Nutritional Opportunities and Challenges with Robot Milked Cows

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Introduction

With continued increases in the adoption of automated (robotic) milking systems (AMS), we have experienced a fundamental shift in nutritional management, with the division of the ration into a partial mixed ration (PMR) and the AMS pellet. In addition, the composition 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 limited controlled research regarding feeding management have led to many 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, and this paper will describe the current state of knowledge along with areas where research is needed.

Varied Concepts in Feeding Management in AMS Herds

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, and potentially some opportunity, 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.

Some 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., 2019). 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 necessarily known nor reported. The difference between the computer programmed value, amount delivered, and amount consumed for the AMS pellet is of major importance. 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). Thus, caution should be applied when considering survey-based 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/d. Assuming cows could consume 11.3 kg/d, each cow would need to consume over 2.8 kg/milking (assuming 4 milkings/day) equal to 350 to 400 g/min 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/d (Paddick et al., 2019), whereas similar treatments in a free-flow barn resulted in more frequent voluntary milkings (Schwanke et al., 2019). One might 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.

Effect of AMS Pellet Allocation on DMI, Voluntary Milking, 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. Studies have been conducted in the past 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/d, pellet delivery was 2.6 and 6.8 kg/d (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 feed first guided-flow barn at the University of Saskatchewan, AMS pellet delivery ranged between 0.5 and 5.0 kg of dry matter/cow/d (Hare et al., 2018; Paddick et al., 2019). 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, in a recent study conducted at the University of Guelph in a free-flow barn, it was reported that with total diets (PMR + AMS pellet) that were the same in nutrient composition, increasing the AMS pellet from 3 to 6 kg/d (and correspondingly reducing the same pellet in the PMR), stimulated greater DMI (+1.3 kg/d), increased voluntary visits by 0.5 milkings/d, and numerically increased milk yield by 1.5 kg/d (Schwanke et al., 2019). In a similar study at the same facility, Schwanke et al. (2022) demonstrated that by increasing AMS pellet (6 vs 3 kg/d) when cows were fed the same PMR, cows again demonstrated greater total DMI (+1.3 kg/d) and numeric increase in milk yield (+1.6 kg/d)

It might seem counter-intuitive that increasing the AMS pellet allocation does not necessarily stimulate voluntary visits or milk yield in all situations. However, simply providing more pellet in the AMS does not necessarily translate to greater DMI, as cows will generally eat to a set level of intake based on BW and requirements (including production and DIM).. 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. (2019) 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. These effects of greater concentrate consumption in the AMS and subsequent PMR substitution rate may also vary due to the energy density of the PMR; Menajovsky et al. (2018) reported a 0.78 and 0.89 kg/d reduction of PMR for every 1 kg of concentrate, depending on PMR energy density (low or high). In contrast, in Schwanke et al. (2019) and (2022) it was reported that for every 1 kg increase in AMS pellet intake there was only a 0.63 kg and 0.54 kg, respective, reduction in PMR DMI (Table 1).

In those two later cases, providing more pellet in the AMS resulted in greater total DMI and likely explains their numerical improvement in milk yield. Across studies, 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.

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

Study	DIM (mean ± SD)	Cows, parity, and study design	Traffic and diet, dietary scenario	Substitution ratio, kg PMR/kg AMS concentrate
Bach et al., 2007	191 ± 2.13	69 primiparous Holstein, 46 multiparous Holstein Completely randomized design	Free Isocaloric	1.14
Hare et al., 2018	227 ± 25 123 ± 71	5 multiparous Holstein 3 primiparous Holstein	Guided Isocaloric	1.58
Henriksen et al., 2018	32-320 14-330	22 primiparous Holstein, 19 multiparous Holstein 11-week study	Free Static PMR with 2 concentrate	0.58 – 0.92
Henriksen et al., 2018	29-218 17-267	14 primiparous Jersey 28 multiparous Jersey 11-week study	Free Static PMR with 2 concentrate allocations	0.69-0.50
Menajovsky et al., 2018	141 ± 13.6	8 multiparous Holstein Replicated 4x4 Latin square	Guided Low energy PMR High energy PMR	0.89 0.78
Henriksen et al., 2019	Early (5 to 14) Mid (15 to 240) Late (241 to 305)	128 cows (68 Holstein + 60 Jersey) Continuous lactation study	Free Static PMR with 2 differing concentrate allocations	5 1.1 2.9
Paddick et al., 2019	90.6 ± 9.8	8 primiparous Holstein Replicated 4x4 Latin square	Guided Isocaloric	0.97
Schwanke et al., 2019	47.1 ± 15.0	15 primiparous Holstein cows, crossover design	Free, Isocaloric	0.63
Schwanke et al., 2022	123.9 ± 53.2	14 muliparous, 1 primiparous Holstein cows, crossover design	Free, static PMR	0.54

