Feeding Management for Cows in Automated Milking Systems: What We Know and What We Still Need to Learn

Gregory Penner[1], Jennifer Haisan[1,2], Keshia Paddick[3], and Trevor DeVries[4]

[1]University of Saskatchewan, Saskatoon, SK; [2]University of Alberta, Edmonton, AB; [3]Lakeland College, Vermillion, AB; [4]University of Guelph, Guelph, ON
Email: greg.penner@usask.ca

Take Home Messages

- There are a limited number of controlled research studies evaluating feeding management for cows milked with automated milking systems (AMS).
- Changing the amount of pellet offered in the AMS impacts the whole diet for that cow.
- When cows eat more pellet in the AMS they reduce partial mixed ration (PMR) intake; however, predicting the reduction in PMR intake is not currently possible.
- The amount of pellet programmed into the software, delivered by the AMS to the cow, and consumed by the cow all differ.
- Achieving high AMS pellet intake relies on frequent AMS visits but this increases variability in AMS pellet intake.
- The PMR is the major component of the diet.

Introduction

Diversity in nutritional management among Canadian dairy farms is evident and dictated by factors such as producer goals, milking system, amounts and types of feed (silage, hay, and cereal grains) produced on farm and those purchased off farm. With automated (robotic) milking systems (AMS), the diversity is increased relative to that in total mixed ration (TMR) fed herds, because the division of the TMR into a partial mixed ration (PMR) and the AMS pellet imposes a fundamental shift in nutritional management. In addition, the nature of the PMR, allocation of the PMR, type of pellet, and feeding strategy of the pellet delivered in the AMS differ. The large diversity coupled with relatively recent adoption of AMS and limited controlled research regarding feeding management have led to recommendations being largely based on survey studies or based on anecdotal data from single-farm case studies. However, research on feeding management strategies for cows managed in AMS has increased, particularly in Canada, and this paper will describe the current state of knowledge along with areas where research is needed.

▪ Does Cow-traffic Design Influence the Feeding Management Approach?

There are two main goals when considering the nutritional program for cows milked with AMS. The first, as with all planned nutritional programs, is to provide a diet that meets nutrient requirements for maintenance and production. However, with AMS, there is a perception that this goal can be shifted from the pen level to the cow level. Thus, producers could be providing a different diet for each cow within the same pen by adjusting the amount of pellet provided in the AMS. The second goal, which is unique to AMS, is to stimulate cows to voluntarily enter the AMS by dispensing pellet in the AMS. A disproportionately large focus has been placed on the AMS pellet, considering that the PMR provides the majority of the dry matter and nutrients consumed. For example, assuming a static dry matter intake (DMI) of 28 kg, the PMR could be estimated to contribute between 89 and 71% of the total dietary dry matter for cows offered three and eight kg of pellet in the AMS (dry matter basis), respectively.

Current survey data suggest that producers with free-flow traffic barns program greater AMS pellet allocations than those with guided-flow traffic barns (Salfer and Endres, 2018). Feeding greater quantities of pellet in the AMS, by default, also indicates the PMR will be less nutrient dense. While this may not be considered to be a problem, recent research has demonstrated that feeding a PMR with a greater proportion of forage increases the ability of cattle to sort that PMR (Menajovsky et al., 2018; Paddick et al., in press). Providing more pellet in the AMS with free-flow barns is typically done because cows can choose when, and if, they voluntarily enter the AMS, whereas with guided flow barns, cows are ultimately directed to the commitment pen and the AMS using automated sorting gates. While the survey data indicate that producers with free-flow barns provide more pellet in the AMS, it is not known whether those cows consume more AMS pellet because the amount actually delivered and the amount consumed are not reported. The difference between the computer programmed value, amount delivered, and amount consumed for the AMS pellet is of major importance and will be discussed subsequently in this paper. Moreover, survey-based studies have neglected to evaluate PMR composition and do not have the ability to evaluate PMR intake at a cow level (Bently et al., 2013; Tremblay et al., 2016; Salfer and Endres, 2018). With single-farm case-studies, many confounding factors may promote a specific response, but the study cannot delineate which one or ones are contributing factors to that response. These confounding factors may or may not be related to the nutritional strategies and as such, data is not robust to apply more broadly. Thus, caution should be applied when considering survey-based data or single-farm case-study data as a means to evaluate potential recommended feeding strategies.

Salfer and Endres (2018) reported that the upper limit for pellet allocation in AMS (computer programmed value) in their survey was 11.3 kg /cow/day. Assuming cows could consume 11.3 kg/day, each cow would need to consume over 2.8 kg/milking (assuming 4 milkings/day) equal to 350 to 400 g/minute if milking duration was between seven and eight minutes. This high rate of pellet feeding may outpace the ability of cows to consume pellet while milking, and likely would result in a significant quantity of pellet that is either not delivered to the cow (Penner et al., 2017) or delivered in the AMS but not consumed by the cow (Bach and Cabrera, 2017).

