adults can have improved production and reduced behavioural reactivity later in life. We encourage producers to test out group housing by starting with pairs of calves that are similar in age, and if this works well, groups can be expanded to 3 or 4, and up to 12 calves easily. We predict that producers will see the benefits within weeks of transitioning to group housing and will have the opportunity to use the data generated by the automated milk feeders to help manage their operations.

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Rethinking Colostrum: It's More than Just Immunoglobulins

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■ Take Home Messages

- The pre-weaning period is a period of life where the calf is undergoing significant developmental changes and this development is directly linked to future productivity in the first and subsequent lactations.
- Pre-weaning growth rate and primarily protein accretion appears to be a key factor in signaling/communicating with the tissues that enhances lifetime milk yield.
- Anything that detracts from feed intake and subsequent pre-weaning growth rate reduces the opportunity for enhanced milk yield as an adult.
- Nutrient supply, both energy and protein, are important and protein quality and digestibility are essential.
- There are no substitutes for liquid feed prior to weaning that will enhance the effect on long-term productivity.
- Factors other than immunoglobulins in colostrum modify feed intake, feed efficiency and growth of calves and can enhance the effect of early life nutrient status.
- As an industry and as nutritionists we need to talk about metabolizable energy, protein intake and status relative to maintenance, and stop talking about cups, quarts, gallons, buckets and bottles of dry matter, milk, milk replacer, etc. The calf has discrete nutrient requirements not related to dry matter and liquid volume measurements.
- The effect of nurture is many times greater than nature and the pre-weaning period is a phase of development where the productivity of the calf can be modified to enhance the animal's genetic potential.
- Adhering to specific growth targets throughout the rearing period and calving as early as feasible is essential to ensure optimum economic returns in the first lactation within the management system.

▪ Lactocrine Hypothesis: Colostrum's role

It has been well recognized that the phenotypic expression of an individual is affected by both genetic ability and the environment. To some degree, while in the uterus, the mother controls the environment in which the fetus is developing, influencing in this way the expression of the genetic material. There is good evidence that this environment can play a role in long-term productivity in beef cattle (Summers and Funston, 2012). For example, heat stress of the dam during late fetal development has been shown to affect subsequent growth, immune function and feed efficiency in the calf (Tao et al., 2012), and subsequent milk production (Monteiro et al., 2016). In that study calves from heat stressed dams had lower circulating IgG's, lower efficiency of absorption, reduced immune cell proliferation and lower growth rate through weaning, indicating that the effect of heat stress on the calf carried over through at least the weaning period. Thus, environmental factors affect the calf during fetal development and the productivity of the calf can be modified – an outcome that has not been fully recognized and appreciated through the pre-weaning period. Once the calf is born, it will carry these effects with it into post-natal life, where other environmental and maternal factors will continue to impact the productivity of the animal. The first mammary secretion, colostrum, plays an important role in the development of the calf and although traditionally considered only for its role in immune system function, data generated over many years suggests that its role in immune system function is more complex than immunoglobulins.

▪ It's Not Just IgG's - Role of Maternal Leukocytes

Colostrum is rich in many different cell types, many of which are lumped into the term "somatic cells," analyzed as such and not always considered positively. However, those cells are important and data generated in other species clearly demonstrated the presence and "trafficking" of cells, primarily leukocytes, into circulation of the neonate (Williams, 1993; Sheldrake and Husband, 1985). More recently, work has been conducted to understand if the uptake of the maternal leukocytes into circulation has any impact on the function and capacity of the immune system of the calf. The implication is that leukocytes from the dam will carry "maternal memory" from prior exposure and recognition of pathogenic organisms, which if functional, can enhance cellular immunity in the calf. This adds a new dimension to the role of colostrum with respect to immunity and impacts colostrum management if the presence and availability of these cells is important for full immune system stimulation and function in the calf.

Papers have been published over the last decade that clearly demonstrate the uptake of leukocytes from colostrum into the circulation of the calf (Reber et al, 2006; 2008ab; Donovan et al. 2007; Langel et al., 2015; Novo et al., 2017). The data from Reber et al. (2006) clearly demonstrated that maternal leukocytes were transferred into the calf within 12 to 24 hr of colostrum ingestion and disappeared from circulation within 36 hr after ingestion. The implication of this data was that maternal leukocytes from the blood stream of the dam were modified in the mammary gland to be more functional and capable of being absorbed into circulation in the calf. This is significant because it implies an active process and not just a process that passively accepts whatever cell might be present in the colostrum. Follow-up work from Reber et al. (2008ab) further demonstrated that the maternal leukocytes were absorbed into circulation and those cells enhanced the rate of maturation of immune cells in the calf, as well as the ability of the cells to recognize particular antigens. The majority of these developmental changes occurred within the first two weeks post colostrum ingestion.

Following this concept, Donovan et al. (2007) studied the effect of maternal leukocyte uptake on cellular immunity in the calf by targeting specific antigen responses. In this study, they vaccinated the dams against BVDV using an inactive vaccine, but did not vaccinate them for mycobacterial antigens, thus the cells would be naïve to the mycobacteria. The colostrum was then fed intact, after freezing or after cell-removal. Calves were then challenged with BVDV antigens. Calves fed the intact colostrum had enhanced immune responsiveness whereas calves fed the frozen and cell free colostrum did not respond similarly. All calves had similar responses to the mycobacterium antigens demonstrating the lack of maternal information transfer. This study suggests freezing colostrum negatively affects the population of maternal leukocytes, preventing them from being absorbed. It further begs the question about the significance of this outcome given our management of colostrum to ensure low bacteria counts and disease transmission through freezing and pasteurizing.

The positive effect of cell transfer from colostrum on cellular immunity was further demonstrated in both Holstein and Jersey calves in work from Langel et al. (2015) and Novo et al. (2017). In the study from Langel et al. (2015) calves were fed 4 qt of either whole colostrum or cell-free colostrum at birth. Calves receiving the cell-free colostrum had higher respiratory scores at 38 d of age and there were no differences in fecal consistency. Calves fed the whole colostrum had immune cells with the ability to recognize particular pathogens and the only manner in which this could occur would be through the exchange of information from the maternal cells to the intrinsic leukocytes in the calf. In the study of Novo et al. (2017) calves were fed whole fresh colostrum or frozen colostrum in each case from their own dams. Calves given the frozen colostrum had more diarrhea on day 7 than calves fed fresh colostrum. In addition, the calves fed frozen colostrum had less red blood cells, less hemoglobin and more anemia from 21 to 28 days. Overall, the number of leukocytes remained constant in the calves fed whole colostrum whereas the lymphocyte population increased in the calves fed frozen colostrum after 7 days of age. Taken together, these studies demonstrate changes in cellular immunity in neonatal calves with modifications to their ability to recognize possible pathogens and challenges to the system. Implications for colostrum management are that fresh colostrum is best for ensuring the transfer of this information from the dam to the offspring, whether freezing or pasteurizing, but the degree to which this lack of leukocyte transfer would affect the long-term immune function of the animal is still unknown. Thus, it is more prudent to maintain our current protocols and freeze and or pasteurize colostrum to ensure pathogens are managed and colostrum quality is maintained.

■ Colostrum as a Communication Vehicle

The effect and extent of maternal influence in the offspring's development does not end at parturition, but continues throughout the first weeks of life through the effect of milk-born factors, including colostrum, which have an impact on the physiological development of tissues and functions. A concept termed the "lactocrine hypothesis" has been introduced and describes the effect of milk-borne factors on the epigenetic development of specific tissues or physiological functions in mammals (Bartol et al., 2008). Data relating to this topic has been described in neonatal pigs (Donovan and Odle, 1994; Burrin et al., 1997) and calves (Baumrucker and Blum, 1993; Blum and Hammon, 2000; Hammon et al., 2012). The implication of this hypothesis and the related observations are that the neonate can be programmed maternally and postnatally to alter development of a particular process and potentially modify the genetic ability of the animal.

At birth, the gastrointestinal tract (GIT) is highly developed but naïve and will undergo significant growth, specifically protein synthesis, cell growth and enzyme production, to enhance digestion, absorption and create a more robust barrier for immune system defense. Colostrum contains many growth factors that are active at enhancing the development of the GIT (Table 1) – an area that has been extensively researched and reviewed (Odle et al., 1996; Blum and Hammon, 2000; Steinhoff-Wagner et al. 2011; Hammon et al. 2012). For example, colostrum feeding has been shown to positively affect the development of the gastrointestinal tract (GIT) and enhance energy metabolism of the calf. Adequate intake of these non-nutritive factors appears to be important for establishing gastrointestinal development for enhanced nutrient intake and nutrient utilization (Blum and Hammon, 2000; Hammon et al. 2012).

Table 1. Nutrients, energy, immunoglobulins, hormones and growth factors in colostrum and milk.

Components	Units	Colostrum	Mature Milk
Gross Energy	MJ/L	6	2.8
Crude protein	%	14.0	3.0
Fat	%	6.7	3.8
Immunoglobulin G	g/L	81	<2
Lactoferrin	g/L	1.84	Undetectable
Insulin	µg/L	65	1
Glucagon	µg/L	0.16	0.001
Prolactin	µg/dL	280	15
Growth hormone	µg/dL	1.4	<1
IGF-1	µg/dL	310	<1
Leptin	µg/dL	30	4.4
TGF-α	µg/dL	210	<1
Cortisol	ng/ml	11.2	1.2
17βEstradiol	µg/dL	3.3-4.7	0.54

Several studies have identified factors in colostrum that enhance crypt cell growth and development, which in turn enhances villus height in calves (Blum and Hammon, 2000; Blätter et al., 2001; Roffler et al., 2003). In addition to the increase in absorption capacity through increased surface area, there is a concomitant increase in enzyme production, especially lactase that enhances digestion and absorption of glucose (Hammon and Blum, 1997; Steinhoff et al., 2010). This leads to data like that from Steinhoff-Wagner et al. (2011) where they clearly demonstrated that colostrum feeding compared to iso-nutrient levels of a milk-based formula enhanced the glucose uptake of calves fed solely colostrum for up to four days of life. In that experiment, first milking colostrum was fed as the first meal and second, third and fourth milking colostrum was fed over the next three days, respectively, to examine differences in dietary glucose uptake, insulin responsiveness and endogenous glucose production. Calves fed colostrum had higher levels of plasma glucose, similar endogenous glucose production and higher plasma insulin concentrations post feeding. This suggests that colostrum enhanced the absorption of glucose, and the insulin in the colostrum was absorbed by the GIT, which contributed to the endogenous insulin production. It is also important to note that glycogen reserves were greater in the calves fed colostrum and that serum urea nitrogen was lower and amino acid concentration was greater, implying a more anabolic state with colostrum intake as compared to similar nutrient intake from formula. Thus, it appears that in addition to the Ig's, the other non-nutritive factors in colostrum are important to establish enhanced energy utilization and GIT development in newborn calves. These potential effects should be considered when evaluating and diagnosing differences in calf performance under similar management and nutritional conditions.

Given the data on development of the GIT, the next logical outcome is to look for growth responses based on the amount of colostrum fed in the first few hours of life or to find comparison where alternatives to the dam's colostrum were fed and evaluate differences. For example, Jones et al. (2004) examined the differences between maternal colostrum and a serum-derived colostrum replacement. In that study, two sets of calves were fed either maternal colostrum or serum-derived colostrum replacement with nutritional components balanced. The colostrum replacer was developed to provide adequate immunoglobulins to the neonatal calf, however the other non-nutritive factors found in colostrum were not considered. The results demonstrated that in the first 7 days of life, the calves fed maternal colostrum had significantly higher feed efficiency; the difference established in that period was still apparent at 29 days compared to calves fed serum-derived colostrum replacement. It is important to recognize the IgG status of calves on both treatments were nearly identical suggesting that factors in colostrum other than IgG's were important in contributing to the differences. Further, data from Faber et al. (2005) demonstrated that the amount of colostrum, 2 L or 4 L, provided to calves at birth significantly increased pre-pubertal growth rate under similar nutritional and management conditions, as well as tendencies for greater herd life and milk yield through two lactations.

To extend and try to better understand this data, Soberon and Van Amburgh (2011) examined the effect of colostrum status on pre-weaning ADG and also examined the effects of varying milk replacer intake after colostrum ingestion (Table 2). Calves were fed either high levels (4 L) or low levels (2 L) of colostrum, and then calves from these two groups were subdivided into two groups that were fed milk-replacer in limited amounts or ad-libitum. Calves fed 4 L of colostrum had significantly greater average daily gains pre-weaning and post-weaning and greater post-weaning feed intake, consistent with the data from Faber et al. (2005) and Jones et al. (2004). The observations from these experiments reinforce the need to ensure that calves receive as much colostrum as possible over the first 24 hr and possibly over the first 4 days, as described by Steinhoff-Wagner et al. (2011), to ensure greater nutrient availability and absorption for the calf. The non-nutritive factors in colostrum other than Ig's appear to be important for helping the calf establish a stronger anabolic state and develop a more functional GIT barrier and surface area for absorption.

Table 2. Effect of high (4+2 L) or low (2L) colostrum and ad-lib (H) or restricted (L) milk replacer intake on feed efficiency and feed intake in pre and post-weaned calves (Soberon and Van Amburgh, 2011).

Treatment[1]	***HH***	***HL***	***LH***	***LL***	*Std dev*
N	34	38	26	27	
Birth wt, kg	44.0	43.4	41.8	43.3	0.95
Birth hip height, cm	80.5	80.3	80.0	80.9	0.56
IgG concentration, mg/dl*	2,746[a]	2,480[b]	1,466[c]	1,417[c]	98
Weaning wt, kg	78.2[a]	63.5[b]	72.2[c]	62.4[b]	1.89
Weaning hip height, cm	93.0[a]	88.6[b]	91.5[a]	89.6[b]	0.60
ADG pre-weaning, kg	0.79[a]	0.42[b]	0.67[c]	0.39[b]	0.028
Hip height gain, pre-weaning, cm/d	0.248[a]	0.158[b]	0.227[a]	0.161[b]	0.009
ADG birth to 80 d, kg	0.78[a]	0.59[bc]	0.66[b]	0.53[c]	0.034
Hip height gain, birth to 80 d, cm/d	0.214[a]	0.157[b]	0.184[c]	0.148[b]	0.008
Total milk replacer intake, kg DM	44.4[a]	20.5[b]	40.9[c]	20.0[b]	1.2
Grain intake pre-weaning, kg	2.5[a]	12.0[b]	2.1[a]	9.7[b]	1.5
ADG/DMI, pre-weaning	0.60	0.61	0.67	0.61	0.042
ADG post-weaning, kg	1.10[a]	0.97[ab]	0.88[b]	0.92[b]	0.061
DMI post-weaning, kg/d	2.89[ab]	2.89[a]	2.58[c]	2.66[bc]	0.104
ADG/DMI post-weaning	0.359	0.345	0.335	0.358	0.020

[1]HH = high colostrum, high feeding level, HL = High colostrum, low feeding level, LH = Low colostrum, high feeding level, LL = Low colostrum, low feeding level. Rows with different superscripts differ $P < 0.05$.

Also, colostrum is the first meal and accordingly is very important in establishing the nutrient supply needed to maintain the calf over the first day of life. The amount of colostrum has always focused on the idea that we are delivering a specific amount of immunoglobulins (Ig's) to the calf, and many times we underestimate the nutrient contribution of colostrum. Further, many times of year, we tend to underestimate the nutrient requirements of the calf, especially for maintenance. For example, a newborn Holstein calf at 38 kg birth weight has a maintenance requirement of approximately 1.55 Mcals ME at 22 °C. Colostrum contains approximately 2.51 Mcals metabolizable energy

(ME)/lb, and a standard feeding rate of 2 L of colostrum from a bottle contains about 1.5 Mcals ME. Thus, at thermoneutral conditions, the calf is fed just at or slightly below maintenance requirements at its first feeding. For comparison, if the ambient temperature is 0 °C the ME requirement for maintenance is 2.4 Mcals, which can only be met if the calf is fed approximately 0.45 kg of DM or about 3.3 L of colostrum. This simple example illustrates one of the recurring issues with diagnosing growth and health problems in calves – the use of volume measurements to describe nutrient supply instead of discussing energy and nutrient values. Two liters of colostrum sounds good because that is what the bottle might hold, but it has little to do with the nutrient requirements of the calf.

Managing the calf for greater intake over the first 24 hours of life is important if we want to ensure positive energy balance and provide adequate Ig's and other components from colostrum for proper development. For the first day, at least 3 Mcals ME (approximately 4 L of colostrum) would be necessary to meet the maintenance requirements and also provide some nutrients for growth. On many dairies this is done via an esophageal feeder and the amount is dictated by the desire to get adequate passive transfer. Those dairies not tube feeding should be encouraging up to 4 L by 10 to 12 hours of life to ensure that colostrum fed not only meets the Ig needs of the calf, but also ensures that the nutrient requirements are met for the first day of life.

▪ Nutrient Status

There are several published studies and studies in progress that have both directly and indirectly allowed us to evaluate milk yield from cattle that were allowed more nutrients up to eight weeks of age (Table 2). The earliest of these studies investigated the effect of suckling versus controlled intakes or ad-libitum feeding of calves from birth to 42 or 56 days of life (Foldager and Krohn, 1994; Bar-Peled et al, 1997; Foldager et al, 1997). In each of these studies, increased nutrient intake prior to 56 days of life resulted in increased milk yield during the first lactation, which ranged from 450 to 1,361 additional kilograms (Table 3). Although they are suckling studies, milk is most likely not the factor of interest, but nutrient intake in general – a fact that is demonstrated in the more recent data.

A meta-analysis was conducted to evaluate the data presented in Table 3 using Comprehensive Meta-Analysis software (CMA, v2.2.064, Biostat, Englewood, NJ; Borenstein et al., 2005). In the first analysis, the treatment calves, or those calves that received more nutrients from milk or milk replacer prior to weaning, were estimated to produce 429 ± 106 kg more milk in first lactation ($P < 0.001$) compared to control calves. This analysis did not include ADG or any other predictors and was simply an evaluation of treatment effect. It should be immediately recognized that within these data sets, starter intake was not well described and any starter intake or additional nutrient intake would enhance the outcome; this, however, is difficult to quantify. In the paper by Soberon et al. (2012), the role of starter intake was discussed and based on recent studies investigating starter intake and growth rates, it would be very difficult for calves to achieve the nutrient intakes and associated growth rates in the first 4 to 6 wk of life necessary to realize the milk yield outcome identified in this analysis. Equally important was the odds ratio from this analysis of 2.09 ($P = 0.001$) which indicated that a calf receiving more nutrients during the pre-weaning period was two times more likely to produce more milk than a calf that is restricted during the same period.

Table 3. Milk production differences as adults among treatments where calves were allowed to consume approximately 50% more nutrients than the standard feeding rate prior to weaning from either milk or milk replacer.

Study	Milk response (kg)
Foldager and Krohn, 1994	$1{,}405^{s}$
Bar-Peled et al., 1997	453^{t}
Foldager et al., 1997	519^{t}
Ballard et al., 2005 (@ 200 DIM)	700^{s}
Shamay et al., 2005	981^{s}
Drackley et al., 2007	835^{s}
Raeth-Knight et al., 2009	718^{ns}
Terre et al., 2009	624^{ns}
Morrison et al., 2009	0^{ns}
Moallem et al., 2010	732^{s}
Davis-Rincker et al., 2011	416^{ns}
Soberon et al., 2012	552^{s}
Margerison et al., 2013	595^{s}
Kinzelback et al., 2015	0^{ns}

Milk response is the difference between treatment milk yield minus control. ^{s} $P < 0.05$, ^{t} $P < 0.1$, ^{ns} $P > 0.1$

Each study offered different quantities and qualities of nutrients to treatment groups, thus to help evaluate the outcome of milk yield, ADG was included in the analysis to account for the effect of nutrient intake and nutrient quality. In order to evaluate the effect of ADG on first lactation milk yield, ADG was included in the analyses as a predictor variable and analyzed by meta-regression. In that analyses, a prediction equation was generated where first lactation milk yield = -106 kg + 1,551.4 (± 637) kg*ADG (Low limit 301 kg, upper limit 2,801 kg; Z value 2.41; $P = 0.01$), where ADG is kg pre-weaning average daily gain. This means that for every kg of pre-weaning ADG, calves produced 1,551 kg more milk during their first lactation (Soberon and Van Amburgh, 2013). This was a higher but consistent response to what was observed among two herds of 850 kg and 1,113 kg per kg of ADG (Soberon et al., 2012) indicating that the response to pre-weaning nutrient intake is not constant among herd and most likely varies with the management and environment of the herd, along with the herd's genetic potential for milk yield.

