How Can Automation be Used to Optimize Cow Nutrition?

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Take Home Messages

- Automated technologies are being increasingly adopted within the dairy industry to not only reduce human labour requirements, but to also increase the accuracy and precision of application of various management tasks.
- Various forms of feeding technologies are currently available to increase our ability to optimize the nutrition of dairy cows.
- At a herd level, technology can be used to monitor feed ingredients and mixing protocols, and to automate diet preparation, delivery, and push-up.
- At a cow level, there are opportunities to meet individual cow nutritional needs through individualized supplementation, particularly in association with robotic milking.

Introduction

There is much recent discussion regarding precision dairy cattle management, which can be defined as automation using sensor-based management tools that define animal needs, and robotic equipment that automatically delivers individual animal and herd management applications. Much of this stems from the current rapid development, introduction, and refinement of various forms of automation in the dairy industry. Probably the best example here in Canada is robotic (automated) milking, which continues to be adopted widely within the industry. Automation is also available and being used for health management, reproductive management, barn cleaning, ventilation, bedding, and nutrition and feeding management.

Much of the draw to adopt automation relates to the current availability and cost of labour. Beyond that, there are also benefits to the cows themselves, with the adoption of technologies that allow for greater accuracy and precision in their deployment than that traditionally realized. For dairy cow nutritional management, at a herd level, automation can reduce the variability in the composition of the diets we provide, the composition of the diets consumed by the cows, and the timing of that consumption. Further, at a cow level, automation (particularly through robotic milking) can potentially be used to accurately and precisely meet the nutritional needs of individual cows throughout lactation.

Automation to Improve Ration Accuracy and Precision

The goal of any nutritional program for dairy cows should be to meet the basic nutrient requirements for maintenance, while optimizing supply of nutrients for health and production. This should be done as accurately as possible to minimize the risk of shortchanging nutrients supplied (and thus not meeting production targets) or oversupplying nutrients (resulting in poor efficiency and waste). Despite our best efforts on these fronts, the delivered ration on many dairy farms does not accurately match that which was formulated for the cows.

As the variability between the ration offered to the cows and the original formulated ration becomes greater, so does the chance that cows will not perform to expectation. In a study by Sova et al. (2014) we sampled the mixed and delivered total mixed ration (TMR) for 22 free-stall, parlour-milked herds for seven consecutive days both in summer and winter. The nutrient analysis of these feed samples was then compared to that formulated for those farms. Across farms, the average TMR fed did not accurately represent that formulated by the nutritionist. The average TMR delivered exceeded TMR formulation for net energy of lactation (NE_L), non-fibre carbohydrate (NFC), acid detergent fibre (ADF), calcium, phosphorus, magnesium and potassium, and underfed crude protein (CP), neutral detergent fibre (NDF) and sodium. Across farms, however, there was a huge range in this variation, with some farms consistently experiencing a 5–10% discrepancy (both positive and negative) between the fed and formulated ration for nearly all nutrients. Theoretically, overfeeding might not be problematic because a safety margin is generally included in formulation to account for uncertainty in ingredient composition. However, excessive overfeeding can result in waste and decreased efficiency, while underfeeding could lead to production targets not being met.

Similar deviations in diet accuracy were observed in a study by Trillo et al. (2016) of 26 California dairies (ranging in size from 1,100 to 6,900 cows) throughout a 12-month observation period. Those researchers observed that the median deviation for high cow production recipe was below the target weight on 10 dairies or above the target weight on 16 dairies. Further, they observed that the absolute deviation from target was more than 2% at least 50% of the time on seven of those dairies. As result of these deviations from the target weight, those researchers demonstrated that the cost of high cow production recipe increased in many dairies on many days, was decreased in lesser cases, and was only consistent to the target cost in very few instances. Those researchers concluded that these deviations from target were partly influenced by ingredient type, with certain ingredients being more consistently loaded with poor accuracy and precision.