Unfortunately, there is a lack of data evaluating whether traffic flow truly affects the amount of pellet required to be offered in the AMS. A study conducted in a feed-first, guided-flow barn reported no effect on voluntary attendance or milk yield when the amount of pellet delivered varied from 0.5 to 5.0 kg of DM/day (Paddick et al., in press), whereas similar treatments in a free-flow barn resulted in more frequent voluntary milkings (DM basis; DeVries, personal communication). It would be nice to conclude that these data provide support for allocating greater quantities of AMS pellet under free-flow systems; however, the AMS pellet composition, PMR composition, total DMI, and days in milk also differed between the two studies thereby preventing a direct comparison. Moreover, Bach et al. (2007) reported that the amount of pellet provided in a free-flow system did not affect voluntary attendance or milk yield. As a result, studies should not be interpreted to indicate the absolute amount of pellet provided because the amount likely differs on a farm-to-farm basis.

▪ Does Increasing the AMS Pellet Allocation Increase Voluntary Attendance and Milk Yield?

One of the most common claims with AMS feeding strategies is that increasing the amount of pellet delivered in the AMS will stimulate voluntary attendance and milk yield. The approaches used to increase the AMS pellet allocation should be considered because there are two very different nutritional strategies. First, producers need to decide how much pellet is required from a basal level and this basal amount must consider the formulation of the PMR. Previous studies have been conducted to evaluate how the amount of pellet offered in AMS affects production responses when the total dietary nutrient supply is equivalent. In other words, with this strategy, increasing the amount of pellet provided in the AMS requires an equal reduction in the amount of pellet in the PMR such that the total diet (PMR + AMS) does not differ. The first study published using this nutritional strategy compared treatments with computer programmed values of three or eight kg of pellet in the AMS in a free-flow barn design (Bach et al., 2007). In that study, despite having programmed values of 3 and 8 kg/day, pellet delivery was 2.6 and 6.8 kg/day (dry matter basis) and the amount of pellet delivered did not affect milk production or milk component production. In two recent studies conducted in a guided-flow barn at the University of Saskatchewan, AMS pellet delivery ranged between 0.5 and 5.0 kg of dry matter/cow/day (Hare et al., 2018; Paddick et al., in press). Altering the amount of AMS pellet while maintaining equal dietary nutrient composition did not affect voluntary visits, milk yield or milk component yield. In contrast, a recent study conducted at the University of Guelph in a free-flow barn reported that with total diets (PMR + AMS pellet) that were the same in nutrient composition, increasing the AMS pellet from 3 to 6 kg/day (and correspondingly reducing the same pellet in the PMR), stimulated DMI, increased voluntary visits by 0.5 milkings/day, and numerically (but not significantly) increased milk yield by 1.5 kg/day (DeVries, personal communication).

It might seem counter-intuitive that increasing the AMS pellet allocation does not necessarily stimulate voluntary visits or milk yield. However, simply providing more pellet in the AMS does not necessarily translate to greater DMI. For example, Hare et al. (2018) reported that for every 1 kg increase in AMS pellet delivered, there was a corresponding decrease in PMR DMI of 1.58 kg. Bach et al. (2007) reported a 1.14 kg reduction in PMR DMI and Paddick et al. (in press) reported that PMR DMI decreased by 0.97 kg for every one kg increase in AMS pellet delivered. The large or at least equal reduction in PMR DMI with increasing AMS pellet intake demonstrates that nutrient intake may not be positively affected. In contrast, DeVries (personal communication) reported that for every 1 kg increase in AMS pellet intake there was only a 0.63 kg reduction in PMR DMI (Table 1). In that case, providing more pellet in the AMS resulted in greater total DMI and likely explains the numerical improvement in milk yield observed in that study. The variable and currently unpredictable substitution rate may challenge the ability to formulate diets for individual cows in the same pen given that only the amount or types of pellet in the AMS can differ. It should be noted that the inability to predict the substitution rate (and hence PMR intake) does not preclude imposing such precision feeding programs; we simply cannot evaluate the individual response or adequately predict the outcome. Clearly, this remains a challenge for nutritionists and producers alike.

Table 1. Effect of increasing pellet in the automated milking system (AMS) on the reduction in PMR intake (DM basis).