■ Summary

Colostrum is an important part of early calf development, from immune function to digestion and metabolism. The constituents of colostrum are there to ensure the calf is provided support that enables success at the beginning of extra-uterine life. Given the data on the effects of colostrum on metabolism, growth and development of the calf, a management suggestion would be to feed first milking colostrum to the calf immediately, then feed colostrum from milkings 2 through 4 (day one and two of lactation) to the calves over the first 4 days. This would ensure the non-nutritive factors are supplied to the calf during the period the calf is responsive to them in an effort to enhance intestinal development and function, along with enhancing glucose absorption during a period when energy status is extremely important. Our management approaches and systems need to recognize these effects and capitalize on them. Improving the nutrition and management of calves appears to improve the sustainability of the animal through increased productivity throughout life. This has implications for animal welfare, the environment and profitability. We have much to learn about the consistency of the response and the mechanisms that are being affected.

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Digestibility of Starter Feeds in Calves: Modeling the effects of liquid intake and weaning on digestibility of nutrients in pre- and post-weaned dairy calves

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Take Home Messages

- Digestion of nutrients (particularly carbohydrates) from calf starters depends on rumen development.
- Consumption of more than approximately 700 g/d of milk replacer solids may depress starter intake and rumen development.
- Delayed rumen development reduces post-weaning digestion of nutrients and may predispose calves to reduced growth, increased stress, and potentially increased risk of disease.

Introduction

Accurate predictions of nutrient supply and nutrient requirements are essential to modern ration formulations and animal production. Accurate and precise models allow the provision of nutrients to meet requirements for maintenance and optimal production without supplying excess nutrients that contribute to inefficiency or environmental damage.

Most nutrient models predict supply of metabolizable energy (ME) and metabolizable protein (MP); in lactation models, flow of nutrients are predicted from endogenous, microbial, and undegraded dietary sources. Nutrient requirements are usually predicted using factorial calculation of requirements for maintenance (adjusted for environmental and management considerations), growth, pregnancy, and lactation. Only maintenance and growth predictions are used to predict nutrient requirements for calves, with requirements for pregnancy included for primiparous heifers.

For young calves and heifers, prediction of nutrient supply by the 2001 Nutrient Requirements of Dairy Cattle (NRC, 2001) assumes fixed digestibility and metabolizability of energy and protein. For example, calculation of ME from milk replacer is assumed to be the caloric content of protein, fat, and lactose adjusted for digestibility and metabolizability:

$$\text{ME (Mcal/kg)} = [(0.057 \times \text{CP}) + (0.092 \times \text{EE}) + (0.0395 \times \text{CHO})] \times 97\% \times 96\%,$$

where: CP = crude protein %, EE = ether extract %, CHO = carbohydrate %, 97% = digestibility of nutrients, and 96% = metabolizability of digested nutrients.

Metabolizable energy content of calf starters is calculated as the sum of the digestible fractions of protein, non-fibre carbohydrates, neutral detergent fibre (NDF), crude protein (CP), and fat as described in the 2001 Dairy NRC (NRC, 2001) for adult cattle. Neither liquid nor starter feeds are corrected for differences in digestibility caused by age or development of the gastrointestinal tract in these models.

In young calves, digestibility of dry feeds (concentrates and forages) depend on the development of ruminal fermentation and intestinal digestion. This is particularly true for NDF (primarily fermented in the rumen) and starch (dependent on ruminal fermentation and small intestinal digestion). Studies have shown that fibre fermentation is limited in neonatal calves (Chapman et al., 2016; Hill et al., 2016a, b). Further, pancreatic α-amylase production is low at birth (Siddons, 1968) but increases with age (Huber et al., 1961; Morrill et al., 1970) along with total pancreatic secretion (McCormick and Stewart, 1966) thereby affecting small intestinal digestion of starch (Morrill et al., 1970).

Development of microbial fermentation changes the flow of nutrients from the stomach. Prior to weaning, nutrients are derived primarily from milk protein, fat, and lactose; after weaning, nutrients are provided by volatile fatty acids absorbed from the rumen and microbial protein that increases in flow with increasing dry feed intake (Leibholz, 1975; Quigley et al., 1985).

Changing the amounts and types of liquid fed to calves may alter age at which dry feed intake begins (Hill et al., 2006a, b; Strzetelski et al., 2001) thereby altering rumen development. This is particularly true when large amounts of liquid are fed (i.e., greater than about 700 g of solids from liquid/day for Holstein calves) since large amounts of liquid consumed will delay rumen development (Terré, et. al, 2007). Several studies have reported increased BW at weaning for calves fed large amounts of liquid pre-weaning; however, the advantage in growth compared to conventional feeding methods (500-700 g of solids/day) may be lost as BW gain slows dramatically in the period immediately post-weaning. We have attempted to quantify the effects of increased milk replacer allowance on digestibility of starter and its effects on growth and efficiency of young calves to determine if differences in the digestion of nutrients, particularly of carbohydrates, might be at least partially responsible for differences in growth.

■ Digestion of Solid Feed

Calves are commonly weaned between 1 and 3 months of age in most dairy systems, with the most common age being approximately 9 weeks of age in the U.S. (USDA, 2016). Weaning to dry feed requires that the calf has sufficient digestive and fermentative capability to provide nutrients to support maintenance and growth. Further, the source of nutrients changes from milk digested primarily in the small intestine to grain-based ingredients fermented in the rumen and (or) digested in the small intestine. Therefore, gastrointestinal, hepatic, and systemic enzyme systems must be sufficiently adapted to changing sources of nutrients. If a calf is inadequately prepared for weaning, performance may suffer and predispose calves to reduced growth, poor efficiency, and even increased susceptibility to disease (Roth et al., 2008, 2009).

The most important factor in promoting rumen development and adaptation in preparation for weaning is consumption of dry feed containing fermentable carbohydrates – particularly sugars and starches – that are fermented to propionate and butyrate in the rumen by resident rumen bacteria. Production of volatile fatty acids and microbial protein stimulate a series of adaptations in the rumen, gastrointestinal tract, hepatic tissues, and systemically that promote gluconeogenesis, production and release of β-hydroxybutyrate by rumen epithelium, and utilization of acetate by peripheral tissues (Howarth et al., 1968; Huber, 1969; Baldwin et al., 2004).

In the past 15 years, some dairy experts have recommended feeding milk or milk replacer in excess of the traditional recommendations (approximately 10% of body weight as milk or reconstituted milk replacer) to increase rate of gain and take advantage of improved calf efficiency (Diaz et al., 2001; Davis-Rincker et al., 2011; Moallem et al., 2010). High digestibility and metabolizability of liquid feeds compared to higher fibre ingredients in calf starters naturally contribute to greater efficiency of BW gain.

Calves fed whole milk ad libitum or milk replacer to amounts >1 kg of powder per day gain impressive amounts of BW. For example, Jasper and Weary (2002) reported that calves fed milk ad libitum were 8 kg heavier at the end of a 63-d feeding period compared to calves fed milk at 10% of BW. All calves were weaned at 42 d. However, daily BW gains in calves fed ad libitum were markedly lower during the week of weaning (0.36 vs. 0.53 kg) and after weaning (0.68 vs. 0.85 kg) so that BW differences at 63 d were not as great as the difference prior to weaning.

Differences in growth rate post-weaning in calves fed differently pre-weaning may be due to differences in gastrointestinal development and digestion. Several recent studies indicate that digestion of nutrients from dry feeds varies when calves are fed varying amounts of liquid pre-weaning. Terré et al. (2007) fed Holstein bull calves (19 d of age at start of the trial) milk replacer (MR) at levels typical of conventional feeding (CF; 4 L/d with weaning at 35 d of the study) or an enhanced feeding (EF) program wherein the amount of MR was increased to 7 L/d and then reduced to weaning. Total starter intake on the CF and EF programs prior to weaning were 23.8 and 12.6 kg, respectively. Results of a digestion trial conducted during d 38-42 of the study are in Table 1. These data indicate clearly that digestion of dry feed was impaired in calves fed EF, likely due to inadequate rumen development as a result of lower starter intake.

Table 1. Apparent total tract digestibility of dry feed in calves fed 4 L/d of milk replacer (MR) at 12.5% DM dilution rate from d 1–28, and 2 L/d from d 29 to d 35 (CF) or MR at 18% DM dilution rate: 4 L/d from d 1–6, 6 L/d from d 7–13, 7 L/d from d 14–20, 6 L/d from d 21–28, and 3 L/d from d 29 to 35 (EF). Digestibility was measured the week after weaning. Adapted from Terré et al. (2007).

Digestibility, %	CF	EF	SE	P
Dry matter	77.4	71.8	1.23	0.01
Organic matter	78.7	73.2	1.18	0.01
Crude protein	77.1	71.6	1.29	0.01
Neutral detergent fibre	34.7	20.3	3.79	0.02
Gross energy	75.6	69.8	1.25	0.01

Digestion of NDF (derived primarily from wheat middlings, soybean hulls, and wheat distiller's grains) in the study by Terré et al. (2007) was lower in EF calves compared to CF calves (20.3 vs. 34.7%; Table 1). Since the disappearance of NDF is due primarily to ruminal fermentation, it is likely that reduced NDF digestion was due to inadequate or incomplete rumen fermentation in EF calves. Reduced NDF digestibility occurred in EF calves in spite of a higher rumen pH (5.73 vs. 5.99). Ruminal pH less than approximately 6.0 is associated with impaired ruminal fibre fermentation (Allen, 1997; Shriver et al., 1986) due to the pH sensitivity of cellulolytic bacteria in the rumen (Hoover, 1986; Russell et al., 1996). In the study by Terré et al. (2007), the authors attributed higher ruminal pH to lower ruminal activity due to lower starter intake and a lack of substrate available for fermentation.

Leibholz (1975) monitored digestion of nutrients in calves fed whole milk or MR to weaning at 35 d of age. After weaning, calves were offered a pelleted feed consisting of 58% barley, 20% soybean meal, 15% wheat straw, 3%

molasses plus vitamins and minerals. The diet contained 15% protein and 13% ADF; we estimated the diet contained 2.7 Mcal of ME/kg and 50% non-fibre carbohydrate.

By 6 wk of age (1 wk post-weaning), digestibility of ADF reached 57% and did not change markedly thereafter. However, the site of ADF digestion changed dramatically with time after weaning as most ADF was digested in the hindgut during the first 4 wk of the trial (Figure 1).

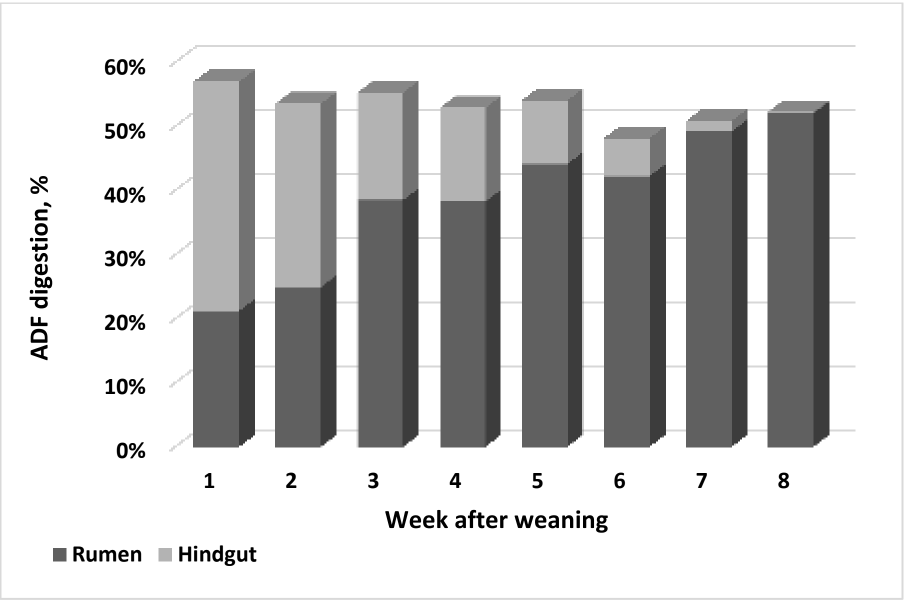

Figure 1. Digestion of acid detergent fiber in calves fed milk or milk replacer to weaning at 5 wk of age. Digestion was measured in the stomach and intestines using duodenally cannulated calves. Adapted from Leibholz, 1975.

Weekly DMI for each week of the 8 wk study were 0.6, 1.1, 1.5, 2.1, 2.2, 2.4, 2.5 and 2.5 kg/d. Intake of ADF ranged from 77 g/d in the 1st week post-weaning to 325 g/d at wk 8. Therefore, it is possible that the higher digestion of ADF in the hindgut during the first few weeks after weaning was due to small amounts of ADF consumed.

Hill et al. (2010) fed calves (2-3 d of age at start of study) one of four MR programs: 0.44 kg of DM of a 21% CP, 21% fat MR powder fed daily for 42 d (A); 0.66 kg of DM of a 27% CP, 17% fat MR powder fed daily for 42 d (B); 0.66 kg of DM of a 27% CP, 17% fat MR powder daily fed for 28 d (C); or up to 1.09 kg of DM of a 29% CP, 21% fat MR daily fed for 49 d (D). Digestibility estimates were made on d 53 to 56. Table 2 shows clearly that digestion of dry matter (DM) and organic matter (OM) were lower when calves were fed large amounts of MR prior to weaning (treatment D). During the digestibility period (d 53 to 56), intake of starter DM was 2.2, 2.3, 2.5 and 1.9 kg/d for treatments A, B, C, and D, respectively. The trend (P < 0.08) for low starter DM intake coupled with significantly lower digestion of DM resulted in calves on treatment D only consuming about 71% of the digestible DM of calves on the other treatments.

Table 2. Total tract apparent digestion of dry matter (DM), organic matter (OM), crude protein (CP) or fat in calves fed one of four MR programs: 0.44 kg of DM of a 21% CP, 21% fat MR powder fed daily for 42 d (A); 0.66 kg of DM of a 27% CP, 17% fat MR powder fed daily for 42 d (B); 0.66 kg of DM of a 27% CP, 17% fat MR powder daily fed for 28 d (C); or up to 1.09 kg of DM of a 29% CP, 21% fat MR daily fed for 49 d (D). Adapted from Hill et al., 2010.

Digestion, %	A	B	C	D	SE	P
DM	75.6^a	78.3^a	78.7^a	67.3^b	2.19	0.01
OM	77.4^a	78.3^a	78.7^a	68.0^b	2.20	0.01
CP	72.4	72.3	74.1	71.8	2.58	0.83
Fat	70.3	75.4	76.3	75.4	3.37	0.33

^{a,b}Means in the same row with different superscripts differ, $P < 0.05$.

More recently, Chapman et al. (2016) reported that digestion of nutrients, particularly of NDF and ADF, were reduced during the digestion period of d 52-58 of age when calves were fed MR up to 0.87 kg/d (Table 3). Although digestion of all nutrients (except starch) were reduced significantly, digestion of NDF and ADF were reduced nearly 50% in calves fed large amounts of milk pre-weaning.

Conversely, Chapman et al. (2017) reported no difference in NDF digestion when calves were fed milk replacer at 446, 669, or 892 g/d of milk replacer during the digestibility measurement period. Further, NDF digestion was 58, 69, and 69%, respectively, suggesting extensive digestion of fibre by the calves. However, the starter used in the study contained only 16% NDF and starter intake during the trial was 1.1, 0.7 and 0.4 kg/d, respectively. Measurements were taken prior to weaning, which may have increased the error associated with measurement.

Table 3. Body weight (BW), DM intake (DMI) and total tract digestibility of nutrients in calves fed conventional [CON; 0.44 kg of dry matter (DM) 21% crude protein (CP), 21% fat powder fed for 42 d], moderate (MOD; 0.66 kg of DM 27% CP, 17% fat powder fed for 42 d), and aggressive program (AGG; up to 0.87 kg of DM 27% CP, 17% fat powder fed for 49 d). Digestibility was measured from d 51-56. From Chapman et al., 2016.

Item	CON	MOD	AGG	SE	P
BW, kg	62.7[a]	72.3[b]	82.8[c]	4.05	0.01
DMI, kg/d	2.04	2.30	2.28	0.258	0.08
Digestibility, %					
DM	77.6 [a]	76.9 [a]	66.0 [b]	1.67	0.01
OM	79.2 [a]	78.2 [a]	67.9 [b]	1.65	0.01
ADF	56.3 [a]	53.2 [a]	26.7 [b]	3.89	0.01
NDF	54.1 [a]	50.7 [a]	26.2 [b]	2.86	0.01
Starch	96.7	94.5	94.0	1.33	0.36
CP	71.9 [a]	74.1 [a]	56.3 [b]	2.72	0.02
Sugar	93.1 [a]	91.5 [a]	86.2 [b]	1.68	0.02
Fat	81.4 [a]	83.2 [a]	74.1 [b]	1.84	0.01

[a,b,c]Means in the same row with different superscripts differ, $P < 0.05$.

Finally, Dennis et al. (2018) compared elevated MR feeding programs and methods of weaning on temporal changes in nutrient digestibility in pre- and post-weaned calves. In this study, calves were fed 0.66 kg of DM from MR from d 0 to 39, 0.33 kg from d 40 to 42 (MOD); 0.87 kg from d 0 to 4, 1.09 kg from d 5 to 35, 0.54 kg from d 36 to 42 (HIGH6); 0.87 kg from d 0 to 4, 1.09 kg from d 5 to 45, 0.54 kg from d 46 to 53 (HIGH8); or 0.87 kg for 4 d, 1.09 kg from d 5 to 39, 0.87 kg from d 40 to 43, 0.66 kg from d 44 to 47, 0.44 kg from d 48 to 50, 0.22 kg from d 51 to 53 (GRAD8). Calves were fed starter (21% CP, 37% starch, 3.7% fat) to 56-d, then 95% starter plus 5% hay (7% CP, 64% NDF) to d 112. Digestion of NDF and ADF were consistently higher in calves fed MOD6 compared to other treatments to 84 d. Only at 112 d of age were digestibility coefficients similar among treatments, suggesting that level of MR feeding can depress nutrient digestion from dry feed post-weaning and that weaning strategy (6 vs. 8 wk of age and abrupt vs. gradual) had little effect on this depression.

The majority of these data suggest that calves fed large amounts of milk pre-weaning may have difficulty digesting nutrients from dry feed during the immediate post-weaning period. There are numerous implications to these findings. For example, digestion of starters containing greater amounts of fibrous by-products may be difficult if calves are fed large amounts of liquid pre-weaning. Also, it may be necessary to use increasingly complex liquid reduction strategies to ensure that starter intake (and digestibility) is adequate prior to weaning.

Because fibre digestion is primarily influenced by cellulolytic fermentation in the rumen, the low digestibility of ADF and NDF (Table 3) indicate that the rumen is less well developed in calves fed greater amounts of MR (Chapman et al., 2016). Also, fibre digesting microorganisms are established in the rumen more slowly than starch and sugar digesting microorganisms (Anderson et al., 1987). Finally, selection of ingredients that may negatively affect rumen fermentation (e.g., inclusion of oil-containing ingredients) may also reduce total DM digestion (Hill et al., 2015).