In addition to challenges with diet accuracy, there are probably even greater challenges with diet precision, that is, providing the same diet day in, day out. In the study by Sova et al. (2014), we investigated the day-to-day consistency in physical and chemical composition of TMR and associations of that variability with measures of productivity. Greatest day-to-day variability was observed for refusal rate, particle size distribution, and trace mineral content. Delivery of a more consistent ration was associated with improved production. For example, greater dry matter intake (DMI; Figure 1a), milk yield (Figure 1b), and efficiency of milk production (Figure 1c) were all associated with less daily variability in energy content of the ration (Sova et al., 2014). Lower daily variability in the percentage of long forage particles in the offered TMR was associated with greater milk yield and efficiency of milk production. On average, day-to-day variability was greater for physical characteristics (i.e., particle size distribution) of the ration compared with the ration's nutritional composition.

Deviations in diet accuracy and precision are largely going to be influenced by variability in feed ingredients and possibly even more so by mixing errors associated with operators (timing, sequencing) or equipment. This suggests that increased surveillance of the TMR composition, in addition to individual feed ingredients (e.g., regular, frequent forage DM determination, regular nutrient testing of feeds) are helpful as a regular component of feeding management to ensure delivery of TMR with the intended nutrient composition to maintain production and feed intake. Of that, probably the biggest contributor to feed ingredient variability would be lack of knowledge of feed dry matter (DM), particularly that of ensiled forages. Often DM content is not measured frequently enough due to the time and labor required to do so. Using technology (for example, NIR sensors on feed loading/mixing equipment) can help with that. Further, having proper protocols in place (and training for those), and monitoring of that through feed management software may be important for minimizing that risk of variation. Finally, probably the biggest opportunity the industry has to reduce variability is to lessen the amount of human operated equipment in the feeding process and employ more automation therein. To that end, the adoption of automated feed (TMR) preparation and mixing equipment is expected to increase, along with improvements to those technologies.

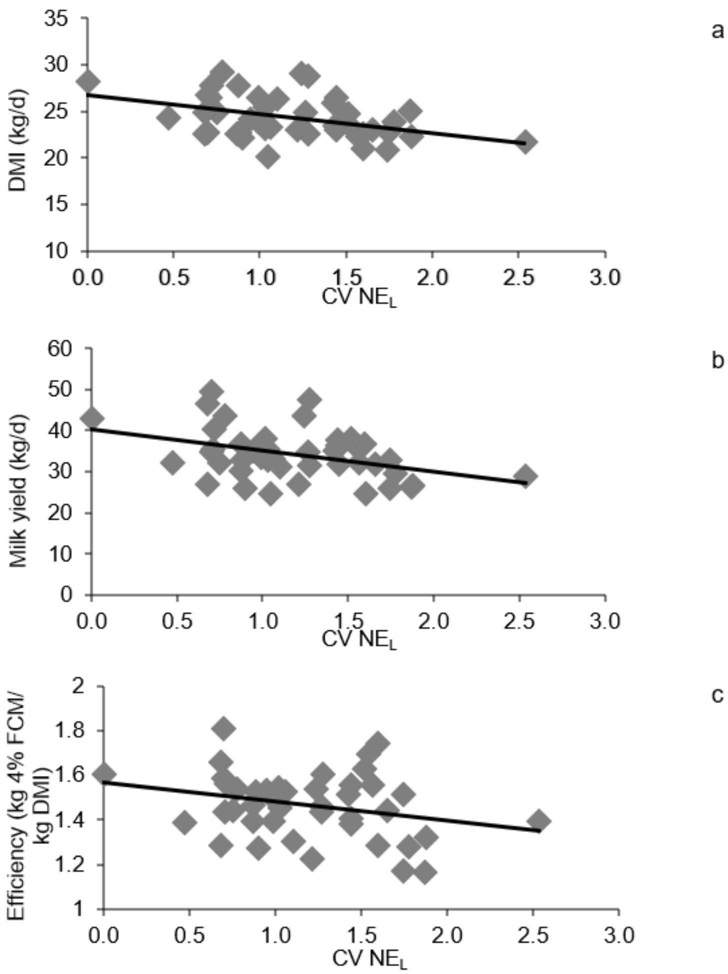

Figure 1. Association between fed ration coefficient of variation (CV) in NE_L and average a) DMI, b) milk yield, and c) feed efficiency. Coefficient of variation was calculated as the standard deviation of NE_L over 7 d divided by the average NE_L over 7 d. Figure adapted from Sova et al. (2014).