Study	Days in milk (Average ± SD)	Number of cows, parity, and study design	Traffic flow	Dietary Strategy	Substitution Ratio (kg DM)
Bach et al., 2007	191 ± 2.13	69 Primiparous and 46 Multiparous, Completely randomized	Free	Isocaloric	1.14
Hare et al., 2018	227 ± 25 123 ± 71	5 Multiparous and 3 Primiparous, Cross-over	Guided	Isocaloric	1.58
Menajovsky et al., 2018	141 ± 13.6	8 Multiparous, Replicated 4 × 4 Latin square	Guided	Low Forage PMR High Forage PMR	0.89 0.78
Paddick et al., in press	90.6 ± 9.8	8 Primiparous, Replicated 4 × 4 Latin square	Guided	Isocaloric	0.97
DeVries, personal communication	47.1 ± 15.0	15 Primiparous, Cross-over	Free	Isocaloric	0.62

As a second strategy, the energy density of the diet for an individual cow can be changed by increasing or decreasing the AMS pellet allocation without changing the composition of the PMR. This approach is one strategy to apply precision feeding management. There has been limited research with this strategy; however, in a recent study where cows received two or six kg of AMS pellet (dry matter basis), there were only subtle differences in milking frequency and only numerical improvements for milk and milk protein yield (Menajovsky et al., 2018). At a farm level, Tremblay et al. (2016) reported a negative relationship between the amount of pellet offered in the AMS and milk yield. Their rationale was that poor forage quality requires more pellet; however, there was no information provided on PMR characteristics. To our knowledge, there is still a lack of research focusing on the use of precision feeding strategies, particularly with high-yielding and early lactation cows.

A challenge with adopting precision feeding strategies is that predictions are needed for the amount of PMR and AMS pellet that the cow will consume on a daily basis. The data are clear that increasing the quantity of AMS pellet offered in the AMS increases the day-to-day variability in the consumption of the AMS pellet and hence creates more dietary variability (Hare et al., 2018; Menajovsky et al., 2018; Paddick et al., in press). Based on the available data, the coefficient of variation (CV) in AMS pellet delivered averages 13.5%. Using this CV, we can calculate the standard deviation for AMS pellet delivery by multiplying the amount delivered by the CV (Figure 1). Using this approach, it is clear that as the amount of AMS pellet delivered increases, the day-to-day variation in the amount delivered also increases. In fact, we would expect that the day-to-day variation in the amount of pellet delivered for 96% of the cows would increase from 0.54 kg/day to 2.7 kg/day as the AMS pellet delivered increases from 2 to 10 kg/day. Using a 10 kg/day value and a fixed DMI of 28 kg/day, we would expect that AMS pellet would range between 8.7 and 11.4 kg/day. If we assume that total DMI (AMS pellet + PMR) is relatively constant, the variability in AMS pellet delivery could imply that PMR intake could also vary from 19.4 to 16.7 kg/d. However, the amount of pellet offered in the AMS did not affect PMR intake or variability in PMR intake in previous studies (Menajovsky et al., 2018; Paddick et al., in press).

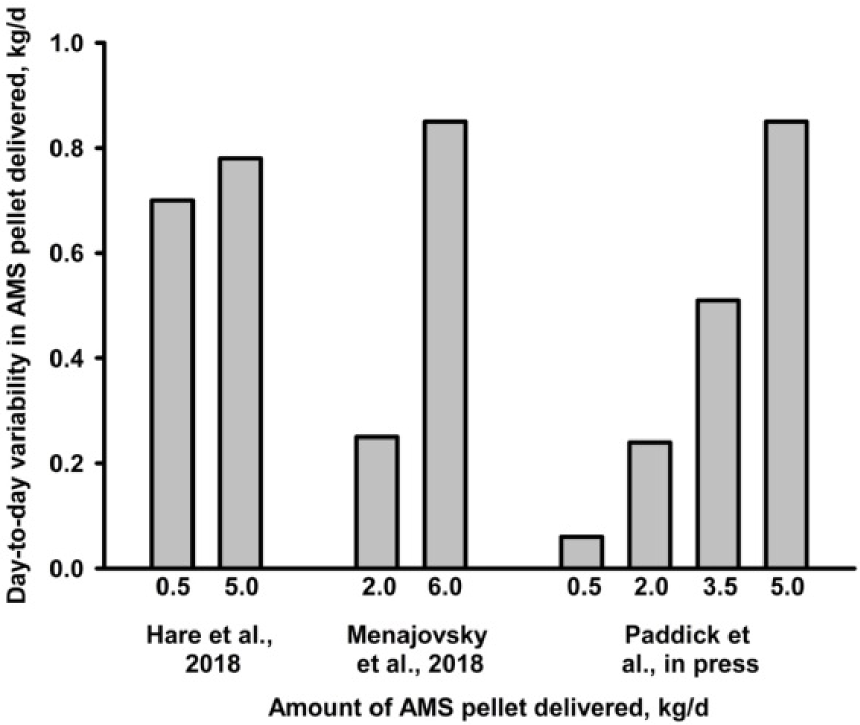

Figure 1. Variability in day-to-day pellet delivered in the AMS based on the amount of pellet offered in the AMS.