To better understand the changes in NDF digestion with age and diet, Hill et al. (2016b) fed calves a moderate or aggressive milk replacer feeding program and monitored changes in nutrient digestion with advancing age. Figure 2 shows changes in NDF digestion with advancing age. The effect of diet is clearly shown, as calves fed more milk (AGG in Figure 2) maintained lower NDF digestion throughout the three digestibility periods. Also, calves fed functional fatty acids and nutrients (NeoTec5g®, Provimi North America, Brookville, OH, USA) as feed additives (MOD+ and AGG+ in Figure 2) had higher NDF digestion in periods 2 (42-46 d of age) and 3 (54 to 58 d of age). Previous studies (Guilloteau et al., 2009, 2010; Hill et al. 2007) have shown that feeding sodium butyrate (a component of NeoTec5g) improved fibre digestion in young calves.

Calves fed the moderate MR program (MOD in Figure 2) consumed more starter throughout the trial, which likely hastened rumen development and the ability of calves to digest NDF. In calves fed MOD, NDF digestion increased from approximately 15% at 19-23 d of age to approximately 35% by 51-56 d of age. Digestion of NDF in calves fed the higher level of MR (AGG) did not change markedly through the 56-d study and there were few differences with advancing age.

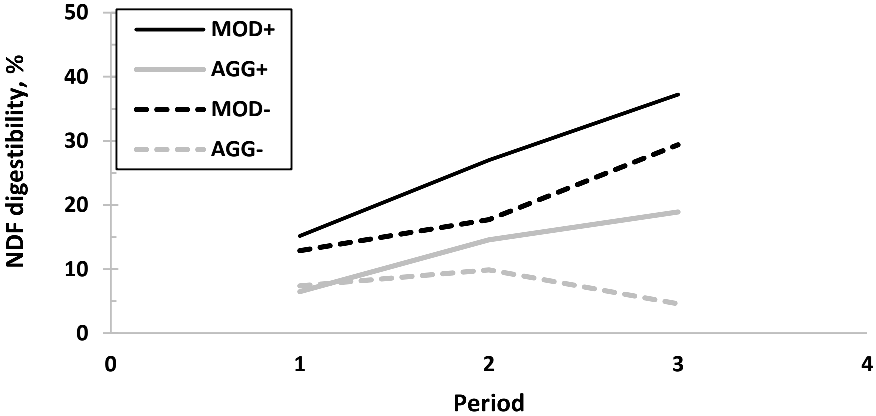

Figure 2. Change in total tract NDF digestibility in calves fed 0.66 kg of DM of a 27% CP, 17% fat MR powder daily fed for 49 d (MOD) without (-) or with (+) added NeoTec4 feed additive; or 0.66 kg of DM of a 27% CP, 17% fat MR powder fed for 4 d, then 0.96 kg of DM for 4 d, then 1.31 kg of DM fed for 34 d, then 0.66 kg of DM for 7 d (AGG). Effect of feeding level, NeoTec4 inclusion and age were significant (*P* < 0.05). Digestibility periods were 1 = 19-23 d; 2 = 40-44 d; and 3 = 52-56 d of the study. Calves were 2-3 d of age at initiation of the study. Adapted from Hill et al. (2016b).

In addition to age of calf, digestion of nutrients post-weaning is affected by ingredient source and form of calf starter. Digestion of DM, OM, and CP were higher in starters containing ground corn, whereas ADF and NDF digestion were greatest in starters containing soybean hulls (Table 4). Hill et al. (2016a) also reported that texturized calf starters containing whole corn and whole oats (51-54% starch and 13% NDF) had higher DM, OM, and CP digestibility than pelleted starters containing wheat middlings, soybean hulls, and dried distiller's grains (20% starch and 36% NDF; Table 5). On the other hand, pelleted, high-fibre starters had higher ADF, NDF, starch, and fat digestion. Gain of BW and hip width increased as OM digestibility increased in these trials.

Collectively, these data suggest that the availability of energy from starters is dependent on the type of carbohydrate, form of the starter (texturized vs. pelleted) and carbohydrate, age of the calf, and intake of liquid pre-weaning.

Table 4. Nutrient digestibility in calves 15-16 wk of age fed starters containing soybean hulls (S), wheat middlings (M) or corn (C). Contrast 1 = (S+M) vs. C; contrast 2 = S vs. M. Adapted from Hill et al., 2016a.

Digestibility, %	S	M	C	SE	Contrast 1	Contrast 2
DM	76.9	78.9	85.2	1.58	0.01	0.23
OM	77.5	79.6	85.8	1.56	0.01	0.21
ADF	65.5	53.5	55.4	3.48	0.20	0.01
NDF	70.7	56.1	66.2	3.13	0.34	0.01
Starch	97.6	98.9	97.0	0.57	0.13	0.15
CP	78.1	80.7	84.4	1.75	0.01	0.16
Sugar	94.2	95.6	94.2	1.79	0.63	0.47
Fat	84.1	86.3	89.6	2.61	0.08	0.42

Table 5. Nutrient digestibility in calves 15-16 wk of age fed high starch texturized (TX) or low starch pelleted (PL) starters containing low (MPL) or high MPH) amounts of metabolizable protein. No main effect of metabolizable protein was reported. P = probability of a main effect of starch level. Adapted from Hill et al., 2016a.

Digestibility, %	TX-MPL	TX-MPH	PL-MPL	PL-MPH	SEM	P
DM	84.3	84.7	79.7	78.8	0.51	0.001
OM	84.9	85.0	80.2	78.9	0.57	0.001
ADF	41.5	54.0	65.2	66.1	1.86	0.001
NDF	56.8	62.8	69.4	66.1	1.64	0.005
Starch	95.1	95.7	99.0	98.7	0.29	0.001
CP	84.9	84.6	79.5	78.6	0.54	0.001
Sugar	95.3	95.6	95.7	92.4	0.68	NS
Fat	86.3	82.7	88.3	87.8	0.78	0.08

Current nutrient models for calves and heifers (e.g., 2001 Dairy NRC) ignore the effects of previous nutrition and the extent of rumen development. The ME content of starters is a static calculation based on expected digestibility of nutrient fractions (NDF, non-fibre carbohydrate, protein, and fat). No provision is made for differing nutrient digestibilities with advancing age or intake. Conversely, other models for lactating cows utilize dynamic calculations of energy based on rates of ruminal digestion of each fraction (NFC, NDF, protein, fat) and rate of passage (Higgs et al., 2015). Intestinal digestibility coefficients are then applied to the ruminally undegraded fraction to estimate total nutrient supply.

Using data from Chapman et al. (2016) and Hill et al. (2016b), we estimated ME concentrate of calf starter using the method outlined in the 2001 NRC Nutrient Requirements of Dairy Cattle (NRC, 2001) and calculated ME based on analyzed values using digestibility data from Table 3 and Figure 2. Results are in Table 6. The column labeled "NRC" contains calculated ME concentration in starter based on the 2001 NRC method, assuming digestibility values typical for adult ruminants. The column "Calculated" contains data using total tract digestibility measured in the studies by Chapman et al. (2016) and Hill et al. (2016b). We also used the 2001 Dairy NRC model to predict ME-allowable BW gain using the ME values calculated for calf starter using the NRC (NRC ME-g) or calculated values (Calc. ME-g) in Table 6.

Table 6. Estimated ME concentration (Mcal/kg of DM) in calf starters from Chapman et al. (2016) and Hill et al. (2016b) using methods of 2001 Dairy NRC (NRC) or calculated using total tract digestibilities reported in each experiment. ME-allowable BW gains were calculated using equations [2-4 a-e and 2-5 to 2-10] in 2001 Dairy NRC Requirements for Dairy Cattle (NRC, 2001) or using digestibility estimates from Table 3 and Figure 2, respectively. Digestibility estimates were made at 52-56 d.

	Starter ME, Mcal/kg			Predicted ME grain, kg/d		
Item	**NRC**	**Calculated**	**%**	**NRC**	**Calc.**	**%**
Chapman et al. 2016						
CON	2.81	2.59	92	0.77	0.67	87
MOD	2.81	2.56	91	0.93	0.82	88
AGG	2.84	2.30	81	0.94	0.70	74
Hill et al. 2016b						
MOD-	2.81	2.52	90	0.83	0.71	86
AGG-	2.89	2.45	85	0.61	0.45	74
MOD+	2.83	2.60	92	0.77	0.68	88
AGG+	2.87	2.50	87	0.70	0.55	79

Differences were significant for all measurements, but ME was markedly overestimated in calves fed higher levels of milk in both studies. Consequently, predicted ME-allowable gains using the calculated ME values for calf starter were lower compared to predicted gains using the ME values calculated with the NRC calculations.

The implications of calculation errors of ME content are clear, as calves fed high levels of milk pre-weaning will be ill prepared for weaning and unable to extract nutrients from calf starters efficiently. Consequently, growth of calves will be compromised until sufficient maturation of the digestive tract and associated tissues allows the calf to fully utilize nutrients in the calf starter. The existing NRC model over-predicts ME supply from starters by 12 to 26% (Table 6).

These data also suggest that additional time may be needed for a weaning transition to ensure that calves fed high levels of milk will consume sufficient starter prior to weaning. In most of the studies cited in this review, liquid intake was reduced for 7-10 d prior to weaning. For calves fed 1 kg of powder or greater, this is probably insufficient time for adaptation.

■ Summary

The 2001 Dairy NRC represented an important improvement in our understanding of nutrient requirements for young calves and heifers. Further refinement of methods to estimate nutrient supply of young calves will improve our ability to calculate growth under a wide range of feeding and management conditions.

Feeding varying amounts of liquid from milk or MR has important implications to growth post-weaning. Increasing liquid consumption above approximately 650-700 g of solids per day will delay initiation of calf starter intake and will delay onset of rumen development. Digestion of all nutrients, particularly NDF, is essential to ensure that rumen development is adequate prior to weaning.

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NOTES

Genetics, Genomics and Beyond: What to Expect from New Technologies in Dairy Cattle

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Take Home Messages

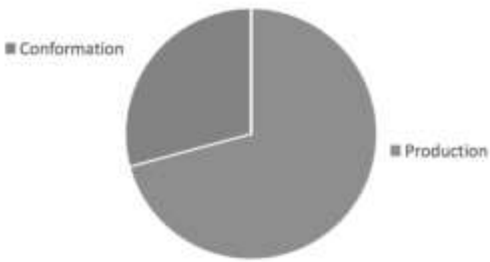
- Genetic improvements can help build and sustain profitable dairy production. If anything is lacking, such as poor calf care, poor management, or poor quality feed, animals will not reach their full genetic potential.
- Implementation of new technologies in routine breeding programs can allow for more exact trait definitions, and permit further genetic gains in both production traits and low heritability traits like health and fertility.
- Many new technologies are emerging, each of which much be carefully scrutinized with regards to associated cost/benefits.
- Exact, well-measured phenotypes which are as close as possible to the biology of the cow remain an integral part of breeding value estimation.
- Genetic diversity, economics, and societal acceptance will play an increasing role in how selection programs evolve.

Introduction

Many developments have helped to transform and advance the dairy cattle industry. Besides improved management and feeding regimes, as well as other environmental progress, genetic selection for traits with clear economic value, high genetic variation between individuals, and which can be distinctly defined, measured and consistently recorded have contributed greatly to the increase in production efficiency of dairy cattle. The economic value of traits has driven genetic selection in the past; early selection programs were designed to achieve maximum genetic change in production, with additional but lesser emphasis on conformation traits. Simultaneous selection for other traits came only recently (figure 1; adapted from *Miglior et al., 2017*), mainly from the recognition that increased production is associated with a deterioration in cow health and fertility.

Since genetic selection began, the number and type of traits considered for selection in dairy cattle populations have evolved as a response to changes in the needs of producers, consumers, and society. The rapid developments in automated data recording technologies, modern analytical techniques, and genomic information over the past decade are setting the stage for a new era in dairy cattle breeding. The implementation of new technologies in routine breeding programs will not only further accelerate genetic gains in traditional milk production traits, but also, and perhaps more importantly, in low heritability traits like health, fertility, and workability. As the demand for high-quality dairy products increases, dairy breeders will need to optimize the use of available technologies and to consider the emerging forces driving our industry.

A) Relative emphasis of breeding objectives in 1960



B) Relative emphasis of breeding objectives in 2010

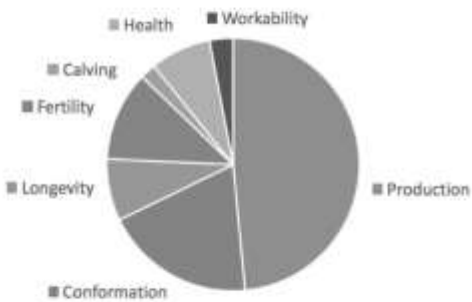


Figure 1. Relative emphasis of traits included in an average selection index in 1960 (A) and 2010 (B) (adapted from *Miglior et al., 2017*).

Here we briefly review technologies that will help shape new dairy breeding programs, along with those in development. Powerful tools have emerged in the areas of on-farm data collection, genotyping and sequencing, genetic modification, and bioinformatics. Although many of these technologies bring encouraging opportunities for genetic improvement and transformation of the dairy cattle population, their applications and benefits need to be weighed with their impacts on economics, genetic diversity, and society. Background information on genetic and genomic selection is given, as well as an overview of novel traits and technologies that will affect our industry in the future.

▪ Genetics as a Tool to Improve Dairy Cattle

Pedigree, dairy production recording programs, and a “good eye” provided the initial data for comparing and choosing dairy cattle. With time, a better understanding of inheritance in dairy cattle evolved into the science of breeding. Major methodological developments, such as the introduction of selection index theory and Best Linear Unbiased Prediction, helped accelerate genetic advancements.

The concepts of genetic variation and heritability are pivotal to the rate of genetic progress possible within a selection program. Traits vary in the amount of both phenotypic and genetic variation observed, and they may be more or less heritable. Heritability defines the proportion of phenotypic variance observed in a given trait which is attributed specifically to genetics. This means that important environmental factors, such as management, nutrition, etc. are corrected for and thus removed from the calculations. Traits may also be dependent on each other. There may be either positive or negative correlations between traits, and they can be strong or weak. Such correlations are exploited by the use of indicator traits, which may be favored if they are simpler or cheaper to measure than a trait of interest.

The easiest traits to improve genetically are those that show high genetic variance between animals, and can be directly, accurately, and consistently measured. These traits are likely controlled by only a few genes. Examples of such traits include milk, fat and protein production, and to a certain extent, some conformation traits. As shown in Figure 2 (adapted from *Miglior et al., 2017*), heritabilities for both production and conformation traits are markedly higher than those for other traits. Health, fertility, and workability traits are more challenging to improve genetically, as they are not well defined and often much more difficult to measure cost-effectively. In some cases, the heritability of these traits may not be precise, as “fuzzy” trait definitions limit proper partitioning of environmental and genetic variance.

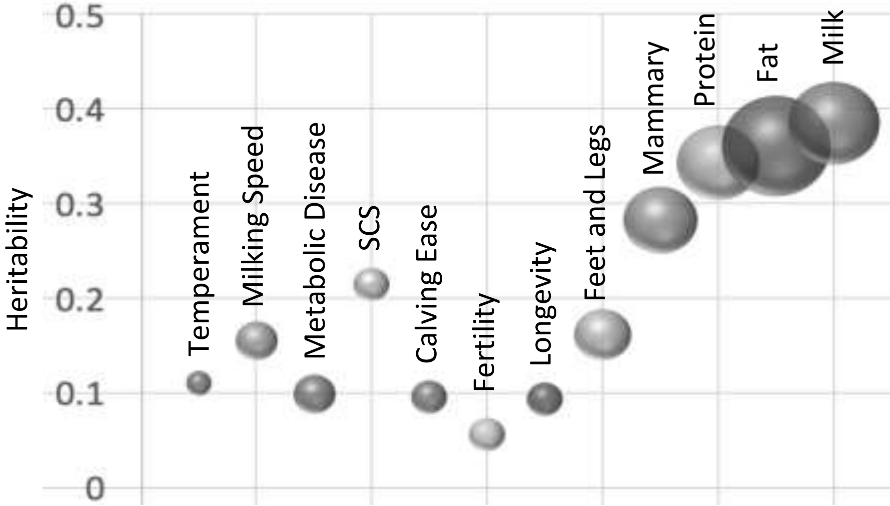


Figure 2. Ranges in heritabilities for various traits used in current Interbull evaluations (April 2017 run, Interbull, Uppsala, Sweden). Bubble size indicates variance of heritability values across countries (adapted from *Miglior et al., 2017*)

Despite these difficulties, improvements in health, fertility, and workability traits through genetic evaluation are attainable. When these traits are included in selection indices, we can see genetic progress (see Figure 3; adapted from *Miglior et al., 2017*). We are still challenged with further improving measurement techniques, trait definitions, and data collection for these types of traits, however initial efforts have shown measurable success. Technological developments in the area of on-farm sensors and data collection methods have the potential to improve this situation, however there are a number of logistical and data quality-related issues which must be addressed before the full potential of such technologies can be attained.

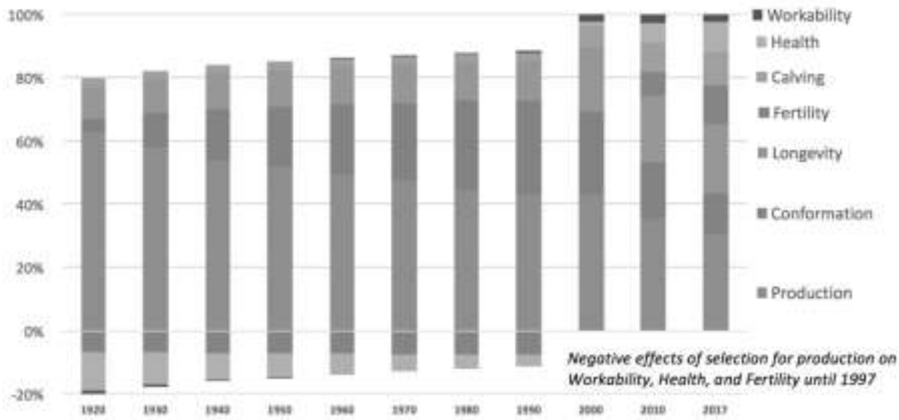


Figure 3. Schematic representation of the proportion of estimated selection response for various trait categories over time (summing to 100%) (adapted from *Miglior et al., 2017*)

■ From Genetics to Genomics

The emergence of genomic technologies was initially slow, but has dramatically increased in the last decade. In contrast to genetics, which generally refers to the study of inheritance using conventional theoretical principles and models, genomics uses high throughput molecular information to analyze the function and structure of entire genomes. Various types of molecular markers were initially used for parentage verification and for genetic defect testing. One specific type of genetic marker, the single nucleotide polymorphism (SNP), is found where different nucleotide bases appear at a given position in a DNA sequence. Inexpensive, highly prevalent in the bovine genome, stably inherited, and suitable for high throughput analysis, SNP markers currently provide the information required for genomic selection, as they are often either linked to or directly within many of the genes responsible for phenotypic variation.

The release of the Illumina Bovine SNP50 chip in 2008 allowed efficient genotyping of over 50,000 SNP simultaneously, which were highly polymorphic in different breeds and evenly spaced across the genome. While these SNP represent only a small fraction of genomic variation within the bovine genome, they provide enough information to increase the accuracy of genetic evaluation models. The implementation of genomic selection strategies in dairy breeding have successfully accelerated the rate of genetic gain in many traits of interest in dairy cattle (Figure 4; adopted from *Beavers & van Doormaal*), and thus have changed the landscape of genetic selection. However, accuracies achieved in genomic selection can still be improved.

Genomic selection is based only on those variants that have been discovered and included on SNP arrays. There is still a long way to go before all the information within the genome (totaling approximately 3 billion base pairs per animal) can be understood and implemented in selection programs.