▪ Automation to Optimize Cow Eating Behavior

Even if we get the TMR right and deliver it as formulated on a consistent basis, it does not mean cows will eat that ration as distributed to them or in a manner that is good for them. Because changes in DMI must ultimately be mediated by changes in feeding behaviour, and that behaviour can also influence rumen health and efficiency, it is important to understand the factors that influence cow feeding behaviour patterns.

Total mixed rations are designed as homogenous mixtures with the goal to minimize the selective consumption of individual feed components by dairy cattle and promote consistent intake of a complete diet. Despite this, dairy cattle have been shown to preferentially select (sort) for the grain component of a TMR and discriminate against the longer forage components. The sorting of TMR by dairy cows can result in the ration actually consumed by cows being greater in fermentable carbohydrates than intended and lesser in effective fibre, thereby increasing the risk of depressed rumen pH (Miller-Cushon and DeVries, 2017a; DeVries, 2019). Likely related to this, sorting of a TMR has been associated in several of our studies with cows producing milk with lower fat percentage (DeVries et al., 2011a; Fish and DeVries, 2012; Miller-Cushon and DeVries; 2017b).

Imbalanced nutrient intake as a result of sorting also has the potential to impact the efficiency of digestion and production. In support of this, Sova et al. (2013) demonstrated that efficiency of milk production decreased by 3% for every 1% of group-level selective over-consumption (sorting) of fine ration particles. We also demonstrated in that study that every 2-percentage point increase in selective refusal (i.e., sorting against) of long ration particles on a group level was associated with a per cow reduction of 0.9 kg/d of 4% fat-corrected milk.

It is important to not only consider what dairy cows actually consume from their provided ration, but also the manner in which the ration is consumed. Intensively housed dairy cattle fed a TMR typically consume their daily DMI in up to 6 hours/day, spread between seven or more meals per day (DeVries et al., 2003). When cows have more frequent, smaller meals throughout the day and eat more slowly, rumen buffering is maximized, large within-day depressions in pH are avoided, and the risk of sub-acute ruminal acidosis is decreased (DeVries, 2019). These improvements in the rumen environment may also translate into improved DMI. In recent research we demonstrated, using data from multiple studies of high production cows, that both meal frequency and total feeding time were stronger predictors of daily DMI, and subsequently milk yield, than the size of meals consumed or the speed at which they were consumed (Johnston and DeVries, 2018). Thus, to promote consistency in consumption and digestion, it is important to use rations, management, and housing that promote the frequent consumption of feed in small meals, spread over a longer period of time at the feed bunk.

One method to achieve that type of feeding behaviour is to increase the frequency of feed delivery (DeVries et al., 2005). Greater frequency of TMR delivery has been associated with greater DMI (Sova et al., 2013; Hart et al., 2014) Further, delivering a TMR 2x/day or more often reduces the amount of feed sorting compared with feeding 1x/d (DeVries et al., 2005; Endres and Espejo, 2010; Sova et al., 2013), which would further contribute to more consistent nutrient intakes over the course of the day. Such desirable feeding patterns are conducive to more consistent rumen pH, which likely contributes to improved milk fat (Rottman et al., 2014). In support of that, Woolpert et al. (2017) reported that dairy herds with high de novo fatty acid (FA) concentration in bulk tank milk, compared with those with low de novo FA concentration, tended to be 5x more likely to be fed 2x versus 1x per day, confirming the positive impacts of feeding >1x/day on maintaining a consistent rumen environment. Similarly, Castro et al. (2022) demonstrated in a study of 124 automated (robotic) milking system (AMS) farms that greater frequency of partial mixed ration (PMR) delivery (>2×/day vs. 1 and 2×/day) was positively associated with a greater proportion (g/100 g of FA) of de novo FA in the bulk tank milk of those farms.