While we might expect daily variability in AMS pellet delivered to increase with increased AMS allocation, data from two free-flow traffic herds in Alberta did not show such a response (Figure 2). However, in these data, there was much more variability in the daily amount of AMS pellet delivered with a mean standard deviation of 1 kg/day for an average allocation of 5.5 kg/day (17.4% CV compared with the 13.5% CV listed above). This means that we would expect pellet delivery to range between 4.5 and 6.5 kg/day on average.

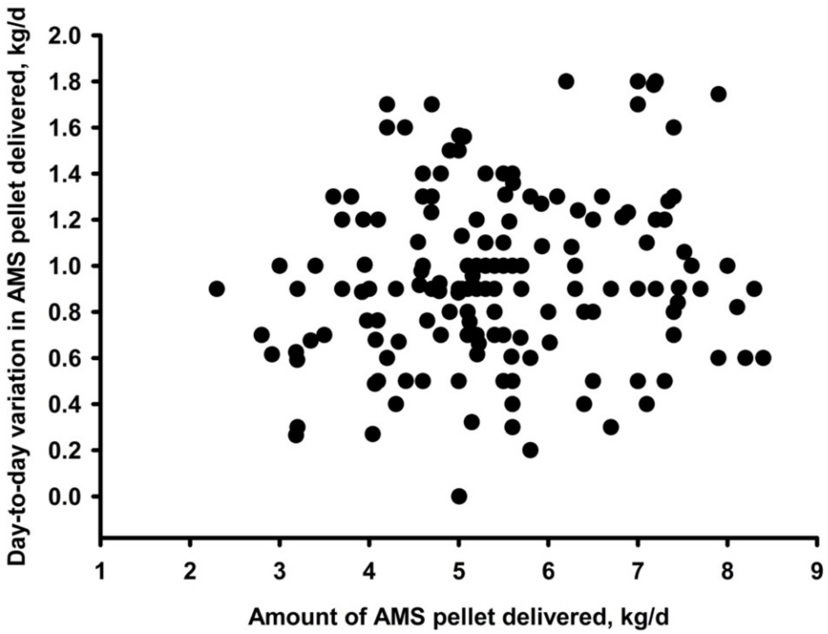

Figure 2. Variability in day-to-day pellet delivered in the AMS in two commercial herds in Alberta.

In the example presented above, a fundamental assumption was that as AMS pellet delivered, and presumably consumed, increased, PMR intake would decrease with equal magnitude. We know this assumption is not true as substitution rates (amount of decrease in PMR intake for every 1 kg increase in AMS pellet intake) range from 0.62 to 1.58 kg (Table 1). Obviously, the reduction in PMR intake with increasing AMS pellet allocation will change the nature of the total diet and depending on the direction and magnitude of the PMR substitution, the proportions of forage neutral detergent fibre (NDF) or physically effective NDF may become marginal coupled with increases in ruminally degradable starch.

In AMS systems, there are three values that are relevant when considering AMS pellet delivery. The first value is the computer programmed target value. This value is the maximum amount that can be offered to cows in the AMS, assuming that carry-over of pellet is not included in the equation. The second value is the amount that is delivered to the cows in the AMS. The third value is the amount consumed in the AMS. The amount of pellet programmed in the computer does not correspond with the amount delivered (Figure 3). For example, Bach et al. (2007) allocated either 3 or 8 kg/day in the AMS but only 2.6 and 6.8 kg/day were delivered, respectively.