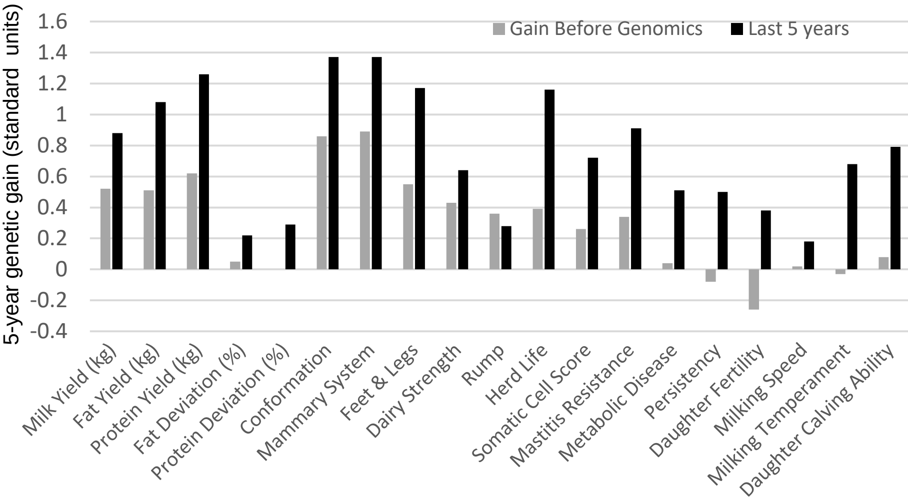
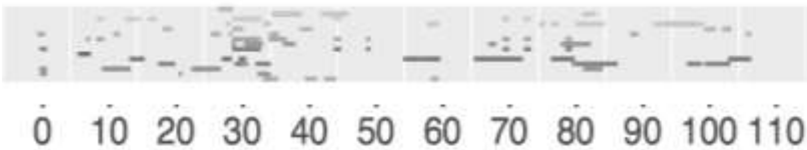


Figure 4. Relative genetic gain by trait realized during the past 5 years (2011-2016) and before genomics (2004-2009). (Adopted from *Beavers and Van Doormaal, CDN Article, 2017*)

▪ From Genotypes to Phenotypes

In the age of genomic selection, the ability to identify exact regions of DNA which have an effect on a particular trait is improving rapidly. The genome-wide association study (GWAS) is a tool used frequently over the past decade to identify and map SNPs with a significant effect on a given trait. One of the most impressive findings using GWAS was the localization of the Diacylglycerol O-acyltransferase 1 (DGAT1) gene on chromosome 14 of the bovine genome, which explains up to 50% of genetic variation in fat yield and up to 10% of genetic variation in milk yield (*Grisart et al., 2002*). While most SNPs explain only a small amount of variation in a given trait, DGAT1 is a picture-perfect example of identifying and harnessing the genetic architecture underlying economically important quantitative traits. As the identification of measurable and consistent biological markers impacting economic traits of interest improve, so too will the precision of associating genomic regions with these traits.

Similarly, the ability to identify long stretches of homozygous DNA (termed “runs of homozygosity” or ROH) is also improving rapidly, as is the ability to associate such regions with traits of interest (e.g., *Howard et al., 2017*). These types of analyses will help us to understand exactly which regions of the genome have negative or positive effects on traits of interest when ROH are present. For example, Figure 5 shows the homozygous regions on bovine chromosome 11 which have an effect on various calving and fertility traits. It can be seen that some specific regions are associated with many different traits affecting calving and fertility in both heifers as well as first parity cows. These areas can now be identified and further investigated with more powerful analyses to find the specific causal mutations.



Position (mbps) of ROH on Chromosome 11. Traits defined below (from top to bottom).

Figure 5. Location of Runs of Homozygosity (ROH) on chromosome 11 with an effect on various fertility traits. Lines represent traits as follows (from top to bottom: ac0 & ac1 = age at calving (heifer & 1st parity, respectively); afs0 = age at first service (heifer); ctfs1 = calving to first service (1st parity); cz0 & cz1 = calf size (heifer & 1st parity, respectively); do1 = days open (1st parity); fstc0 & fstc1 = first service to calving (heifer & 1st parity, respectively); gl0 & gl1 = gestation length (heifer & 1st parity, respectively); ns0 & ns1 = number of services (heifer & 1st parity, respectively); sb0 & sb1 = still birth (heifer & 1st parity, respectively) (Marras et al., in preparation)

■ Novel Traits

For a long time, selection in dairy cattle focused on the improvement of highly heritable production and conformation traits. Selection goals have since broadened to include economically important traits with low heritability or that are expensive to measure (Figure 1 & 2; adapted from *Miglior et al., 2017*). This is partly due to the realization that such traits can indeed be genetically improved and partly due to the fact that modern and automated technologies can be used to provide more data. Genomics also provides a mechanism for improving such traits. By thoroughly measuring phenotypes in reference populations and extrapolating the results to the national herd (e.g. *Cole et al., 2014*), accurate and reliable breeding values can be achieved if the reference population is large enough. *Chesnais et al*. (2016) provided a description of novel traits expected to be implemented in national evaluations in North America within the next 5 years (Table 1; adapted from *Chesnais et al. 2016*).

Table 1. Novel traits with ongoing research or official evaluations in Canada (adapted from *Chesnais et al. 2016*)

Trait	Definition
Udder Health	Mastitis Incidence (recorded by producer or veterinarian) Alternative predictors of mastitis (conductivity, mid infra-red (MIR), etc.) Hoof Health (hoof trimming, locomotion, lameness)
Other Health Traits	Reproductive disorders (retained placenta, metritis, cystic ovaries) Predictors of reproductive disorders (activity monitors, hormone measures, etc.) Metabolic diseases (ketosis, displaced abomasum) Predictors of metabolic disease (BHB, fat:protein ratio) Resistance to Johne's disease (*Mycobacterium avium* ssp. *Paratuberculosis*) Immune response (antibody, cell-mediated)
Feed Efficiency	Individual feed intake (DMI, residual feed intake, energy balance) Predictors of feed intake (production, direct or indirect cow weight, MIR) Emission of methane (calorimeter, other methods) Predictors of methane emissions (e.g. MIR)
Other Novel Traits	Workability (Milking speed, temperament) Profitability (number of embryos, profit per cow, milk composition, etc.)

"In the age of the genotype, the phenotype is king" (*Mike Coffey*, personal communication). We are currently challenged to identify traits that measure phenotypes of interest more exactly, more cost-effectively, and more comprehensively than those in our current index. This implies a clear and quantitative breeding objective and involves carefully considering the cost of measurement, potential gain through implementation in a selection program, ease of measurement, genetic variance, phenotypic and genetic correlations to other traits, and long-term effects of selection. We then need to understand the trade-offs between including these traits or not including them in our selection index. Genetic gains are cumulative, and small improvements provide cumulative savings to all farmers, particularly those using selection indices to combine many different traits (*Egger-Danner et al., 2015*).

▪ Novel Technologies

Novel technologies have had, and continue to have, a huge impact on the industry. Many facets of dairy farming have been revolutionized through technology. From implements for field work, feed harvesting, feed storage, feed mixing, and feed additives to milking equipment and housing systems, all the way to waste management techniques, dairy farmers are avid implementers of new technologies. Reproductive technologies, such as artificial insemination, sexed semen, embryo transfer, and cloning, are readily available to producers and have become an integral part of our industry. These technologies, when used properly, can boost farm efficiency substantially, while saving time and money.

A myriad of sensors and gadgets are available, most of which are designed to help herd managers better control their herds. Common sensors include those measuring real-time body weight, online milk composition/amount, behavioural sensors (heat detection, etc.), and rumination and heart-rate sensors. Sensors can provide diagnostics or simply gather information; data flow is normally a variation of the following: 1) collect data, 2) transfer data to a program, 3) implement algorithms within the program to calculate a likely physiological interpretation and, possibly, a recommended action, and finally 4) execution a decision by the herd manager based on the summarized information. While helpful for management, the information collected is often only of limited suitability for genetic and genomic analyses. Some sensors are more accurate than others, however they are very rarely standardized across suppliers and data extraction from the provider's software is often difficult. Another question is data ownership – does it belong to the farmer, or the provider, or both? Automatic data collection is an area of huge potential, but standardized, correct, and curated data is a major caveat that needs to be addressed before any real advances can be made in this area.

New molecular technologies such as those used to conduct next-generation sequencing, methylation and gene expression analyses are being developed at an unprecedented rate. Although they are currently being used as research tools, they have the potential to expand into wide-spread applications. In a report by the McKinsey Global Institute, the use of next generation genomics was listed the 7th most potentially economically disruptive technology on the horizon. Despite initial public denunciation, various methods of genetic modification are under development. The first genetically modified animal, the Aqua Advantage Salmon, has been introduced into the human food chain after federal regulators in both Canada and the United States considered it fit for consumption in 2015. This would have been unthinkable only a decade ago.

What to Expect in the Future?

Understanding the influence of various genes and genomic variants on phenotypes will bring forth many future opportunities for the genetic improvement of quantitative traits. For example, analyses on gene editing have expanded in the literature and some researchers are hypothesizing developments that may soon be applied in livestock breeding (*Van Eenennaam, 2017*). Many possible applications of the technology are the same as those already considered in current breeding programs, but with targeted efforts on known causative variants. In particular, the use of novel technologies to improve the health and welfare of livestock are strong public arguments which highlight the power of these technologies positively. Examples of edited dairy cattle include cattle with increased resistance to tuberculosis (*Wu et al., 2015*), the knockout of the beta-lactoglobulin gene (*Yu et al., 2011*), and enhanced mastitis resistance (*Liu et al., 2014*). A promising first use of gene editing in the dairy industry to address welfare issues may be the production of hornless dairy cattle through the introduction of the POLLED allele, which is nearly fixed in some beef breeds but low in frequency in Holsteins (*Carlson et al., 2016*). Other animal agriculture fields are also editing animals, including pigs resistant to porcine reproductive and respiratory syndrome virus (*Whitworth et al., 2016*).

Finally, only 2% of the population is directly involved in agricultural food production; the other 98% represent consumers, who are increasingly removed, both literally and figuratively, from the farming industry. Despite this fact, the changing needs, wants, and demands of the consumer play an integral role in the future of our industry. There are marked differences between consumer cohorts of the past and the large, critical, information-seeking cohort currently entering the marketplace. They are driven by incentives different to those of previous generations, which will affect what technologies we use, as well as how we select, breed and raise livestock in the future.

Conclusions

New technologies, both in terms of those applied to studying the molecular basis of inheritance, as well as those used to measure various physical characteristics of animals, have had, and will continue to have, disruptive effects on livestock breeding practices. Advances in technologies are being made at an unprecedented rate and large-scale implementation of these technologies will affect both the genetic diversity of future livestock populations and the economics of genetic improvement. Furthermore, with an active, information-seeking consumer cohort entering the marketplace, past breeding goals centred on production may no longer be attractive and new phenotypes will need to be collected on a large scale. The implications of increasing the use of reproductive and genomic technologies, as well as applying novel technologies and methodologies in livestock breeding populations, must be carefully considered. In particular, the effects on the genetic diversity of livestock populations, the financial implications for all stakeholders, and the societal acceptance of these technologies and their wide-spread use must be evaluated. Despite these caveats, the use of these technologies, together with their integration in breeding, could contribute to sustainable and further genomic improvements, if properly managed.

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Farm Management Decisions in the Era of Genomics

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Take Home Messages

- Genomics has had a major impact in terms of sire selection by A.I. organizations due to the increased accuracy of selection of young bulls for entry into A.I.
- Given the high genetic merit of A.I. – genomic young bulls with significantly higher levels of Reliability compared to traditional Parent Averages – 70% of semen used by Canadian dairy producers is from genomic young bulls while 30% is from progeny proven sires.
- The full adoption of genomics on the sire side has more than doubled the realized rate of genetic progress for LPI in Canadian Holsteins and Brown Swiss with a rate of 1.7 fold in Ayrshire and 1.5 fold in Jersey.
- Genomic testing of females provides significant opportunity for more accurate herd management decisions to boost rates of genetic gain in the herd, especially in conjunction with the use of sexed semen to breed elite heifers and first lactation cows.
- The return on investment (ROI) associated with genomic testing, with or without the use of sexed semen, is dependent upon several variables that are different from herd to herd.
- Genomic testing of females is the only accurate way to manage the impact of genetic recessive characteristics, including haplotypes affecting fertility in all breeds and cholesterol deficiency in Holsteins.
- CDN and Holstein Canada will jointly launch a new software tool in 2018 to help Canadian producers assess the economic benefit of genomic testing and/or sexed semen for herd management decisions

▪ Introduction

Canadian Dairy Network (CDN) introduced official genomic evaluations for the Holstein breed in August 2009, which has now proven to be a very significant event that has permanently changed the genetic selection scheme for dairy cattle improvement in Canada and internationally. Realized genetic progress in a population or breed of dairy cattle is primarily driven by the selection of A.I. sires having semen offered to producers. Due to the competitive nature of the A.I. sector, with each organization striving to offer the highest level of genetics, the adoption of genomics for sire selection was very rapid and has already had a significant impact within the first few years. Today, essentially every A.I. bull with semen actively marketed in Canada to Holstein, Ayrshire, Jersey, Brown Swiss and Guernsey breeders has a genomic evaluation.

The adoption of genomic testing of females by Canadian producers has not seen the same dramatic uptake, compared to how the A.I. sector has embraced the technology. While this is true on an overall basis, some herd owners have recognized the value of heifer genotyping as a cost effective herd management tool and routinely collect a DNA tissue sample at the time of ear tagging newborn heifers. In reality, hundreds of Canadian Holstein breeders today have over half of their herd genotyped, but across all Holstein heifers born each year, less than 10% are genotyped. Canadian producers need the proper tools available to them to assess the economic benefit of genomic testing to the overall profitability of their herd. Currently, CDN and Holstein Canada are collaborating to develop such a software tool, in partnership with Zoetis Canada, which will be launched in 2018 and freely available to all Canadian breeders for their registered animals. This software tool will also help producers assess the economic benefits associated with investing in semen from the highest ranking A.I. sires, as well as the use of sexed semen either on its own or in conjunction with genomic testing of heifers. While the benefits of these tools vary from herd to herd, a growing percentage of Canadian producers are expected to adopt some level of genomic testing in their herd to assist with various herd management decisions.

▪ Impact of Genomics

The rate of genetic progress achieved in a population, breed or herd is determined by the following formula.

$$\text{Genetic Gain per Year} = \frac{\text{Genetic Variation x Selection Intensity x Accuracy}}{\text{Generation Interval}}$$

Genetic variation may gradually change over several generations, but for practical purposes this component of the formula can be considered as a constant value. With genomic selection, however, there has been a significant impact on the other three variables, mainly due to the important gain in the accuracy level of genetic evaluations used for making selection decisions.

Accuracy of genomic evaluations are a function of the size of the reference population used to estimate them. In Canada, the reference population for the Holstein breed in December 2017 includes over 33,000 genotyped sires that are progeny proven for both production and type. For the other breeds, even though genotyped cows with performance data in Canada are also included, the relative size of their reference population, in terms of proven sire equivalents, is significantly smaller, at approximately 6,800 for Brown Swiss, 5,300 for Jersey, 1,500 for Ayrshire and 400 for Guernsey. Figure 1 presents the average Reliability value for LPI, which is the same for Pro$ in the Holstein and Jersey breeds, for Parent Average (PA) in heifers before genomics and for the Genomic Parent Average (GPA) that results after including the heifer's genomic information.

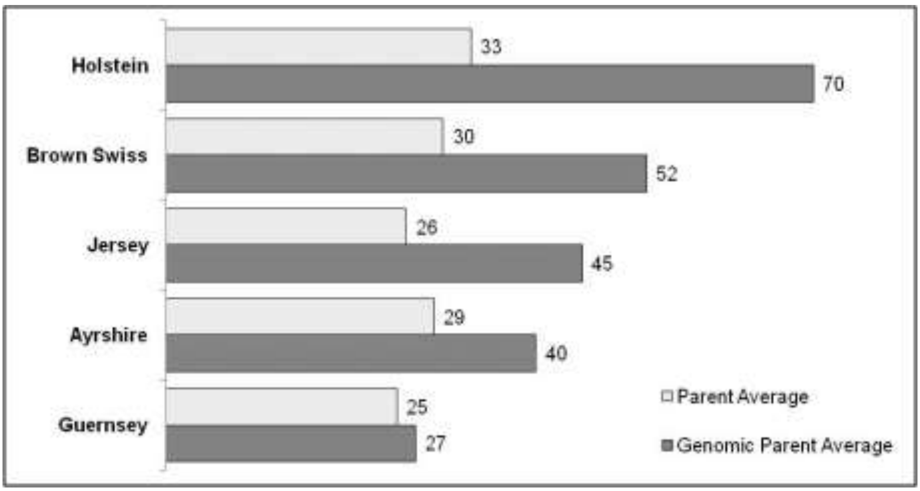

Figure 1: Average Reliability (%) for LPI (and Pro$) of genotyped heifers based on Parent Average before genomics versus Genomic Parent Average with genomics.

With Parent Average information, which was the only tool available for the selection of young bulls for entry into A.I. and for replacement heifers on the farm before the arrival of genomics, the average Reliability ranged from 25% to 33% depending on the breed. Today, for genotyped heifers and young bulls with genomic information included, the average LPI Reliability reaches 70% in Holsteins, which represents a gain of 37 percentage points. For the Brown Swiss, Jersey and Ayrshire breeds, the Reliability gain due to genomics is 22, 19 and 11 percentage points, respectively. For the Guernsey breed, the reference population is not currently large enough to yield any substantial benefit with genomics but this may be possible in the future through the international exchange of bull genotypes and increased adoption of female genotyping by Guernsey breeders.

During the first few years with genomic evaluations, the A.I. organizations gained confidence in the improved level of accuracy offered by this technology, which has now resulted in its full adoption. Not only does every A.I. bull with semen available to Canadian producers have an official genomic evaluation, but those bulls were pre-selected by the various A.I. organizations based on genomic results for a broader group of young bull candidates. Figure 2 shows the increase in the number of young Holstein bulls genotyped in North America for birth years since 2005. Based on this genotyping activity in recent years, which surpassed 30,000 bulls annually, compared to approximately 1,500 bulls being progeny proven each year, A.I. companies in Canada and United States are currently purchasing and proving one bull out of every 20-25 that are being genotyped. In the equation presented earlier for calculating genetic gain per year, this pre-selection step based on genomics has significantly increased the selection intensity in terms of young bulls entering A.I. in North America.

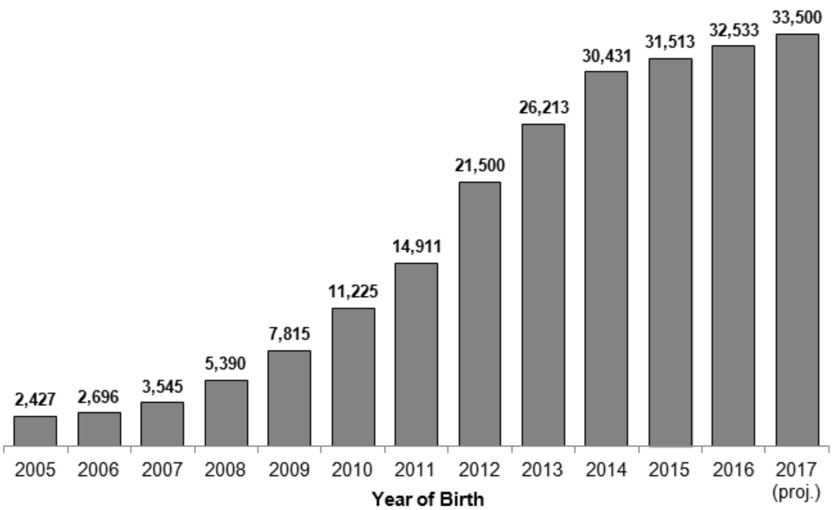

Figure 2: Number of young Holstein bulls genotyped in North America

The third variable significantly affecting genetic gain per year with genomics is generation interval, which is measured by the average age of parents when their progeny are born. Figure 3 shows the trend in age of the sires and dams of the Holstein candidate young bulls genotyped each year. Prior to the introduction of genomics in 2009, the average age of sires of young bulls entering A.I. consistently exceeded 6 years since they generally first needed to be progeny proven. The dams of the same young bulls were approximately 4 years of age, on average, suggesting they had completed one or more lactations. In recent years, the generation interval for both parental sides has reduced to less than 3 years and continues to gradually decrease to below 30 months of age (Figure 3). This major trend, which translates to faster rates of genetic progress, is a consequence of the high level of confidence and selection intensity that A.I. organizations are now placing in genomic evaluations of very young animals, without a significant loss of accuracy.