Clearly there are benefits to delivering feed (i.e., TMR or partial mixed ration (PMR)) more often per day. Practically, implementation of greater TMR delivery frequency on dairies is often constrained by time and cost associated with TMR preparation and its delivery. Thus, implementation of feeding automation, not only for diet preparation, but also for frequent delivery to cows across the day may have significant benefits in terms of achieving greater precision. Automated TMR delivery systems (e.g., autonomous, rail, or conveyor) are available for use within the industry, allowing for high feed delivery frequencies without additional labour needed. There is, however, a paucity in research on the effectiveness of the implementation of these automated TMR mixing and delivery systems.

TMR push-up is also critical to ensure that feed is accessible when cows want to eat. Feed push-up needs to occur frequently enough such that any time a cow decides to go to the feed bunk, there is feed available to her. Feed push-up also helps minimize variation in feed consumed because it mixes up the feed that is no longer in reach with that which is currently available in the bunk. Thus, frequent pushing up of TMR in the bunk is necessary, particularly in the first few hours after feed delivery, when the bulk of the feeding activity has occurred. We have demonstrated that greater lying duration is associated with greater frequency of feed push-ups (Deming et al., 2013; King et al., 2016), suggesting that frequent push-up minimizes the time cows need to spend waiting for feed access and cows can devote more time to lying down. More frequent feed push-up may be particularly beneficial for robotic milking systems, where voluntary milkings are often centred around times of feeding activity at the bunk (DeVries et al., 2011b).

Feed push-up will also ensure that DMI is not limited and, thus, production is optimized. Evidence for this was shown in a cross-sectional study of 47 herds, all with similar genetics and feeding the exact same TMR (Bach et al., 2008). In that study it was reported that those herds where feed was not pushed up (5 out of

47 herds) produced 3.9 kg/d/cow less milk (-13% difference) than herds where feed was pushed up. Siewert et al. (2018) reported that robot farms with automatic feed push-up produced 352 kg more milk/robotic unit and 4.9 kg more milk/cow per day than farms that manually pushed up feed. In a more recent study by our group (Matson et al., 2021), we demonstrated in an observational study of 197 Canadian robot milking farms, that each additional 5 feed push-ups per day was associated with 0.35 kg/d/cow greater milk yield. Interestingly, given the mean push-up frequency between those that pushed up feed manually (4.4 times per day; 19% of farms) and those that used a robotic feed pusher (16.8 times per day; 71% of farms) in our study, it is likely that our findings and that of Siewert et al. (2018) were driven by the frequency feed was pushed up within each system, rather than by the method itself. More specifically, these effects may not be directly attributable to the use of an automated feed pusher, but rather that those farms using such automated equipment had more consistent feed push-up, and thus continuous feed access, than those pushing up feed manually. In situations where manual feed push-up is done consistently and frequently, the same results should be achievable. Unfortunately, in reality, manual feed push-up, performed by farm staff, is more prone to inconsistency, in time and frequency, and many farms lack the required labour needed to do so; thus, this again provides support for the use of this type of automation.

▪ Automation to Meet Individual Cow Requirements

Along with herd-level nutrition precision achieved through automation, there is also opportunity to use automation to achieve that precision at an individual animal level. The rapid adoption of technologies that allow for individualized feeding, including automated milking and calf feeding systems, has also increased our potential ability to feed cattle according to their individual requirements.