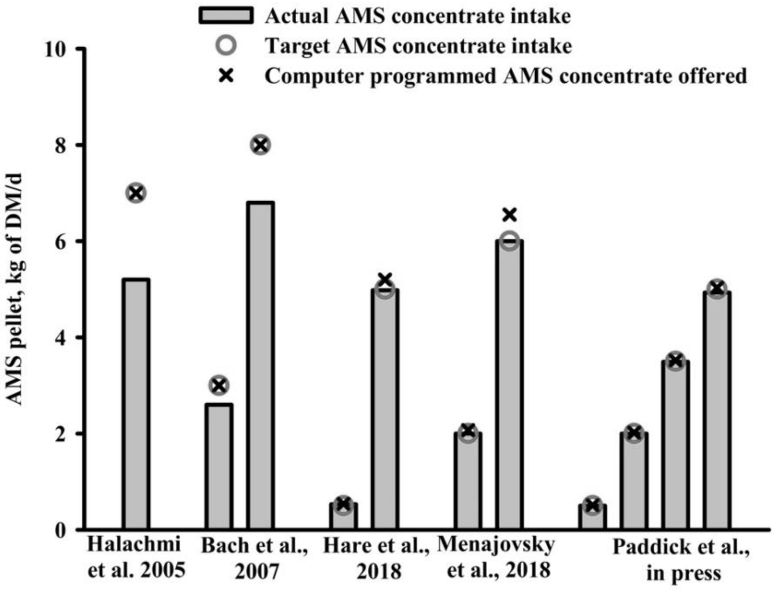

Figure 3. Comparison of computer programmed target AMS pellet allocation and AMS pellet consumption. The circles indicate the target quantity of AMS pellet desired, the 'x' indicate the computer programmed quantity, and the grey vertical bars indicate the average quantity that cows are delivered (adapted from Paddick and Penner, 2018).

Halachmi et al. (2005) offered either 7 kg/day or 1.2 kg/visit to cows and reported that cows offered 7 kg/day were only delivered 5.2 kg/day while those offered 1.2 kg/visit received 3.85 kg/day. Pellet delivery and pellet consumption below that of the formulated diet are major concerns. Evaluating the deviation between the amount programmed and the amount offered is an important management tool because it demonstrates the ability to deliver the formulated diet to the cows. The deviation between the amount programmed and the amount delivered increases as the amount programmed increases (Figure 3). This can also be viewed under commercial settings (Figure 4). The data in Figure 4 were obtained from a commercial free-flow barn in Alberta and demonstrate some important findings.

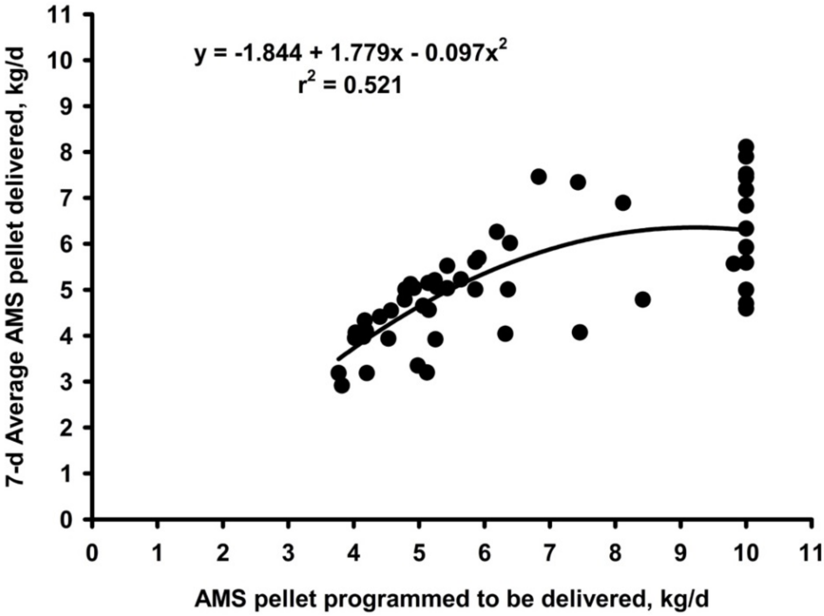

Figure 4. Relationship between the programmed quantity of pellet to be provided in the AMS and the actual amount delivered in a commercial herd in Alberta.

Firstly, in this barn, the average maximum pellet delivered was approximately 6.3 kg in the AMS, although some individual cows were delivered as much as 8.1 kg. It is important to note these maxima as the amount of pellet programmed to be available was 10 kg. Data from this farm also show a similar response as reported by Menajovsky et al. (2018) and Paddick et al. (in press). Specifically, as the quantity of AMS pellet programmed increases, the deviation between the computer programmed quantity and the amount that is delivered increases (Figure 5). Based on a linear regression, we would expect that cows programmed to receive 2.7 kg did in fact receive that quantity, while as the quantity of AMS pellet programmed increased by 1 kg, cows only were delivered an additional 0.62 kg. However, the variability in the difference between the programmed and delivered quantities was very large, particularly at the higher target pellet allowances. While it cannot be evaluated on farm easily, residual pellet left in the AMS feeder also increases with increasing pellet allocation in the AMS (Bach and Cabrera, 2017). Differences among the amount of pellet programmed, amount delivered in the AMS, and amount consumed by cows in the AMS can pose a challenge to dairy producers and their nutritionists, and diminish the ability to formulate diets that reasonably predict production outcomes.