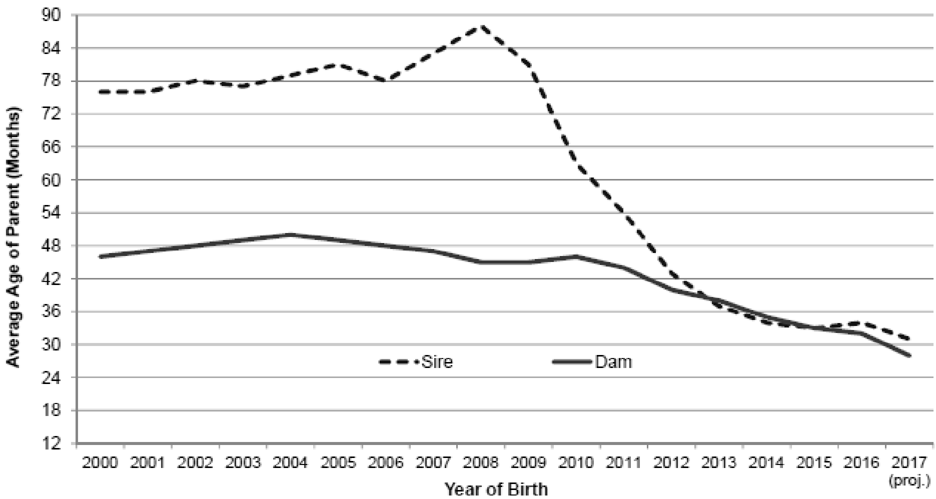

Figure 3: Average age of parents (i.e.: generation interval) of young Holstein bulls genotyped in North America

Canadian dairy producers also have a high sense of confidence in genomic evaluations when making their sire selection decisions. Figure 4 shows the increased usage of young sire semen since the introduction of genomics in 2009. After an initial spike in interest towards genomic young bulls in 2010, the national semen market share occupied by genomic young bulls settled back to normal levels in 2011, but has steadily increased to reach the 70% mark in 2017. This means that only 30% of all Holstein sire semen used in Canada is from progeny proven bulls – a percentage that is expected to gradually decrease further in the coming years.

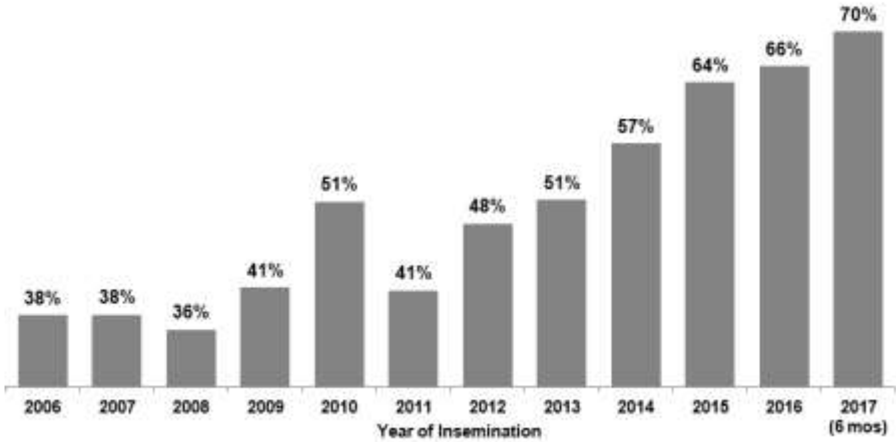

Figure 4: Trend in Holstein young sire usage in Canada

With the full adoption of genomics by the A.I. sector and the increased market demand by producers for semen from genomic young bulls, rates of genetic progress realized in various breeds have significantly increased. Figure 5 shows the genetic trend achieved for both LPI and Pro$ in the Canadian Holstein population for females born since 2000. Prior to genomics, genetic gain was quite steady at 45 LPI points per year and $69 annually for Pro$. Over the past five years, however, after genomics has been fully adopted by A.I. organizations, these rates for genetic progress have reached an average of 106 LPI points and $176 Pro$ per year in Canadian Holsteins. These faster rates of genetic gain with genomics translate to an increase of 2.4 and 2.6 fold, respectively. While the adoption rate and impact of genomics has varied by breed, a consistent result has been faster rates of realized genetic gain, which has increased for LPI by 1.7 fold in Ayrshire, 1.5 fold in Jersey and 2.8 fold in Brown Swiss.

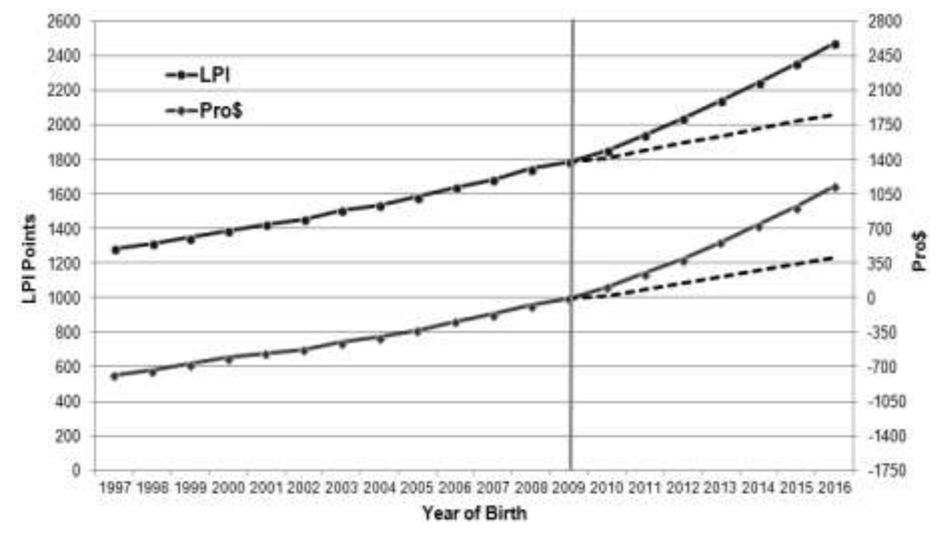

Figure 5: Genetic Trend Realized for LPI and Pro$ in Canadian Holsteins Before and After Genomics

■ Genomics for Herd Management

While sire selection decisions are critical for achieving significant rates of genetic progress in a breed and within each specific herd, breeders also have an opportunity to achieve their breeding goals through improved female selection decisions. Traditionally, Canadian dairy producers have had a strong tendency to keep all heifer calves born on the farm, raise them and breed them to achieve a first calving, and then make herd replacement selection decisions once in first lactation and with type classified. Given the strong export market usually available to Canadian producers, and the relatively low accuracy of Parent Average information for young heifers, this strategy made sense. The arrival of genomics now provides dairy producers with new opportunities to make herd management decisions related to genetic improvement. This is especially the case for most herds in conjunction with the increased availability of sexed semen.

Economically speaking, there are three main areas of potential benefit that result from the use of genomic information for herd management decisions:

1. The opportunity to identify young calves that do not have the level of genetics that warrant keeping them as potential heifer replacements.
2. The opportunity to make improved genetic selection and mating decisions to increase the genetic potential of future heifer replacements for the herd.

3. The opportunity to identify females that are carriers of undesirable genetic traits in order to manage the potential impact on the herd.

In addition, genotyping also provides the benefit of accurate parentage verification when the recorded parents have been genotyped, which is the case for essentially all daughters of A.I. sires.

In reality, the potential return on investment associated with heifer genotyping varies from herd to herd. There are several factors that affect the economics of heifer genotyping, including the:

- cost of genomic testing
- number of heifers born relative to the number of replacements required for the milking herd
- expected change in size of the milking herd during the next two years
- sale value of young heifer calves, bred heifers and/or fresh cows in first lactation
- genetic variability of heifer calves born in the herd
- gain in Reliability of genomic evaluations compared to Parent Average

For herds using sexed semen to breed a significant proportion of their heifers and/or cows, the economics of heifer genotyping is also affected. In this case, a higher number of heifer calves are subsequently born potentially resulting in a greater opportunity to sell heifers not required as herd replacements. Once the combined use of sexed semen and heifer genotyping have been incorporated into the herd management strategy, then it may also be beneficial to incorporate the use of beef sire semen as well. Table 1 provides a summary of the common herd management actions that are likely in herds that adopt a longer term strategy involving both heifer genotyping and sexed semen.

Table 1: Common herd management actions by age group associated with an economical strategy involving heifer genotyping and use of sexed semen

Herd Management Action	Young Calves	Yearling Heifers	1st Lactation Cows	Later Lactation Cows
Genomic test	✓	✓		
Breed with conventional semen		✓	✓	✓
Breed with sexed semen[1]		✓	✓	
Breed with beef sire semen[2]				✓
Sell (remove from herd)	✓			

[1]Use of sexed semen may be replaced by use as a donor for embryo transfer.
[2]Candidates to be bred with beef sire semen may also be used as embryo transfer recipients.

The various herd management actions are somewhat dependent upon the group of females in the herd, with four likely categories being: (a) young calves, usually under 12 months of age, (b) yearling heifers to be bred as replacements for the milking herd, (c) cows in first lactation, and (d) cows with two or more calvings. Within each group the females should be ranked by Pro$, LPI or a custom index defined by the breeder. For specific herds, actions for managing the young calves would be to either genomic test them or to sell those that are genetically inferior when a surplus of heifer calves exists. Those calves identified for genomic testing are targeted to improve the accuracy of the herd owner’s decisions to keep or sell each one, as well as later decisions like sire selection and mating. For yearling heifers, some degree of genomic testing may still be beneficial since the primary herd management decision for this group is to identify those to be bred using sexed semen instead of conventional semen. Similar decisions need to be made for the milking herd, recognizing that sexed semen is mainly an option for younger, first lactation cows, but can also be used to some degree to breed older cows. In a herd achieving steady genetic progress, the females that fall into the bottom group genetically will mainly include older cows beyond first lactation, so fewer will be identified for breeding with sexed semen regardless. Once the highest yearling heifers and milking cows have been accurately ranked based on their genetic/genomic evaluations, the economic decision to use sexed semen is highly dependent upon the increased semen cost versus the genetic sacrifice that must be made given that not all of the highest A.I. sires have sexed semen available to Canadian producers. If herd owners are interested in using embryo transfer (ET) as a means of producing more replacement heifers from their genetically superior dams, the highest candidates recommended for breeding with sexed semen could be considered as ET donors. Either approach ends up generating more heifer calves born in the herd, which then alters the genomic testing strategy and economics the following year and boosts the genetic potential of the milking herd in future years. In addition, for some herds, it may be economically beneficial to breed the genetically inferior cows with beef sire semen to produce a crossbred calf that generates a higher sale value at birth. This economic decision should primarily be driven by the expected increase in sale price of crossbred beef versus purebred dairy calves, but a lower average blend price and a higher average conception rate for beef sire semen could also be considered.

For each herd, the frequency of each herd management action (i.e. genomic testing, sell or breed with conventional, sexed or beef sire semen) will vary and will not be consistent over time as the herd evolves. This reality makes it difficult for herd owners to identify and apply the most profitable strategy for genomic testing, either on its own or in conjunction with the use of sexed semen. For this reason, the new software to be jointly launched by CDN and Holstein Canada in 2018 is being developed. This tool will allow Canadian dairy producers to:

- assess the genetic progress realised with past breeding decisions
- compare past genetic progress across traits to identify those that have received the most and least emphasis
- assess the ranking of the herd on a trait-by-trait basis compared to other herds of the same breed nationally
- understand the expected genetic progress achievable in the herd resulting from selection based on Pro$, LPI or a customized index
- manage the herd inventory of heifers and cows
- view genetic evaluation results for each female and generate individual animal reports and/or group reports
- generate printable herd plots based on a wide variety of variables/traits
- compare the relative ranking of the herd based on both genetics and performance for key traits
- assess the estimated return on investment (ROI) associated with various strategies involving (a) the use of the best A.I. sires possible, (b) genomic testing of heifers, (c) use of sexed semen, or (d) heifer genotyping combined with use of sexed semen
- select and apply a preferred strategy involving genomic testing and/or use of sexed semen, which generates a list of herd management actions for specific females in the herd

- rank A.I. sires according to the custom selection index to identify those that would maximize future genetic progress of the herd
- identify matings to avoid in order to minimize the impact on the herd of genetic recessives, like cholesterol deficiency in Holsteins and haplotypes affecting fertility

Genetic Variability and Genomics Reliability Gain

Figure 1 presented the average gain in Reliability for LPI that results from genomic testing, which also applies to Pro$. For example, for Holsteins, the average Reliability increases from 33% for a heifer's Parent Average to 70% once she is genotyped. Figure 6 helps explain this concept further. Without genomic testing, the typical Holstein heifer is born with a Parent Average (PA) that has a Reliability of 33%, which generally increases to 36% by the time it becomes a yearling heifer. This gain in PA Reliability results from its dam adding more accuracy as a lactating cow, and often, the sire adding more daughter data to its proof. Once calved, the typical Holstein cow receives an LPI with a 55% Reliability, which gradually increases to 59%, 62% and 64% with each additional lactation, respectively. Only dams with a high number of lactating daughters, usually resulting from embryo transfer, end up with an LPI Reliability of 65% or higher without being genotyped. The advantage of genomic testing is that it can be done immediately after birth and the resulting Genomic Parent Average (GPA) achieves, on average, a 70% Reliability level. Basically, with genomic testing, Holstein breeders can now have more confidence in the genomic evaluations of their heifers and cows than they had in the genetic evaluations they traditionally received for their lactating cows, including their own milk recording and type classification performance data. For Brown Swiss, Jersey and Ayrshire breeders, this conclusion is not as obvious (see Figure 1). Still, they can surely have increased confidence in the genetic information they receive for genotyped heifers compared to only having Parent Averages.

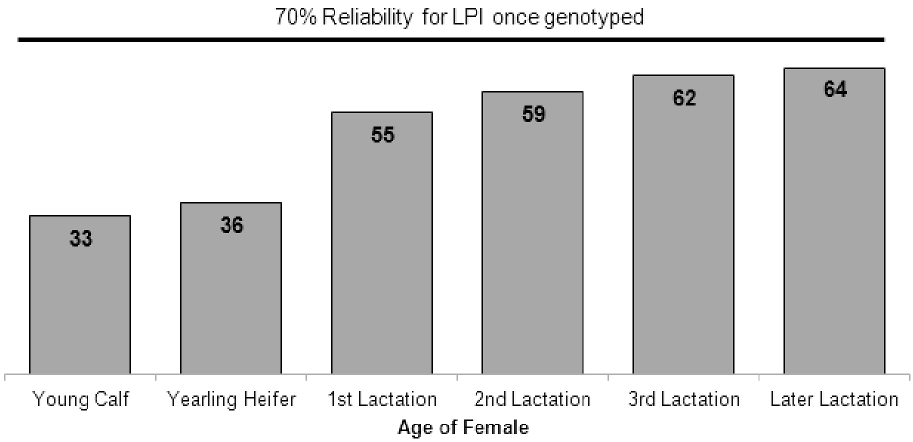

Figure 6: Average LPI Reliability for Holstein females without genomics compared to 70% level achieved once genotyped

In addition to the increased accuracy of evaluations for genotyped heifers compared to only having a Parent Average, genomic testing will also increase the degree of variability of genetic evaluations among the heifers born in a herd. Increasing this genetic variability spreads them out across a wider range and results in some degree of re-ranking. Figure 7 shows actual results for three Holstein herds (i.e.: Herds A, B and C) that each genotyped more than 100 heifer calves. For each herd, the distribution of LPI based on Parent Average is compared to that based on Genomic Parent Average which resulted from genomic testing. Although these are actual results, these three herds were selected based on the fact that they each have a different degree of change between Parent Averages and Genomic Parent Averages.

For Herd A, the Parent Averages for LPI have a narrow distribution and genomic testing the heifers resulted in a much wider range in terms of their genetic evaluation, which also yields a significant re-ranking among the heifers. In this herd, genomic testing clearly helps to separate the genetically superior heifers from the poorer ones. Also of interest with the results for this herd is a downward shift in the average LPI of the heifers, which was 85 points in this case. In most herds, however, the average Genomic Parent Average is expected to be very close to the average Parent Average, which is what is observed for example herds B and C in Figure 7.

For Herd B, genomic testing resulted in a moderate increase in the genetic variability and spread of the heifers. In this herd, genomic testing also created some degree of re-ranking, which would translate to improved genetic selection and mating decisions. For herds like this one, a well-planned strategy for heifer genotyping is expected to yield a good return on investment, especially if there is a surplus of heifer calves available and herd management decisions involve the sale of those heifer below a specific genetic level for an index like LPI or Pro$.

In Herd C, genomic testing did not have a significant impact on the spread of the heifers for LPI based on Genomic Parent Average versus traditional Parent Average. In this case, the degree of re-ranking would be significantly less compared to herds A and B, however, it must be noted that individual heifers do end up with varying results with genomic testing, so some degree of re-ranking occurs in all herds.

In reality, herd owners do not know in advance the degree to which genomic testing will spread out the genetic evaluations of their heifers and cause re-ranking. This result varies from herd to herd, but the new software tool to be launched by CDN and Holstein Canada will help advise producers on the degree of genomic testing that makes economic sense for their herd.

■ Managing Genetic Recessives

As the volume of genotypes in each dairy cattle breed has increased, which now totals more than 2 million at CDN across all breeds, research scientists have been able to discover genetic anomalies in each of the Holstein, Ayrshire, Jersey and Brown Swiss breeds. Technically speaking, the specific genes underlying these anomalies were not discovered, but haplotypes, which are short sections of DNA, were identified. All of the original haplotypes found were negatively associated with fertility by either resulting in early embryonic mortality or stillborn calves. For this reason, they were simply named as Haplotypes Affecting Fertility and labelled as HH1 (i.e.: Holstein Haplotype 1), HH2, HH3, HH4 and HH5 in Holsteins, AH1 and AH2 in Ayrshires, JH1 and JH2 in Jerseys and BH1 and BH2 in Brown Swiss. In recent years, another haplotype – for cholesterol deficiency (i.e.: HCD) – was discovered in Holsteins, for which a gene test was later developed. Table 2 shows the evolution of the estimated frequency for each haplotype within the Canadian population. These frequencies are population averages, but will vary significantly from herd to herd depending on the sire lines used. The only way a herd owner can know the actual frequency of these undesirable genetic recessives is by genotyping all animals in the herd. In Holsteins, it is HCD that requires the most attention in terms of mating carrier sires to carrier females, since its frequency exceeds 10% for heifers born in 2015-2017; this is also true for both AH1 (19.3%) and AH2 (24.1%) in Ayrshire, JH1 (19.2%) in Jersey as well as both BH1 (13.3%) and BH2 (15.6%) in Brown Swiss. Genomic testing helps producers manage these genetic recessives by avoiding the use of carrier sires to breed known carrier females in the herd. For some herds and breeds, depending on the frequency of carriers, managing these genetic recessives can contribute significantly to the economic return on investment associated with genomic testing.