As we have the ability to supplement the feed consumption of dairy cows within AMS, there is potential for applying some type of precision feeding approach in AMS (Bach and Cabrera, 2017). While there is potential, there are also several challenges with such an approach. In AMS, the herd is fed a common diet (PMR) at the feed bunk. As this PMR diet is static, the ‘precision’ aspect, to meet individual cow nutrient needs, would need to be accomplished with the feed provided at the AMS. In theory, if the individual nutrient requirements were known (based on expected milk production, and other known factors including age, body weight, stage of lactation, pregnancy status) then the amount of feed provided in the AMS could be adjusted to the cow’s individual need. The challenge with that is being able to accurately predict the nutrient consumption from the PMR, as that is not measurable on an individual basis in commercial settings. Therein lies the difficulty. It has been demonstrated that the level of PMR consumption is affected by the level of concentrate provided at the AMS, and it is not necessarily an even substitution ratio (Hare et al., 2018; Menajovsky et al., 2018; Paddick et al., 2019; Schwanke et al., 2019; Schwanke et al., 2022). In fact, across studies, the substitution ratio (amount of decrease in PMR intake for every 1 kg increase in AMS pellet intake) has ranged from 0.54 to 1.58 kg (Hare et al., 2018; Schwanke et al., 2022). As such, it may be difficult to predict total DMI, and thus total nutrient intake, when varying the amount of feed provided at the AMS, making precision feeding more difficult. Further, in studies where we have increased the quantity of AMS pellet offered in the AMS, the day-to-day variability in the consumption of the AMS pellet also increased (Hare et al., 2018; Menajovsky et al., 2018; Paddick et al., 2019; Schwanke et al., 2019). This variation then makes the concept of precision more difficult to attain. A further challenge with feeding in AMS is that just because cows are provided feed at the AMS, does not guarantee they will consume it (Bach and Cabrera, 2017). Any unconsumed feed left in the AMS results in another cow potentially consuming more than what she is programmed for; this reduces the ability to precision feed these animals.

While most AMS are only equipped with a single bin for delivering concentrate to cows (Bach and Cabrera, 2017), there is opportunity within many systems to provide multiple feeds. It’s possible that greater precision in feeding could be achieved in such scenarios, as the amount and balance of different types of supplement feeds could be used to match individual cow nutrient requirements. To date, however, there is limited research on this type of approach. In a recent study, we demonstrated that we could improve energy balance and minimize body condition loss in early lactation by supplementing cows milked in AMS with a molasses-based liquid feed supplement in addition to their regular AMS concentrate (Moore et al., 2020).

There may be opportunities to apply such precision feeding principles in other types of milking systems. One such example is that described by Bach (2014), a ‘dynamic concentrate parlour feeder’ which involves the preparation and delivery (in real time) of many different feeds (in both quantity and composition) within a rotary milking parlour. The system calculates the individual nutritional requirements of each cow entering the parlour based on her assigned feed intake (average of the pen where she is), composition of the TMR fed, DIM, parity, BW, BW change, pregnancy status, milk yield, and milk component yields. Based on those needs, the system creates a least-cost formula using up to 6 feeds that are mixed and delivered to the cow in less than 14 seconds. Bach (2014) suggested that such a system would allow for the feeding of a more cost-effective TMR with a low nutrient density, without compromising, and even potentially improving, income over feed cost by delivering nutrients to only those cows in need of them.

One area where there has been more success in application of individualized feeding strategies is with the use of automated calf milk feeders. Automated calf feeders provide the ability to feed calves individualized milk diets that may be calf-specific based on age, weight, or any other parameter deemed appropriate. This may include altering the speed at which milk allowance is increased in early life, as well as decreased at the time of weaning. To date, however, much application of these feeding strategies, while applied at the calf level, is still done similarly across all animals within a farm. There is research to suggest that much gain can be made by tailoring feeding programs for individual calves based on their individual needs. For example, de Passille and Rushen (2016) demonstrated that individual calves differ greatly in when they begin to consume solid feed and how quickly they increase the intake in response to a decrease in milk allowance. Those researchers demonstrated that automated milk feeders could be used to wean calves at variable ages, depending on their ability and willingness to eat solid feed.

▪ Conclusions

Automated technologies have been developed and increasingly adopted within the dairy industry to not only reduce human labour requirements, but also to increase the accuracy and precision of application of various management tasks. Various forms of feeding technologies are currently available to increase our precision in feeding strategies of dairy cattle to optimize nutrition. At a herd level, this includes automated feed preparation and delivery, as well as incorporation of technology in feed monitoring. At the animal level, this includes individualized feeding opportunities, to date primarily through automated milking in lactating cows and automated milk feeders in calves. While there are still many challenges associated with the successful implementation of such precision feeding strategies, on-going research would suggest that these opportunities will continue to grow, allowing for greater nutrient capture, greater efficiency, less nutrient waste, and greater health and production.

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