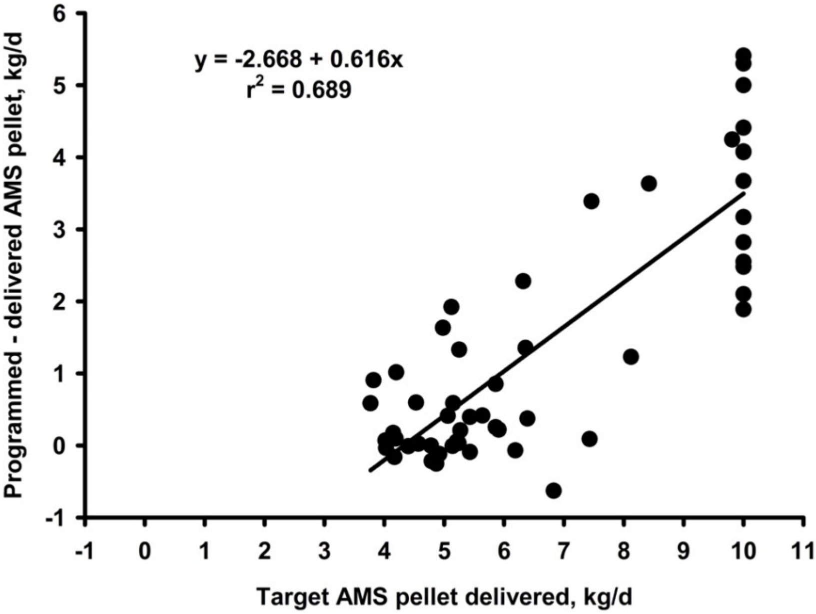

Figure 5. Influence of the amount of AMS pellet programmed for delivery and the difference between the programmed and delivered AMS pellet on a commercial farm in Alberta.

From a nutritional standpoint, minimizing the range in the amount of pellet allocated in the AMS among cows within a group can help to ensure the diet is adequately balanced despite still allowing for differences in the amount of pellet allocated through the AMS. Maintaining a moderate quantity of pellet provided in the AMS can also reduce the bias between the computer programmed amount, amount delivered to the cow in the AMS, and amount consumed by the cow in the AMS. Moderate pellet allocations in the AMS should also minimize day-to-day variability in AMS pellet delivered (Figure 1).

Automated milking systems also enable producers to impose adaptation programs for cows in early lactation. While increasing the energy density of the diet by increasing pellet allocation may seem like a plausible option, recent results suggest that such an approach may actually decrease DMI and milk yield (Deiho et al., 2016). We are not aware of any studies that have evaluated precision feeding strategies to determine whether such approaches improve milk and milk component yield and profitability. Studies that have evaluated fermentability of the diets following parturition have shown that increasing the rate of grain inclusion (Deiho et al., 2016), or increasing fermentability by including more rapidly fermentable grain sources may not be optimal (Albornoz and Allen, 2016). Deiho et al. (2016) reported that cows adapted to a diet that consisted of a concentrate supplement (45% DM basis) with the remainder of the diet consisting of grass silage, corn silage, and soybean meal. Their results showed that increasing concentrate gradually (0.25 kg/day) resulted in greater milk production than increasing concentrate rapidly (1 kg/day increase). Despite the improvement in milk yield, fermentable organic matter intake was less for gradually adapted cows than rapidly adapted cows, suggesting that feeding strategies designed to more closely meet nutrient demand may overwhelm the ability of cows to consume such diets and may not improve performance. Increased concentrate feeding is expected to increase feed costs without the corresponding increase in revenue. Although Albornoz and Allen (2016) used a completely different model, they found that replacement of dry rolled corn with high moisture corn reduced DMI and milk yield. Collectively, these studies highlight the need for future research under AMS conditions.

▪ Is the AMS Pellet Likely to Induce Ruminal Acidosis?

There is often concern about risk for ruminal acidosis with AMS because a component feeding system is imposed and large quantities of pelleted feed may be programmed to be offered through the AMS. We have recently reported that the PMR formulation, rather than the quantity of pellet in the AMS, has a greater impact on ruminal pH (Menajovsky et al., 2018). It is logical that the PMR had greater impact than the AMS pellet considering it accounted for over 80% of the DMI in that study. Additionally, AMS pellet meal size in that study was constrained to a maximum of 2.5 kg and the amount delivered in the AMS was managed to not exceed 6 kg/cow/day on a DM basis. Based on recent information, cows in commercial operations may be provided up to 11.2 kg (as fed basis) of pellet in the AMS (Salfer and Endres, 2018). With this strategy, large swings in dietary composition can occur based on the expected reduction in PMR intake and increased pellet intake in the AMS. Under such scenarios, we could expect that the dietary physically effective NDF content would be dramatically reduced (and potentially deficient) and that ruminally degradable carbohydrate content would increase thereby creating a diet (PMR + AMS pellet) that could be perceived to be high risk for ruminal acidosis. Currently, there are no data to support or dispute the previous claim.