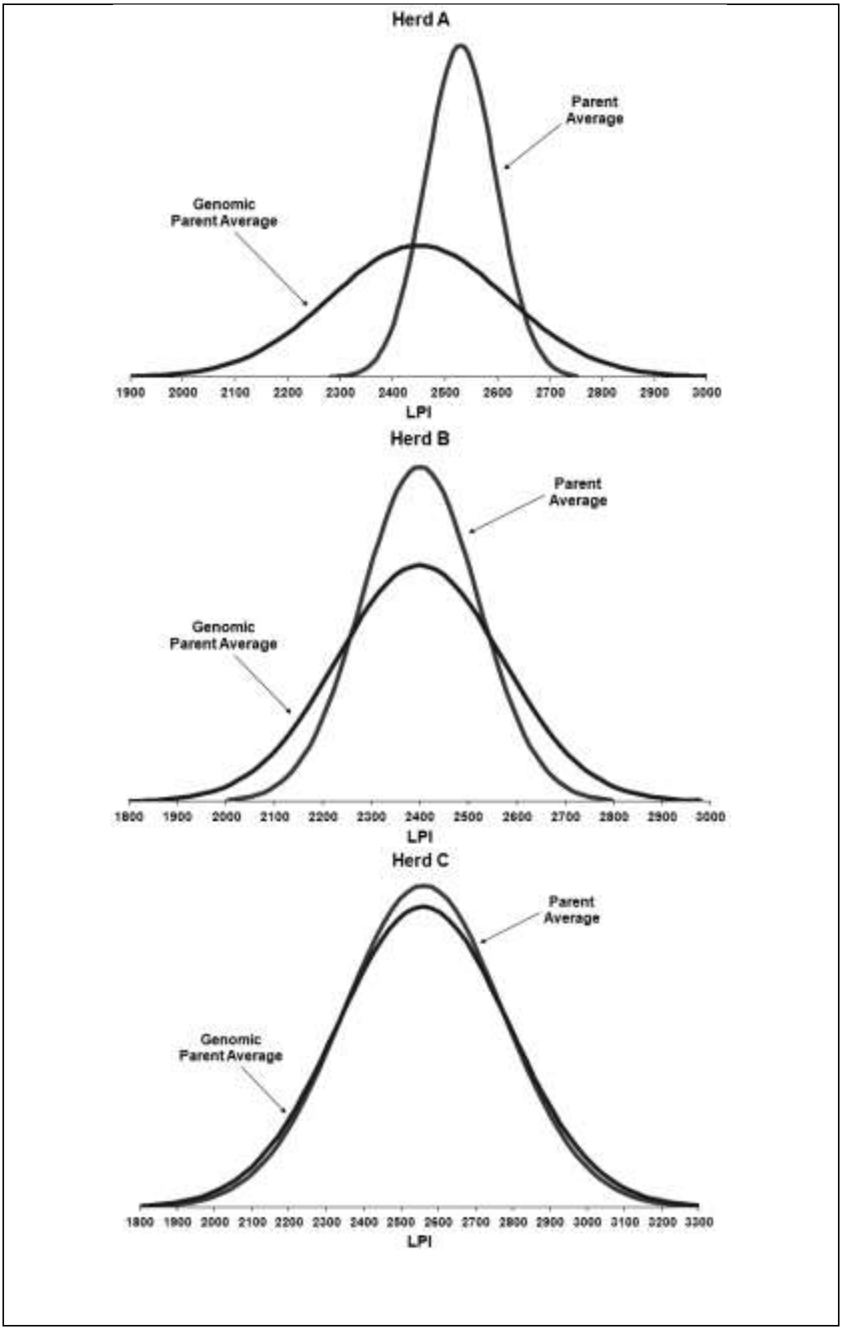

Figure 7: Comparison of the distribution of heifers based on Parent Average and Genomic Parent Average for LPI - Results from three actual Holstein herds with over 100 genotyped heifer calves

Table 2: Evolution of Frequencies for Known Haplotypes in Canadian Dairy Breeds

Birth Year	HH1	HH2	HH3	HH4	HH5	HCD	AH1	AH2	JH1	JH2	BH1	BH2
1970-1974	0.0	0.0	0.0	0.0	0.4	0.0	23.8	1.0	0.2	0.2	0.0	0.2
1975-1979	0.1	0.0	0.0	0.0	0.4	0.0	27.5	2.3	0.4	0.4	0.2	0.2
1980-1984	0.9	0.5	0.2	0.4	0.3	0.0	25.0	2.9	0.7	2.5	2.3	0.3
1985-1989	1.3	1.5	1.4	1.0	0.6	0.0	21.0	4.2	4.1	7.7	2.7	0.5
1990-1994	3.7	1.7	1.4	0.8	0.5	0.0	20.2	4.4	4.6	9.2	6.2	8.4
1995-1999	8.3	2.3	1.1	0.5	0.3	1.9	26.4	6.3	6.8	10.4	6.7	8.8
2000-2004	9.3	4.1	1.3	0.3	0.2	3.6	27.9	13.4	11.0	12.5	9.4	11.0
2005-2009	8.2	2.9	1.5	0.3	0.7	10.6	22.6	19.6	18.2	15.3	10.4	11.9
2010-2014	5.2	3.3	3.6	0.3	3.8	14.2	24.4	22.1	21.4	10.8	15.5	19.5
2015-2017	2.9	2.2	4.4	0.3	5.4	10.3	19.3	24.1	19.2	6.1	13.3	15.6

■ Conclusions

The era of genomics in the Canadian dairy cattle industry began in 2009 when the Canadian Dairy Network (CDN) introduced the first official genomic evaluations for the Holstein breed. In the following year, the same was done for the Jersey breed; genomic evaluations for the Brown Swiss, Ayrshire and Guernsey breeds were also introduced during this time. The general benefits of genomics are directly related to the size of the reference population available for each breed, which gives Holsteins a significant advantage, but it is important for all breeds to establish international exchange agreements for access to the highest possible number of genotypes for progeny proven sires. Breeds with genomic evaluations based on a reference population with thousands of genotyped animals have a distinct advantage over those that do not since annual rates of genetic progress are significantly improved with genomics, as exemplified by the realised rates of gain in all such Canadian dairy breeds.

On the female side, the same statement can be made. Herd owners that decide to genomically test selected females in their herd will be able to make improved herd management decisions compared to others that decide not to adopt this new technology. In most herds, the optimal economic long-term strategy is a combined use of sexed semen to breed the genetically superior heifers and cows along with genomic testing of selected heifer calves that are subsequently born in the herd. The optimal usage level of sexed semen and/or genomic testing is dependent upon several variables specific to each herd, which means that it is difficult for herd owners to determine if it is economically beneficial to use either or both of these technologies to make better herd management decisions, and if so, to what degree they should be used. In 2018, CDN and Holstein Canada will be jointly launching a new software tool to help all Canadian dairy producers assess the return on investment (ROI) in their herd associated with the adoption of genomic testing and/or usage of sexed semen.

References

Canadian Dairy Network (CDN), 2017. Various extension articles authored by Brian Van Doormaal available on the Internet at: http://www.cdn.ca/articles.php

Can Genomics be Used to Improve Reproductive Performance?

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Take Home Messages

- Fertility is an essential component of efficient dairy production. Although fertility traits are strongly influenced by the environment, new evidence supports genetic variability related to multiple reproductive traits, providing opportunity for selection.
- Identifying genomic variation associated with specific fertility measures, such as uterine health, resumption of postpartum ovulation, and establishment and maintenance of pregnancy in cows, would result in a wider understanding of the genetic structure of reproduction.

The Context

Dairy production systems face the challenge of increasing the efficiency of milk production, while minimizing environmental impact and ensuring the welfare of animals (Maltecca, 2013). In this context, adequate fertility is one of the critical factors for achieving this goal.

Poor reproductive performance results in low proportions of cows at their peak production period, higher insemination costs, and delayed genetic progress (Norman et al., 2009; Santos et al., 2010). Moreover, impaired fertility has been reported as one of the most frequent reasons for culling (Pinedo et al., 2010) and increased days open (DO) are associated with a greater risk of death or culling in the subsequent lactation (Pinedo and de Vries, 2010).

As extensively reported, a historical trend of declining dairy fertility has been evident in multiple countries and regions, under diverse production systems (Lucy, 2001; VanRaden et al, 2004; Walsh et al., 2011). Worsened fertility has resulted from high prevalence of anovulation, reduced fertilization, and embryonic survival (Santos et al., 2004; 2009), likely related to changes in cow physiology, greater levels of inbreeding, nutritional management, housing, increased herd size, reduced estrus expression, and current genetic makeup (Lucy, 2001; Weigel, 2006).

Starting in the fifties, breeding programs selecting for milk production have been very successful and current trends indicate increments on milk yield per cow of 1 to 2% per year (Rauw et al., 1998; Bello et al., 2012). However, some unfavorable genetic correlations between production and other traits may exist, resulting in undesirable side effects, such as a higher risk for behavioral, physiological, and immunological problems (Hansen et al., 1983).

Although these negative associations between production and fertility traits are probable (Norman et al., 2009; Bello, 2012), it is possible to select for improved milk yield and fitness traits, including fertility. This fact is, at least in part, evidenced by 2003 genetic evaluations of daughter pregnancy rate (DPR) which showed increments in reproductive performance in Holsteins (Norman et al., 2009). The trend for DPR indicates a partial recent recovery in dairy fertility, despite no apparent slowing down in the rate of increase of milk production per cow. As shown in Figure 1, the trend for lower DPR values in the U.S. dairy herd has now reverted.

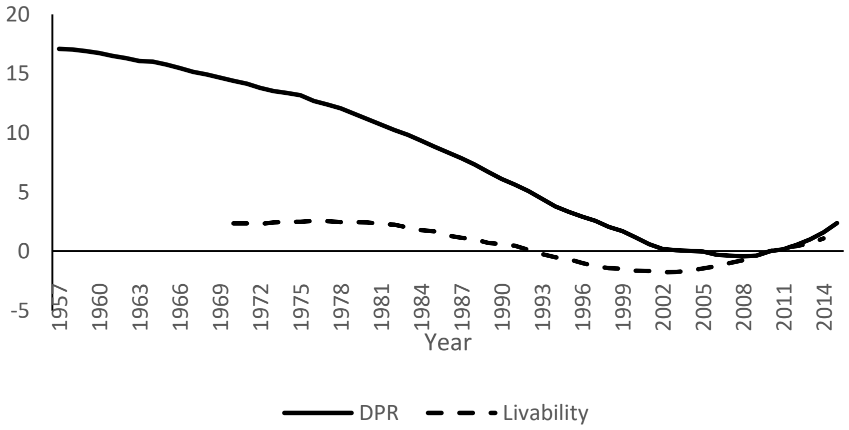

Figure 1: Trends for daughter pregnancy rate (DPR) and livability for US Holstein cows. Adapted from Council on Dairy Cattle Breeding (https://www.uscdcb.com/)

Genetics and Fertility

Fertility traits have a multi-factorial nature, which makes it difficult to determine the degree of involvement of genetics on reproductive outcomes. Genetic variation may be directly involved in the physiology of reproductive processes. However, genetics may also determine, to some extent, the behavior of other related traits that have an impact on fertility. Among others, these comprise the ability to maintain an adequate body condition and DMI during the transition period, the potential for adequate immune responses resulting in adequate health, and the capacity to retain early pregnancy (Walsh et al., 2011; Ferguson and Skidmore, 2013).

It has been established that reproductive traits are polygenic and largely influenced by the environment (Holmberg et al., 2006). Consequently, genetic progress for fertility, by way of conventional breeding strategies, is hindered by low heritability, which represents the proportion of phenotypic variation attributable to genetic differences among animals (Norman et al. 2009). Moreover, high costs of large data collection, the long time period required for data validation, and the potential for biased phenotypes, such as non-return rates and DPR, are significant obstacles (Schnabel et al., 2005). Adding to these limitations, the influence of factors unrelated to fertility, such as breeding policy and voluntary waiting period, is a constant difficulty for precise reproductive estimations.

Several authors have reported heritabilities below 0.10 for reproductive performance traits (Hansen et al., 1983; VanRaden et al., 2004). Yet, when more objective measures of fertility were evaluated (interval to first ovulation, anovulation, and pregnancy loss), heritabilities were moderate to high (0.16 to 0.48; Darwash et al., 1997; Bamber et al., 2009). For reproductive disorders, such as metritis and retained placenta, heritability estimates were close to 0.20 (Zwald et al., 2004). Notably, genetic variation is manifest when DPR is considered, as daughters of the highest and lowest sires for DPR (differing by 7.2% in DPR) differ by 29 d open per lactation.

Genomic Selection of Dairy Cattle

With the sequencing of the bovine genome and the arrival of low cost genotyping of large numbers of single nucleotide polymorphisms (SNP) markers, the use of DNA analysis in the evaluation of dairy cattle genetics has become a reality (Wiggans et al., 2012). Genomic evaluations have been implemented in the United States, Canada, Great Britain, Ireland, New Zealand, Australia, France, the Netherlands, Germany, and the Scandinavian countries (Weller et al., 2017). From a logistics point of view, the use of genomic analyses allows for the estimation of breeding values at birth, which reduces the costs of proving bulls and increases the genetic gain because of shorter generation intervals (Schaeffer, 2006). In addition, genotyping platforms commercially available from several companies have become widely used at the farm level, particularly for genotyping of females.

As with genetic evaluations, genomic selection has not been restricted to production characters. Other traits of economic interest, such as Productive Life, Net Merit, etc. (Ashwell et al., 2004), have been integrated and evaluations have subsequently expanded to more specific health problems. Although genetic selection is an attractive tool for improvement of health traits, contrary to production traits, fitness and health present additional challenges associated with the inconsistency of recording systems and moderate to low heritabilities (Parker Gaddis et al., 2014; Zwald et al., 2004).

In the US, indirect health predictions are available from the Council on Dairy Cattle Breeding and recent data indicate that these traits result in genetic improvements for resistance to adverse health events (McNeel et al., 2017; Vukasinovic et al., 2017). Producer-recorded health events have been successfully used to identify genetic differences between dairy sires in daughter susceptibility to common health disorders, including metritis, displaced abomasum, and mastitis (Zwald et al., 2004; Parker Gaddis et al., 2014).

At the present, genomic evaluations estimating the genetic risk for 6 specific health events in US Holstein dairy cattle have been developed (Vukasinovic et al., 2017). Wellness trait predictions include genetic predictions for retained placenta, metritis, ketosis, displaced abomasum, mastitis, and lameness.

▪ Genomic Selection for Fertility

Specific reproductive traits that are currently evaluated by genomic analyses in the US include daughter pregnancy rate (%), sire calving ease, daughter calving ease, sire stillbirth rate (%), daughter stillbirth rate (%), heifer conception rate (%), and cow conception rate (%).

New research exploring genomic variation related to novel fertility traits is in course. Two main approaches have been developed to determine associations among genetic markers and fertility: the candidate gene approach and the whole genome scan (Veerkamp and Beerda, 2007). As a result, a number of areas of the genome affecting quantitative traits that are governed by multiple genes (known as quantitative trait loci; QTL) for cattle reproductive traits have been mapped. Initial QTL studies used a family structure design with hundreds of markers revealing large linkage regions. More recently, genome-wide association studies (GWAS) performed with thousands of SNP markers have facilitated the resolution of associated regions and the discovery of candidate genes (Matukumalli et al., 2009).

Quantitative trait loci have been identified for many reproductive traits including ovulation rate (Gonda et al., 2004), pregnancy rate (Ashwell et al., 2004; Muncie et al., 2006), DPR (Schnabel et al., 2005), non-return rate, estrus intensity, and calving performance (Holmber and Andersson-Eklund, 2006; Jemaa et al., 2008). Genetic variation has also been identified for gestation length (Schrooten et al., 2000), dystocia and stillbirth (Kuhn et al., 2003).

In addition, genomic analyses have offered the capability to locate lethal genes affecting fertility outcomes; VanRaden et al. (2011) identified five new fertility defects in dairy breeds by examining specific genomic areas that had a high population frequency but were never homozygous. These lethal effects may result in conception, gestation, and stillbirth losses.

As stated previously, some physiological measures of fertility (e.g. resumption of estrous cyclicity after calving, anovulation) have moderate heritabilities; this is also the case for some reproductive disorders (Zwald et al., 2004). Interestingly, it has been established that cows that resume estrous cyclicity soon after calving are more likely to show estrus and to become pregnant in a timely manner. Similarly, healthier cows are advantageously able to conceive sooner after parturition.

Therefore, decomposing aggregate reproductive phenotypes into their detailed components, which are potentially less influenced by management, could prove to be more heritable and, assuming sufficient genetic variation exists, genetic gain for reproductive performance could be accelerated (Carthy et al., 2014). For example, DPR is a function of DO, calculated from a theoretical 60-day voluntary waiting period, which is highly sensitive to breeding policy (voluntary waiting period, use of timed A.I., and use of bull breeding). Another traditional reproductive measure, calving interval, is composed of several reproductive components, such as the postpartum interval to commencement of estrus cyclicity, expression of estrus, conception, maintenance of pregnancy, and gestation length (Carthy et al., 2014).

Presently, a major goal to advance genomic selection for fertility is the collection of high numbers of accurate fertility phenotypes associated with the corresponding genotypes, coupled to large scale evaluations of the aforementioned direct measures of fertility. A subsequent step should aim at the identification of genomic regions with large- to moderate-effects on the quantitative traits of interest. Collecting accurate data represents another challenge and potential strategies may include using DHI and data recorded within on-farm herd management software programs.

Regarding the use of assisted reproductive technologies, from the perspective of embryo production efficiency, SNPs associated with the number of viable oocytes, fertilization, cleavage and developmental rates have been recently explored. Specific genotypes had variable fertilization and embryo development rates (Khatib et al. 2008; Cochran et al., 2013), demonstrating the potential interest of genomic selection applied to embryo technologies. In connection with this point, several studies predicted that new reproductive technologies, such as embryo transfer and multiple ovulation, would have a major effect on genomic selection. In recent years, A.I. organizations have begun using in vitro fertilization (IVF) heavily and selecting embryos for implantation based on genotype, which should reduce the age of donors, as well as the generation interval along the sire-to-bull pathway by up to 7 months (Weller et al., 2017; Wiggans et al., 2017).

Selection for traits with low heritability could be integrated into reproductive technologies that allow for higher rates of genetic improvement by increasing the reproduction of superior females (Parker Gaddis et al., 2017). Studies conducted in the 1980s and 1990s indicated that reproductive technologies could increase genetic gain by 10 to 20% compared with traditional breeding schemes (Ruane and Thompson, 1991).

▪ Some Comments on Our Research

Our team of researchers from different US institutions was awarded a multi-year grant to explore genomic variation associated with reproductive traits in dairy cattle (Genomic Selection for Improved Fertility of Dairy Cows with Emphases on Cyclicity and Pregnancy; Grant no. 2013-68004-20361 from the USDA NIFA). The overall objective was to develop a fertility database with genotypes and phenotypes based on objective and direct measures of fertility in Holstein cows. The subsequent goal was to identify SNPs and haplotypes significantly associated with fertility traits by use of genome-wide analyses and use this information to obtain genomic-estimated breeding values that can be applied in the selection of dairy cattle for improved fertility.

Consequently, our approach was to test a significant number of cows (approximately 12,000 from 7 States in the US) that were enrolled at calving and weekly monitored at farm until pregnancy confirmation. The evaluations included uterine health, metabolic status (subclinical ketosis) during transition, resumption of postpartum ovulation, estrus, pregnancy per A.I., and pregnancy loss, under different management practices and environments.

Our initial analyses indicated that overall, 71% of the population resumed ovarian cyclicity by 50 DIM. Conception at first and second A.I. were 32.8% and 33.7%. Pregnancy loss between 32 and 60 d after A.I. were 10% and 8.7% for first and second A.I, respectively. Overall, 19.7% and 4% of the population was sold or died before 305 DIM.