▪ How Important is the Type of Supplement Provided in the AMS?

In addition to general feeding management, palatability of the pellet provided in the AMS is also important. Madsen et al. (2010) evaluated pellets containing barley, wheat, a barley-oat mix, maize, artificially dried grass, or pellets with added lipid with all cows fed a common PMR. They observed that AMS pellet intake and voluntary visits were greatest when the pellets contained the wheat or the barley-oat mix. However, pelleted barley and wheat are expected to have a rapid rate of fermentation in the rumen and feeding substantial quantities would be expected to increase the risk for low ruminal pH. To reduce fermentability, pellets could be prepared with low-starch alternatives (Miron et al., 2004; Halamachi et al., 2006 and 2009). Substituting starch sources with soyhulls did not negatively affect voluntary attendance at the AMS or milk yield (Halamachi et al., 2006, 2009), and may slightly improve milk fat and reduce milk protein concentrations (Miron et al., 2004).

Producers may also choose to use home-grown feeds in the AMS. In a recent study, we tested whether feeding a pellet was required or if we could deliver steam-flaked barley as an alternative (Gardner et al., unpublished) in a feed-first guided-traffic flow barn. In that study, the pellet comprised only barley grain and the same source of barley grain was used for the steam-flaked treatment. In all cases, cows were programmed to have 2.0 kg of the concentrate in the AMS delivered. While PMR (27.0 kg/d DM basis) and AMS concentrate intake (1.99 kg/d DM basis) did not differ among treatments, cows fed the steam-flaked barley tended to have fewer visits (2.99 vs. 2.83; $P = 0.07$) to the AMS, tended to have a longer interval between milking events (488 vs. 542 minutes; $P = 0.10$), and spent 28 minutes more in the commitment pen prior to entering the AMS ($P = 0.01$) than those fed pelleted barley. While this did not translate into differences in milk yield (average of 44.9 L/d), it may be expected that with a longer-term study, production impacts would be observed. In contrast, Henriksen et al. (2018) reported greater voluntary visits when a texturized feed (combination of pellet and steam-rolled barley) was provided in comparison to a pellet alone. Regardless, utilization of a pellet as the sole ingredient or part of the mix may limit the ability of producers to use home-grown feeds in the AMS.

▪ Partial Mixed Ration: the major, but forgotten component of the diet

As mentioned previously, all surveys published to date focus on AMS feeding with little or no information collected to describe PMR composition or intake. The lack of focus on the PMR is likely because only group intakes can be determined and many of the studies have been conducted using retrospective analysis. However, drawing conclusions or making recommendations for feeding management without considering the PMR could lead to erroneous decisions. We recently completed a study where we varied the formulation of the PMR such that we increased the energy density of the PMR by a similar magnitude to that commonly used when increasing the amount of pellet in the

AMS (Menajovsky et al., 2018). Feeding the PMR with a greater energy density tended to increase milk yield (39.2 vs. 37.9 kg/d; P = 0.10) likely because of greater energy supply. In several studies we have also noted that formulation of the PMR impacts sorting characteristics of the PMR (Menajovsky et al., 2018; Paddick et al., in press). In both cases, reducing the energy density of the PMR (greater forage content as a percentage of DM) increased the sorting potential of the PMR. This may lead to cows selecting for dietary components in an undesirable manner (Miller-Cushon and DeVries, 2017). Research is needed to understand how PMR composition can affect the ability to stimulate voluntary visits and to meet nutrient requirements for cows milked with AMS.

Conclusions

The use of AMS systems is increasing in Canada and sound feeding management practices are needed to support efficient and cost-effective milk production. The data that are available do not support the recommendation that feeding greater quantities of pellet in the AMS will result in greater milk production, likely because of the overall shift in the diet as cows substitute PMR for pellet. Moreover, feeding to meet milk production by increasing AMS pellet provision may not result in the expected benefits, again potentially because of a reduction in PMR intake and the potential shifts in dietary forage-to-concentrate ratio when both the PMR and AMS pellet are considered. Our data suggest that low-to-moderate AMS pellet provision will help minimize variability in AMS pellet intake and, therefore, allow cows to consume diets more similar to that formulated. Low-to-moderate AMS pellet provision may also allow for greater flexibility for the pellet composition provided in the AMS. Regardless of the strategy employed, producers must not only consider the AMS feeding strategy, but also the interaction between AMS feeding approaches and PMR consumption.

References

Bach, A., and V. Cabrera. 2017. Robotic milking: Feeding strategies and economic returns. J. Dairy Sci. 100:7720-7728.