A reproductive index (RI), calculating the predicted probability of pregnancy at first A.I. (PP1) after calving, was developed using a logistic regression models that included cow-level variables that were thought to have a genetic component [diseases, anovulation, body condition score (BCS), milk yield, etc.]. Within each farm and season, cows were ranked using the developed RI as highly-fertility pregnant (850 cows) and a lowly-fertility non-pregnant (1,750 cows). The PP1 for the highest RI quartile was 0.43, while 42% of this population was pregnant at first A.I. The PP1 for the lowest RI quartile was 0.21, with 20.8% of this population pregnant. These high and low fertility subpopulations are the base for our subsequent association studies, using a high density genotyping platform (777k BovineHD BeadChip).

As mentioned before, reproductive performance is affected by multiple variables including the cow's nutritional and health status, as well as environmental factors. In this idea, we performed a sub-study (Chebel et al., 2015) within the overall project testing associations among BCS change from calving to 35 days in milk (DIM), resumption of cyclicity by 50 DIM, and both productive and reproductive performance. Holstein cows (n = 5,175) from 9 dairy herds from the Southwest, Southeast and Midwest of the U.S. were used. Cows had BCS assessed at 3 and 35 DIM and were classified according to BCS change [gained (G), no change (NC), moderate loss (ML) = −0.25 to −0.75, and extreme loss (EL) > −0.75]. Blood sampled at 7 DIM was used to diagnose ketosis (β-hydroxybutyrate; BHB >1.0 mmol/L). Calf gender, occurrences of calving problems (i.e., twins, stillbirth, and dystocia), mastitis, displacement of abomasum, and respiratory illness during the 60 DIM were recorded. Cows were milked thrice daily and average milk yield during the first 90 DIM was recorded.

Our results indicated that among cows calving with BCS <3.25, milk yield was lowest for cows gaining BCS and cows with extreme BCS loss (G = 34.4, NC = 37.1, ML = 38.2, and EL = 34.4 kg/day). Among cows calving with BCS = 3.25 to 3.5 (G = 35.4, NC = 36.3, ML = 37.9, and EL = 39.1 kg/day) and cows calving with BCS >3.5 (G = 26.0, NC = 35.0, ML = 37.5, and EL = 38.5 kg/d), milk yield was greatest when cows had extreme BCS loss from 3 to 35 DIM. Change in BCS was associated with the likelihood of cows resuming cyclicity by 50 DIM (G = 78.8%, NC = 76.4%, ML = 74.8%, and EL = 75.9%). Although BCS change was not associated with the probability of pregnancy after first postpartum A.I., pregnancy hazard ratio (independent of A.I. number) was associated with BCS change from 3 to 35 DIM [G = 1.20, NC = 1.21, ML = 1.10, and EL = referent]. In conclusion, excessive loss of BCS from 3 to 35 DIM was associated with greater milk yield, and reduced cyclicity and reproductive performance.

A second sub-study (Gonzalez-Pena et al., 2015) was completed to estimate genetic parameters of fertility indicators in dairy cattle. Measurements from a regional sub-set of 953 Holstein cows during 2 calving years were analysed.

Three fertility indicators were evaluated: (1) probability of cycling at day 45 postpartum (Pr_Cyc); (2) probability of disease diagnosis at 45 days postpartum (Pr_Sck); and (3) probability of pregnancy after 2 A.I.s (Pr_Prg). These indicators were estimated using a logistic models including the covariables of dystocia, retained placenta, BCS at 7 and 35 days postpartum (BCS7 and BCS35, respectively), and blood BHB as an indicator of subclinical ketosis. Univariate sire models, including the effects of contemporary group and lactation number, were used to estimate the genetic parameters of DO, BCS7, BCS35, Pr_Cyc, Pr_Sck, and Pr_Prg.

The percentage of cows cycling, diagnosed with at least one disease, and pregnant after 2 A.I.s were 69.7%, 14.9%, and 64.6%, respectively. The marginal probabilities indicated that cows diagnosed with dystocia, retained placenta, metritis, and mastitis were 1.7%, 6.0%, 11.4%, and 7.3% and less likely to be cycling than healthy cows, respectively.

Cows were 2.7% and 4% less likely to be cycling per unit of increase in mucus score (indicative of metritis at 7 d after calving) and BHB, respectively. The heritability estimates for Pr_Cyc, Pr_Sck, Pr_Prg, DO, BCS7, and BCS35 were 0.23, 0.29, 0.58, 0.19, 0.25, and 0.25, respectively. Our results indicated that the considered fertility traits have an important genetic component and could be used as effective indicators of fertility in breeding and management decisions.

In summary, at this point, preliminary genome wide analyses with our high and low fertility subpopulations confirm that there is potential for genomic selection in the traits of interest. This large scale evaluation will eventually be combined with current selection traits to further refine genomic selection of cattle by dairy producers.

▪ Conclusions

Fertility is a key component of modern dairy production systems. However, a trend for declining dairy fertility has been evident in diverse production systems. Although fertility traits are strongly influenced by the environment, there is evidence for genotypic variation providing an opportunity for selection, as suggested by a partial recovery in dairy fertility since the incorporation of daughter pregnancy rate into bull genetic evaluations. Current efforts are being made to collect high numbers of accurate fertility phenotypes associated with the corresponding genotypes, coupled with large scale evaluations of the association between direct measures of fertility and genomic variation on dairy cows under different management practices and environments. As the cost of genotyping decreases, the number of animals subject to genomic evaluations is expected to continue increasing. If adequate markers and causal variants for fertility traits are identified, molecular breeding values could be estimated for each trait enabling selection to proceed population-wide.

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New Advances in the Management of Uterine Diseases

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Take Home Message

- Nearly 50% of dairy cows develop uterine diseases, which reduces pregnancy per AI, increases pregnancy loss, prolongs interval from calving to pregnancy, and diminishes the cow's productive lifespan and profitability.
- Peripartum metabolic stress compromises energy and calcium homeostasis, hindering optimal endometrial inflammatory defenses to resist pathogens.
- Treatment of uncomplicated cases of retained fetal membranes (RFM) is not usually justified, but supplementation of vitamin E, selenium, and beta-carotene can reduce RFM incidence. Metritis needs treatment with antibiotics; endometritis can be treated with intrauterine cephapirin and potentially dextrose; pyometra can be resolved with prostaglandin F2α ($PGF_{2\alpha}$).
- The threat of antimicrobial resistance has led to the development of a new wave of therapeutics and preventives for uterine diseases. The list includes an essential oil (carvacrol) that efficaciously cured metritis in organic dairy farms; two new vaccines for metritis (one had promising results); intravaginal lactic acid bacteria, chitosan microparticles, and recombinant IL-8 have also been explored.
- Prevention of compromised immunity at peripartum is critical to reducing uterine infections. Thus, strategies such as optimizing dry matter intake, cow comfort and environment, calcium homeostasis, adequate immunization, selection for smaller calves, and minimizing contamination of the uterus at any interventions are essential to managing uterine diseases successfully.

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Introduction

Uterine diseases occur in nearly 50% of dairy cows after parturition leading to disruptions in endocrine signaling, oocyte and follicle development, embryo quality, conceptus development, and maternal recognition of pregnancy, which hinders fertility, increases culling and causes substantial economic losses for dairy producers (Bromfield et al., 2015). The most common types of uterine diseases include RFM, metritis, endometritis, and pyometra. This manuscript aims to review the definition, incidence, significance, risk factors, and treatments of uterine diseases, as well as discuss the most recent advances and novel therapies and strategies under development to mitigate the adverse impact of uterine diseases in dairy cows.

Defining Uterine Diseases

Retention of fetal membranes is characterized as a failure to release the fetal membranes within 12 or 24 h after calving (McNaughton and Murray, 2009). Puerperal metritis is characterized by an enlarged, flaccid uterus, a fetid, watery red-brown discharge, and usually fever and other signs of systemic illness, such as depression or decreased milk yield and feed intake within ten days post-calving (Sheldon et al., 2006). Endometritis is classified as clinical or subclinical. Clinical endometritis is defined by the presence of purulent vaginal discharge detectable 21 days or more after parturition, or mucopurulent discharge detectable in the vagina after 26 days postpartum. Subclinical endometritis is characterized by inflammation of the endometrium measured by the relative presence of polymorph nuclear leukocytes (PMNL) in a uterine sample (collected by flushing or cytobrush) in the absence of clinical disease (Sheldon et al., 2006). The term for clinical endometritis has been questioned because a large proportion of cows presenting pus in vaginal discharge do not have concurrent neutrophil infiltration and pus in the endometrium (Dubuc et al., 2010). Thus, purulent vaginal discharge (PVD) was suggested as an alternative name for clinical endometritis (Dubuc et al., 2010). Also, the term cytological endometritis has been proposed as a "global" definition of endometritis based on the presence of PMNL in the uterine lumen with or without PVD (Dubuc et al., 2010). Pyometra is characterized by the accumulation of purulent contents within the uterus with a concurrent persistent corpus luteum and a closed cervix (Sheldon et al., 2006)

What is the Incidence of RFM and Uterine Diseases?

Retained fetal membranes affect 7.8% of the US dairy cow population (NAHMS, 2009) and reported incidence in other regions vary from 5% to 15% (reviewed by Gilbert, 2016). The incidence of metritis in dairy cows ranges from 10 to 36% (Lima et al., 2014). The reported incidence of PVD varies between 10% and 20% (LeBlanc et al., 2002; Dubuc et al., 2010). The incidence of subclinical endometritis is dependent on the cut-off for diagnosis and the time after parturition varies from 37 to 74% of animals (Gilbert et al., 2005). The incidence of pyometra is about 4% of dairy cows in each lactation (Akordor et al., 1986), but its rate may increase up to 13 % through routine use of GnRH in the early postpartum period (Etherington et al., 1984).

▪ Why are RFM and Uterine Diseases so Detrimental to Dairy Cows?

The impact of RFM ranges from impaired reproductive performance to the development of severe metritis, resulting in loss of milk production, reduced reproductive performance, increased risk of culling, and other uterine diseases and mastitis (reviewed by McNaughton and Murray, 2009). The economic losses caused by metritis are striking, calculated at $380 per affected cow due to reduced milk production, delayed conception, treatment and increased culling (Drillich et al., 2001). Clinical and subclinical endometritis have been associated with reduced P/AI at first service, increased pregnancy loss, and prolonged time to pregnancy (reviewed by Gilbert, 2016). Cows diagnosed with both clinical and subclinical endometritis had an extended interval from calving to pregnancy compared with those diagnosed with only one of the two diseases or with cows having no diagnosis of uterine diseases (Dubuc.et al., 2011). Subclinical endometritis leads to reduced fertilization and compromises early embryo development and survival (Cerri et al., 2009; Hill and Gilbert, 2008).

▪ What are the Risk Factors for RFM and the Development of Uterine Diseases?

The risk factors for RFM include induced parturition, shortened gestation, abortion, dystocia, fetotomy, cesarean section, twins, and deficiencies of vitamin E, selenium, beta-carotene, and calcium (reviewed by Lima, 2013). The risk factors for metritis include primiparity, dystocia, male offspring, twins, stillbirth, abortion, prolapsed uterus, RFM, ketosis, reduced feed intake 2 to 3 weeks before calving, increased levels of BHBA, NEFA, haptoglobin, and hypocalcemia (reviewed by Lima, 2013). Risk factors for PVD include dystocia, male offspring, twins, stillbirth, abortion, RFM, metritis, vulval conformation, and ketosis (reviewed by Lima, 2013). Risk factors for subclinical endometritis include body condition score, ketosis, haptoglobin, negative energy balance (reviewed by Gilbert, 2016). Risk factors for pyometra include the use of GnRH early postpartum and exposure to Tritrichomonas fetus positive bulls (reviewed by Gilbert, 2016).

▪ Metabolic Stress, Immune Response and Uterine Diseases

A common denominator across uterine diseases is the disruption of the immune response. Dairy cows seem to be prompt to the development of metabolic stress, which in turn compromise the ability of the immune system to recognize fetal membranes and pathogens, that when not eliminated will cause the development of uterine diseases. During the peripartum, stressors such as dietary changes, hind-gut acidosis, systemic inflammation, heat stress, psychological stress, feed restriction, and compromised gastrointestinal integrity can disrupt energy homeostasis (tendency of body biological systems to maintain stability while adjusting to conditions that are optimal for survival) and homeorhesis (tendency of body biological systems to return to a particular state) and immune competence (Sheldon et al., 2017).

Also, calcium deficiency can lead to an impaired immune response and increased odds of developing uterine diseases (Martinez et al., 2012).

The immune system recognizes and eliminates pathogens through the identification of pathogen components called major pathogen-associated molecular pattern (PAMPs). Professional immune cells, endometrial cells, and granulosa cells have a series of receptors – named pathogen recognition receptor (PRR) – that can identify the PAMPs. A major PRR is toll-like receptor TLR4 that when bound by a PAMPs will activate a molecular cascade that leads to the production of proinflammatory cytokines (IL-1β, IL-6, and TNFα) and chemokines (CXCL1, CCL20, and IL-8) that can elicit an effective immune response (Sheldon and Bromfield, 2011).

Recent work by Sheldon and colleagues (2017) discussed how metabolic stress hampers the inflammatory response to pathogens. They showed that glucose and glutamine, the primary energy sources for cells, have their abundance reduced in postpartum dairy cows. They also showed that inflammatory responses aggravate metabolic stress, with cows and tissues using glucose in more significant quantities when challenged by PAMPs. They also showed that perturbing glycolysis or AMP-activated protein kinase activity decreased IL-1β, IL-6, and IL-8 in the endometrium.

▪ How Pathogens Get Access to the Uterus of Dairy Cows?

It is widely believed that uterine bacteria ascend from the vagina or through the vagina from the environment or feces when the cervix, which serves as an anatomical and immunological barrier, opens during parturition (Sheldon and Dobson, 2004). However, pathogens associated with the development of metritis such as Bacteroides, Fusobacterium, and Porphyromonas are part of the natural flora of the rumen in cows and are shed in feces. Thus, ascending uterine contamination from the environment could contribute to the development of metritis. Furthermore, a specific uterine pathogen, Fusobacterium necrophorum, is known to gain access to the circulation, probably during episodes of rumen acidosis, and cause liver abscesses in cows (Tadepalli et al., 2009).

A recent study, considering the scenarios described above, investigated the possibility of hematogenous (through the blood) contamination of the uterus (Jeon et al., 2017). The investigation revealed that significant uterine pathogens such as Bacteroides, Porphyromonas, and Fusobacterium were part of the core genera in blood, feces, and vagina. However, other uterine pathogens such as Prevotella and Helcococcus were not part of the core genera in vaginal samples. Moreover, uterine pathogens showed a significant and robust interaction with each other in the network of blood microbiota, but not in feces or vagina, suggesting that hematogenous uterine contamination might be necessary for the etiology of uterine diseases.

▪ How Can RFM and Uterine Diseases be Treated?

Retained Fetal Membranes

Although manual removal remains a common practice, many studies failed to show any benefit of this approach on reproductive performance or milk production, and more severe uterine infections occurred when compared with more conservative treatment (Bolinder et al.,1988). Therapy of RFM with GnRH, oxytocin, and $PGF_{2\alpha}$ is not beneficial to placental release or future reproductive performance (reviewed by Gilbert, 2016). A study suggested that collagenase, an enzyme capable of breakdown collagen, might aid detachment of the caruncle-cotyledon bond in cows with RFM (Eiler and Hopkins, 1993). The umbilical arteries of cows with RFM were injected with 200,000 IU of collagenase leading to earlier placental release than untreated herd mates. Although collagenase therapy was promising, the high cost (~US$75.00) and lack of studies evaluating effects on milk production and reproduction made its use an unfeasible alternative.

The results of antimicrobial use to treat RFM are controversial. Cows diagnosed with RFM are more likely to develop metritis. Thus, the claim behind using antibiotics to treat RFM is to prevent or mitigate the possible severity of metritis and its subsequent adverse effects on fertility. Intrauterine antimicrobials however were unable to reduce the incidence of metritis or improve fertility (reviewed by Lima, 2013). Oxytetracycline, which is often used for intrauterine treatment in cattle with RFM and metritis, inhibits metalloproteinase (MMPs) essential for endometrial repair in other species, which may interfere with the normal placental detachment mechanisms. The use of systemic antibiotics are believed to be beneficial in RFM cases with concurrent metritis and fever (reviewed by Lima, 2013). A study revealed that treating only cows with RFM and fever can reduce unnecessary antimicrobial use (Drillich et al., 2006). Treatment of cows with RFM for five days with 2.2 mg/kg of ceftiofur hydrochloride was beneficial in preventing metritis when compared with estradiol cypionate or no treatment; however, no significant subsequent improvements in reproductive performance were identified (Risco and Hernandez, 2003).

Metritis

Cows diagnosed with metritis develop moderate to severe illness. There is, therefore, a consensus that most of the metritis cases require systemic antibiotic treatment (LeBlanc, 2008). Currently, the most common treatments of choice for metritis are ceftiofur (2.2 mg/kg IM once a day); procaine penicillin (21,000 IU/kg IM once or twice a day for 3 to 5 days); or ceftiofur crystalline free acid sterile suspension (6.6 mg/kg s.c twice each 72 hours) (reviewed by Lima, 2013). Other alternative treatments reported with similar efficacy to ceftiofur or penicillin include the systemic use of tetracycline at a dosage of 10 mg/kg, systemic use of ampicillin at a dosage of 11 mg/kg, and intrauterine treatments with oxytetracycline and ampicillin (reviewed by Lima, 2013). The addition of one dose of flunixin meglumine does not improve outcomes over the use of systemic antibiotics alone (Drillich et al., 2007). Carprofen decreased the use of antibiotic for metritis from 3.63 to 1.63 doses per cow without altering the incidence of endometritis, reproductive performance, or milk production (Pohl et al., 2016).

Endometritis and Pyometra

Endometritis treatments reported include systemic or intrauterine administered antibiotics, intrauterine substances and systemic use of $PGF_{2\alpha}$. Except for cephapirin and hypertonic dextrose (reviewed by Lima, 2013), all other studies had negligible to no benefits on reproductive performance. Many studies suffered from issues such as a lack of negative controls and statistical power, diagnostic criteria for endometritis that were not validated as having an impact on reproductive performance, and no label approval for intrauterine use with no published information on withdrawal times. Several studies investigated the use of $PGF_{2\alpha}$. However, the majority showed no benefits for reproductive performance (reviewed by Lima, 2013). A meta-analysis evaluated the benefits of $PGF_{2\alpha}$ in cows with endometritis and confirmed a lack of improvement in reproductive performance (Haimerl et al., 2013). Although $PGF_{2\alpha}$ (in cows with a function corpus luteum) induce luteolysis, open the cervix, stimulate uterine contractility and potentially release inflammatory content, these benefits are not sufficient to restore the fertility of cows with endometritis.

Pyometra

Pyometra, on the other hand, can be treated with $PGF_{2\alpha}$ and its analogs (reviewed by Gilbert, 2016). Treatment results in bacteriologic clearance of the uterus in about 90% of treated cases. Recurrence of pyometra after a single treatment occurs in 9% to 13% of cases, and first service conception rate of approximately 30% or more follows treatment; however 80% of animals may be expected to conceive within 3 to 4 inseminations (reviewed by Gilbert, 2016).

▪ Novel Therapies and Strategies to Mitigate the Detrimental Impacts of Uterine Disease in Dairy Cows

Lately, the threat of antimicrobial resistance provided reasons and funds to support a plethora of new studies focused on the development of preventives or novel treatments to reduce the incidence and the negative impact of uterine disease and use of antibiotics.

Mannose and Bacteriophage

Machado et al. (2012) evaluated the effects of intrauterine administration of mannose or a bacteriophage cocktail and the presence of E. coli and T. pyogenes in the uterine lumen on uterine diseases and reproductive performance of dairy cows. Unfortunately, the results of their study revealed no effects on uterine health, reproduction performance, or responses in cultures for E. coli and T. pyogenes.

Essential Oils

A study compared the efficacy of using an intrauterine solution containing a certified organic product – an essential oil based on carvacrol (Optimum UterFlush, Van Beek Natural Science, Orange City, IA) – against a intrauterine use of iodine povidone (control) in organic dairy farms (Pinedo et al., 2015). Cows treated with essential oil had a lower incidence of fetid discharge at days 6 and 14 after the first treatment and increased odds of pregnancy at the first AI, 150 days postpartum, and 300 days postpartum.

Metritis Vaccines

Two vaccines for metritis have been tested (Machado et al., 2014; Freick et al., 2017). The first vaccine contained different combinations of proteins

(FimH; leukotoxin, LKT; and pyolysin, PLO) and/or inactivated whole cells (Escherichia coli, Fusobacterium necrophorum, and Trueperella pyogenes). This formulation, when used subcutaneously, reduced the incidence of metritis from 27.6% in control cows to 11.1% (Machado et al., 2014). The second vaccine was a herd-specific vaccine containing inactivated whole bacterial cells of Trueperella pyogenes, Escherichia coli, Streptococcus uberis, Bacteroides, and Peptostreptococcus species obtained from uterine swabs of primiparous cows diagnosed with metritis. This second formulation was unable to reduce the incidence of metritis (Freick et al., 2017).

Probiotics

A study evaluated the effects of an intravaginal infusion of a cocktail of lactic acid bacteria (LAB) composed of Lactobacillus Sakei FUA3089, Pediococcus Acidilactici, FUA3138, and Pediococcus Acidilactici FUA3140 on the incidence of metritis (Deng et al., 2015). Treatment with LAB at 1 and two weeks before calving reduced incidence of metritis from 38.0% to 15.0 and 6.0%, respectively. Moreover, authors reported lowered incidence rates of metritis and total uterine infections of postpartum dairy cows were associated with enhanced vaginal mucus secretory immunoglublin A. Cows administered intravaginally with LAB had lower systemic inflammation, as denoted by lower concentrations of lipolisaccharide-binding protein (LBP), and a tendency of lower serum amyloid A (SAA) in the serum of the treated cows. Authors suggested that intravaginal administration of LAB might be a key strategy to improve immune status and lower the risk of uterine infections of transition dairy cows.

Chitosan Microparticles

A study evaluated the intrauterine use of chitosan microparticles (CM) a day after calving to prevent metritis (Daetz et al., 2016). Treatment with CM decreased the incidence of metritis up to 7 DIM when compared with CON (46.2 vs. 65.4%). But, differences in the rate of metritis were not present at day 4 (11.5% vs. 17.3%), 10 (61.5% vs. 73.1%), and 14 postpartum (63.5% vs. 73.1%). An ongoing study (presented by Dr. Klibs Galvao at the DCRC webinar) is evaluating the effects of CM as treatment for cows with metritis, and according to his presentation, the results are not encouraging for CM as a treatment for metritis.

Chromium Propionate

A recent study evaluating the use of chromium propionate 21 d before expected calving through 63 d postpartum administered by daily topdress at a rate of 8 mg/d revealed a reduction on the incidence of purulent vaginal discharge and a tendency to reduce the influx PMNL to the uterus between 40 to 60 days postpartum (Yasui et al., 2014). The cows treated with chromium propionate also had an increased infiltration of PMNL at day 7 postpartum, a sign of effective uterine immune response early postpartum, and one that authors suggested was the major driving factor behind the reduced incidence of cows with purulent vaginal discharge between days 40-60 postpartum.

Recombinant IL-8

A recombinant chemokines (rIL-8) developed by Dr. Rodrigo Bicalho's laboratory was used intrauterine within 12 hours of calving to prevent RFM and metritis. The rIL-8 was able to reduce the incidence of RFM from 7.7% to 2.9% and the rate of metritis from 19.2% to 6.8% (Bicalho, 2016). No results on incidence of endometritis were reported.

Automated Health Monitoring System

Stangaferro et al. (2016) demonstrated that the use of health index – an arbitrary numerical value generated according to the postpartum recovery of rumination, activity and days in milk of the cow – produced by Data Flow II software (SCR Ltd., Netanya, Israel) and used as a diagnostic tool resulted in sensitivities (percentage of cows diagnosed as sick) of 49 to 78% for metritis. The specificity of using the health index (percentage of cows diagnosed as healthy) as a diagnostic tool for postpartum disease (e.g., displaced abomasum, ketosis, indigestion, mastitis, and metritis) was 98% (Stangaferro et al., 2016). These are promising results and suggest that herds that have sub-par transition cow monitoring by herd personnel or no other means of evaluating performance (e.g., individual daily milk yield, milk yield deviation, etc.) could benefit significantly from automated rumination-activity monitoring systems.

Although a series of these new preventives and therapies hold promise to overhaul how uterine diseases can be managed, more studies are needed to replicate current successful outcomes and to clarify what is the cost-benefit of using these new technologies to reduce the incidence of uterine diseases.

▪ Management Strategies to Prevent RFM and Uterine Diseases

A common denominator across uterine diseases is a disrupted immune function derived from metabolic stress. Therefore, it is reasonable to surmise that management strategies to prevent uterine disease should focus on optimizing cow comfort, adequate intake of energy, calcium, and antioxidants to maintain homeostasis and a fully functional immune system during the periparturient period. Additionally, adequate immunizations to prevent infectious diseases, the use of sexed semen and calving ease selection to favor the birth of female and smaller calves, and proper techniques to assist cows to calve can help prevent the occurrence of uterine diseases. Dry matter intake is the principal factor of dairy production, and its effects on uterine health have been demonstrated. Thus, several management strategies have been suggested (LeBlanc, 2015) to reduce the odds of uterine disease development:

1. Feed daily for 3 to 5% left over
2. Provide ≥75 cm (30”) bunk space per cow or 4 cows per 5 headlocks
3. Offer ≤85% stall stocking density
4. Provide >11m^2 (120 ft^2) of bedded pack/cow
5. Build a maternity pen that supports 130 to 140% of the average number of monthly calvings with comfort stalls
6. Have an adaptation of <24 h in calving pen
7. House heifers in pens separate from mature cows
8. Minimize group changes
9. Have heat abatement (sprinklers and fans) on when THI > 68
10. Manage nutrition, so cows calve with BCS = 3.0 to 3.5
11. Offer 3 to 4 weeks on close-up diet or 6 weeks as one dry group
12. Meet but do not exceed energy requirements 8 to 3 weeks prepartum
13. Offer water ad libitum with at least 10 cm (4”) linear trough space per cow and two sources per pen
14. Feed 1000 IU vitamin E/d; up to 2000 IU/d for RP; 0.3 ppm selenium (ideally approx. 6 mg/d).
15. Provide anionic salts during the prepartum for multiparous to prevent hypocalcemia.
16. Monitor health for early diagnosis of disease and treatment.

▪ Conclusions

An important factor related to the treatment of uterine diseases is the cost-benefit to dairy producers. For cases of RFM with fever and puerperal metritis, treatment is justified to improve the cow’s welfare and to the reduce odds of death. However, improvements in reproductive performance, the incidence of other diseases, and milk production are not always present (Chenault et al., 2004; McLaughlin et al., 2012). For endometritis, the treatment with intrauterine cephapirin does lead to improved reproductive performance and seems a reasonable choice. However, optimization of cost-benefit is undoubtedly a function of prevention rather than treatment. A fair case can be made that uterine diseases have metabolic stress as a common denominator and strategies that minimize its risks are pivotal to prevent uterine disorders. Moreover, the worldwide threat of antimicrobial resistance has led to the development of an arsenal of surrogate therapies that can aid in the prevention of uterine diseases. Nevertheless, more studies are needed to refine the novel therapeutics, which can consistently lead to improved cost-benefits for dairy producers. Therefore, it is reasonable to surmise that soon a program incorporating the novel preventives and strict management practices to reduce metabolic stress will be available to optimize dairy producers' strategies and mitigate the negative impact of uterine diseases in dairy cows.

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New Developments in Mastitis Research

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▪ Take Home Messages

- The need to decrease the use of antibiotics forces the pharmaceutical industry to create new, innovative solutions
- Improvement of immune status of the fresh cow may reduce susceptibility to mastitis
- Lower milk production at dry off decreases the risk of new intramammary infections during the dry period
- Information about the microbiome of the udder and the bacterial load give new insights into the consequences of antimicrobial treatment
- Selective dry cow treatment has been proven to be feasible without adverse effects on udder health

▪ New Developments from the Pharmaceutical Industry

Over the last ten years, there has been a strong focus on the prudent use of antimicrobials. WHO decided that in the future all new developed antibiotics will only be permitted for human medicine and not for veterinary medicine. This means, that we have to look for new solutions in order to keep our cows healthy or to treat them in different ways, with less or no antibiotics.

Recently, two innovative treatments have been developed:

a. Immuno-modulation: The dairy industry has its first non-antibiotic product that boosts the immune system. It’s a protein that boosts the dairy cow’s natural immune system during the critical time around calving.
b. Abrupt dry-off: The second innovative treatment is a product that induces abrupt dry-off in dairy cows. In combination with selective dry cow treatment, it should diminish milk leaking, risk of new

intramammary infections during the dry period, and increase animal welfare.

Immuno-modulation

Dairy cows often experience decreased immune function around the time of calving, typified by impaired polymorphonuclear neutrophil (PMN; white blood cell) function and a transient neutropenia. This is associated with increased disease incidence, including mastitis, retained placenta, and metritis. This decreased cell function often starts about 2-3 weeks before calving, reaching a nadir at the time of calving (0-2 days after calving), and then recovering in 2-4 weeks (Kehrli et al., 1989). The decreased immune function during the periparturient period is more pronounced in some cows than in others. The decreased immune function has been attributed to fetal growth and colostrum production during the last part of the pregnancy, which induces an increased nutrient demand (Goff et al., 2002). At the start of lactation most cows experience a negative energy and protein balance, as well as changes in vitamin and mineral status which contributeto a decreased PMN function. Supplementation of vitamins and minerals may increase PMN function and decrease disease incidence.

Recently, it was shown that a subcutaneous injection of recombinant bovine granulocyte stimulating factor (rbG-CSF) increased the number of PMN and improved cytotoxicity function by PMN (Kimura et al., 2014). Granulocyte colony-stimulating factor is a glycoprotein cytokine that stimulates the bone marrow to produce stem cells and granulocytes, and release granulocytes into the bloodstream. This increased number of mature and immature granulocytes should improve the immune system of the fresh cow and decreases periparturient diseases.

Abrupt Dry-off

The dry period is an important phase of a dairy cow’s lactation cycle and studies clearly document the importance of a dry period lasting 40 to 60 d for optimal milk production. The overall benefits derived from the dry period are thought to be a consequence of adequate mammary gland secretory cell turnover. Abrupt cessation of lactation has become problematic for the modern dairy cow, which may produce 25 to 30 kg/d of milk at the time of dry-off.

Excessive accumulation of milk at the time of dry-off, may lead to milk leakages and reduce the functional capabilities of mammary leukocyte populations (Oliver and Sordillo, 1989) and make cows therefore more susceptible to new intramammary infection during the early dry period.

Fully involuted mammary glands are more resistant to new bacterial infections and mammary glands that enter the dry period with lower milk production involute at a faster rate than those of cows with a high milk production. On top of that, excessive mammary gland engorgement at the time of dry-off can be seen as a source of discomfort and pain.

In a time where the use of blanket antimicrobial dry cow treatment (BDCT) is no longer a standard in Europe, it is even more important to improve transition management in order to create the most favourable circumstances for dry off cows. In the guideline “The use of antimicrobials for drying off dairy cows,” published in January 2012 in the Netherlands, recommendations are given to decrease milk production before drying off to 12 kg of milk per cow per day. The dairy industry needs practical management strategies to effectively dry off high-producing dairy cows at the end of their lactations. This can be achieved through feed restrictions and decreased protein content at the end of the lactation.

Feed restrictions, however, have several disadvantages. It has been reported that cows exposed to reduced feed intake had a greater frequency of vocalization and probably suffered from hunger. Furthermore, severe feed restriction caused increased cortisol levels, affected non-esterified fatty acid, BHB, and urea concentrations. All these metabolic imbalances indicate a negative energy balance that might cause an impairment of udder defense mechanisms.

Recently, some pharmacological studies explored options to hasten mammary gland involution, like the systemic application of prolactin-release inhibitors. The effect of those inhibitors on mammary gland involution has been investigated. Prolactin-release inhibitors reduce the release of prolactin in the pituitary gland. As a result, the galactopoietic (=milk forming) effect of prolactin is countered.

Cabergoline is an ergot derivative and acts as a prolactine-relase inhibitor. A recent study reported that a single injection of cabergoline is able to reduce plasma prolactine concentrations in dairy cows at dry-off. In addition, the cabergoline treatment at dry-off also reduced udder engorgement (measured by a digital algometer Identifying pressure), decreased the incidence of milk leakage, and improved lying time the day following dry-off (Bach et al., 2015).

Large field trials were conducted in Europe, with positive results shown regarding decreased milk leakage and fewer new intramammary infections. After the official launch of the product on the market, unfortunately, side effects were seen in a few European countries, with symptoms that looked similar to milk fever (lying down and being unable to stand). Many of these affected cows ended up as Downer cows and some of them died. Because of these negative side effects the European Medicine Agency (EMA) recommended that the marketing authorisation for Velactis© be suspended in the European Union (EU) until further information is available to show that the benefits outweigh the risks, possibly under new conditions of use or restrictions. At this moment, new trials are ongoing in Europe and new results are expected soon. Other countries, like Mexico and Brazil, don’t report about those side effects and the product is still allowed to be used in those countries.

▪ The Microbiome of the Udder

For years now, mammary gland inflammation has been considered the result of host pathogen interaction, a result that depends notably on bacterial and host genetic determinants. The immunological response of the mammary gland on invading bacteria is an increase in somatic cell count (SCC). Somatic cell count (SCC) has therefore been used to distinguish healthy quarters from quarters with an inflammatory response, most likely due to an intramammary infection. Also, bulk milk somatic cell counts (BMSCC) are used as an overall indicator of milk quality.

Identification of the bacteria responsible for mastitis is an important component of the eventual clinical resolution of the disease. Currently, bacterial culture is the gold standard method for identification of mastitis-causing microorganisms. Classical bacterial culture needs about 24-48 hours to obtain results, and in approximately 25% of milk samples from clinical mastitis cases, bacteria are not detected or present.

In the last decade new molecular techniques have been used to diagnose mastitis. These techniques are being used to identify bacterial DNA in milk samples. In a recent study, the use of DNA techniques showed the diversity of bacterial communities in human milk samples. Furthermore, they showed that this technique identified a much greater diversity of bacteria in milk than that previously reported in culture-dependent studies.

These DNA-based bacteriological studies were also conducted in milk from dairy cows (Oikonomou et al. 2012). The concept that the mammary gland and milk were sterile, however, has to be interpreted in a different perspective. The DNA-based studies showed a wide variety of micro-organisms in the milk, even in samples from healthy, low SCC quarters. These data led to the concept that intramammary microbiota are composed of a complex community of diverse bacteria. Accordingly, mammary gland infections are not infections by bacteria, but rather a consequence of dysbacteriosis or dysbiosis.

One hundred and thirty-six milk samples were collected from cows with subclinical or clinical mastitis and sent to the lab for bacteriological culture (Oikonomou et al., 2012). Another 20 milk samples obtained from healthy quarters without a history of mastitis and SCC lower than 10,000 cells/ml were also used. No Mycoplasma culture or anaerobic culture was performed on the samples. Samples with a single dominant bacteria or absence of any growth were selected for the study. Results showed that the microbiota from the healthy quarters were quite different from the mastitis milk samples. The presence of bacteria that don't need oxygen to grow, the so called anaerobic bacteria, were found in high proportions by the DNA-based technique. In this study, it was not possible to differentiate between cause and consequence, but it was concluded that a wide variety of udder commensals exist that play a crucial role in the mastitis aetiology. These new findings might have future consequences for the current thoughts about the prevention and cure of mastitis. If we can divide bacteria in the udder into "good guys and bad guys," will this affect our current prevention strategies? Will post milking teat dipping or blanket dry cow treatment still be the best way to go, or might we also kill "the good guys"? Future research will help us to answer these questions.

▪ Implementation of Selective Dry Cow Treatment

An overview of the Dutch national BMSCC over the last 11 years is shown in Figure 1. BMSCC shows a decreasing trend and BMSCC dropped below 200,000 cells/ml in 2015. Since the ban on the preventive use of antimicrobials in 2012 and the introduction of selective dry cow treatment (SDCT) in January 2014, national BMSCC declined by 30,000 cells/ml. As of June 2017, the national BMSCC is the lowest ever.

Somatic cell count dynamics during the dry period were calculated for the 280 dairy herds belonging to the University Farm Animal Practice in the Netherlands. The rate of new intramammary infections during the dry period and the cure rate of existing intramammary infections during the dry period were calculated by the national DHI (CRV), based on the following definitions:

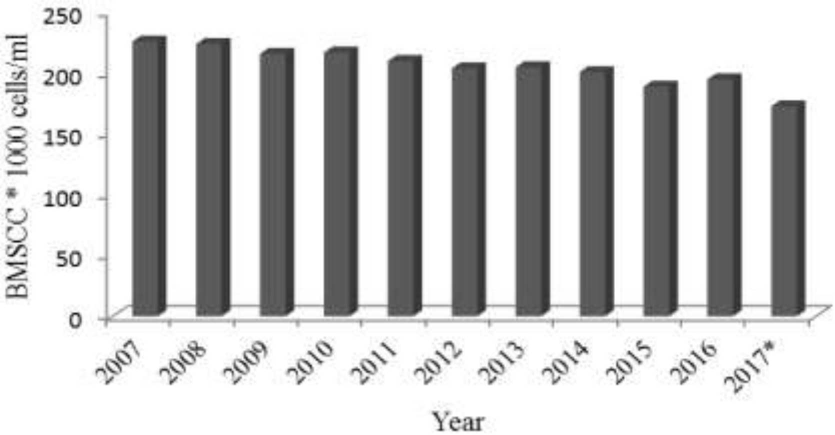

Figure 1. National BMSCC in the Netherlands from 2007 until 2017 (n= approximately 18,000 herds). *Average BMSCC of 2017 is calculated until June 2017.

New intramammary infection (IMI):

Defined as a change in SCC from below the threshold of 150,000 cells/ml for primiparous and 250,000 cells/ml for multiparous cows at the last milk recording before calving to an SCC equal to or greater than the threshold at the first milk recording after calving.

Cured intramammary infection (IMI):

Defined as a change in SCC from equal to or greater than the threshold (150,000 cells/ ml for primiparous and 250,000 cells/ml for multiparous cows) at the last milk recording before calving to an SCC below the threshold at the first milk recording after calving.

Results of these SCC changes during the dry period are shown in Table 1. The annual mean % of new IMI changed from 16% in 2013 to 18% in 2014 and to 17% in 2016, a slight increase in the number of new infections during the dry period. The annual mean % for cured IMI during the dry period was 74% in 2013 and 2014, and 75% in 2017.

Table 1. Somatic cell count dynamics over the dry period from 2013 through 2017 in herds serviced by the University Farm Animal Practice in the Netherlands (n= 280 herds). Thresholds for primiparous cows 150,000 cells/ml and 250,000 cells/ml for multiparous cows

	Year				
Variable	2013	2014	2015	2016	2017*
Mean (SD) % new IMI	16 (9)	18 (10)	17 (9)	17 (10)	15 (8)
Mean (SD) % cured IMI	74 (16)	74 (18)	76 (7)	75 (18)	75 (19)

* calculations for 2017 are carried out until December 1st 2017

Following a period in which BDCT was an essential part of the of the 5-point mastitis control plan, the results from this study indicate that in the Netherlands a nationwide forced shift to SDCT over a relatively short period of time was associated with no significant changes to udder health during the dry period. National figures on BMSCC are lower than ever and there is no significant increase in the percentage of new intramammary infections during the dry period. Despite the investment of extra labour, farmers have become convinced that improving management works better than buying the solution in a tube or a syringe!

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