Bach, A., C. Iglesias, S. Calsamiglia, and M. Devant. 2007. Effect of amount of concentrate offered in automatic milking systems on milking frequency, feeding behavior, and milk production of dairy cattle consuming high amounts of corn silage. J. Dairy Sci. 90:5049-5055.

Bently, J.A., L.F. Tranel, L. Timms, and K. Schulte. 2013. Automated milking systems (AMS) – Producer surveys. Animal Industry report (AS 659). http://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=1826&context=ans_air. Accessed April 10, 2016.

Dieho, K., A. Bannink, A.L. Guerts, J.T. Schonewille, G. Gort, and J. Dijkstra. 2016. Morphological adaptation of rumen papillae during the dry period

and early lactation as affected by rate of increase of concentrate allowance. J. Dairy Sci. 99:2339-2352.
Halachmi, I., S. Ofir, and J. Miron. 2005. Comparing two concentrate allowances in an automatic milking system. Anim. Sci. 80:339-343.
Halamachi, I., E. Shoshani, R. Solomon, E. Maltz, and J. Miron. 2006. Feeding of pellets rich in digestible neutral detergent fiber to lactating cows in an automatic milking system. J. Dairy Sci. 89: 3241-3249.
Halamachi, I., E. Shoshani, R. Solomon, E. Maltz, and J. Miron. 2009. Feeding soyhulls to high-yielding dairy cows increased milk production but not milking frequency, in an automatic milking system. J. Dairy Sci. 92:2317-2325.
Hare, K., T. DeVries, K. Schwartzkopf-Genswein, and G.B. Penner. 2018. Does the location of concentrate provision affect voluntary visits, and milk and milk component yield for cows in an automated milking system? Can. J. Anim. Sci. 98:399-404.
Henriksen, J.C.S., L. Munksgaard, and M.R. Weisbjerg. 2018. Short-term responses in production and behavior during periods of change in concentrate allowance for dairy cows. J. Dairy Sci. 101:7942-7953.
Madsen, J., M.R. Weisbjerg, and T. Hvelplund. 2010. Concentrate composition for automatic milking systems – Effect on milking frequency. Livest. Sci. 127:45-50.
Menajovsky S.B., C.E. Walpole, T.J. DeVries, K.S. Schwartzkopf-Genswein, M.E. Walpole, and G.B. Penner. 2018. The effect of the forage-to-concentrate ratio of the partial mixed ration (PMR) and the quantity of concentrate in an automatic milking system (AMS) for lactating Holstein cows. J. Dairy Sci. 101:9941-9953.
Migliorati L., M. Speroni, S. Calogero, and G. Pirlo. 2009. Influence of feeding flavouring-appetizing substances on activity of cows in an automatic milking system. Ital. J. Anim. Sci. 8:417-419.
Migliorati, L., M. Speroni, S. Lolli, and F. Calza. 2005. Effect of concentrate feeding on milking frequency and milk yield in an automatic milking system. Ital. J. Anim. Sci. 4:221-223.
Miller-Cushon, E.K., and T.J. DeVries. 2017. Feed sorting in dairy cattle: Causes, consequences, and management. J. Dairy Sci. 100:4172-4183. doi:10.3168/JDS.2016-11983.
Miron, J., E. Yosef, M. Nikbachat, A. Zenou, E. Maltz, I. Halachmi, and D. Ben-Ghedalia. 2004. Feeding behavior and performance of dairy cows fed pelleted nonroughage fiber byproducts. J. Dairy Sci. 87:1372-1379.
Miron, J., M. Nikbachat, A. Zenou, D. Ben-Ghedalia, R. Solomon, E. Shoshani, I. Halamachi, N. Livshin, A. Antler, and E. Maltz. 2004. Lactation performance and feeding behavior of dairy cows supplemented via automatic feeders with soy hulls or barley-based pellets. J. Dairy Sci. 87:3808-3815.
Paddick, K.S., T.J. DeVries, K. Schwartzkopf-Genswein, M.A. Steele, M.E. Walpole, and G.B. Penner. 2019. Effect of the amount of concentrate offered in an automated milking system on milk yield, milk composition,

ruminal digestion, and behavior of primiparous Holstein cows fed iso-caloric diets. J. Dairy Sci. In press.

Salfer, J., and M. Endres. 2018. Feeding and management practices for robotic milking success. Proc. 4-State Dairy Nutrition Conference. pp. 77-80. June 13 and 14. Debuque, Iowa, USA.

Tremblay, M., J.P. Hess, B.M. Christenson, K.K. McIntyre, B. Smink, A.J. van der Kamp, L.G. de Jong, and D. Döpfer. 2016. Factors associated with increased milk production for automatic milking systems. J. Dairy Sci. 99:3824–3837. doi:10.3168/jds.2015-10152.