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 2 or 6 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., 2019; Schwanke et al., 2019). Based on the available data, the coefficient of variation (CV) in AMS pellet delivered averages 13.5%.

In most studies, a fundamental assumption is that as AMS pellet delivered, and presumably consumed, increased, PMR intake would decrease with an 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 0.54 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. For example, Bach et al. (2007) allocated either 3 or 8 kg/d in the AMS but only 2.6 and 6.8 kg/d were delivered, respectively. Halachmi et al. (2005) offered either 7 kg/d or 1.2 kg/visit to cows and reported that cows offered 7 kg/d were only delivered 5.2 kg/d while those offered 1.2 kg/visit received 3.85 kg/d. 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. 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.

Type of Supplement Provided in the AMS

Another factor which influences the amount of feed provided and consumed in the AMS is it composition, palatability and physical form. The rate of consumption of various feeds may limit the amount which may be consumed in the AMS. It is well established that eating rates vary with physical form of concentrate. For example, Kertz et al. (1981) demonstrated that a 4mm pellet was consumed by cows quicker than a pellet with cracked corn, a crumbled pellet, and a meal (in that order), with a maximal rate of consumption of ~430 g/min of the pellet. Pellet consumption rate in other studies has averaged 265 g/min (Beauchemin et al., 2002) and 199 g/min (Maekawa et al., 2002). Sporndly and Asberg (2006) recording concentrate intake rates of up to 200 g/min, with preferences of pellets to ground grain. Additionally, Harper et al. (2016) recorded eating rates varying from 223 - 312 g/min of non-pelletized concentrates with various flavors. Across the literature, it appears that the ‘average’ cow consumes concentrate at ~250 g/min. In a typical 7 min milking, this would equate to 1.75 kg/milking that the average cow can consume in concentrate. Thus, with a target of ~3 milkings per day, the ‘average’ cow would be expected to be able to consume ~5 to 5.5 kg/d of feed in the AMS.

The palatability of the pellet provided in the AMS may also be important. Madsen et al. (2010) evaluated pellets containing barley, wheat, a barley-oat mix, maize, artificially dried grass, or pellets with added fat, with all cows fed a common PMR. Those researchers 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; 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 more recent study at the University of Saskatchewan, it was tested whether feeding a pellet was required or if they could deliver steam-flaked barley as an alternative (Johnson et al., 2022) 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 had fewer visits (2.71 vs 2.90 visits/d) to the AMS, tended to have a longer interval between milking events (541.7 vs. 505.8 min), and spent more time in the commitment pen prior to entering the AMS (139.9 vs. 81.2 min/d) than those fed pelleted barley. While this did not translate into differences in milk yield (average of 44 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.

Management of the Partial Mixed Ration

As mentioned above, all surveys that have been 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 may lead to erroneous decisions. We 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) likely because of greater energy supply.

Management of the PMR may be a key factor in success of AMS, largely due to the fact that milking activity in AMS is largely tied to PMR feeding activity (DeVries et al., 2011; Deming et al., 2013). Stimulation of PMR eating behavior, through frequent feed delivery and push up across the day may, thus, be important for optimizing AMS usage. Interestingly, in recent observational study of AMS herds, Siewert et al. (2018) reported that 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 an even 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.

Early lactation challenges?

Automated milking systems provide the ability to milk and feed cows individually based on production potential and stage of lactation. However, individualized milking may not only lead to more frequent milking and greater milk yield in early lactation, but may lead to issues with negative energy balance and metabolic disorders. Tatone et al. (2017) reported that AMS herds in Ontario, Canada had higher within-herd prevalence of SCK (26%; as measured through milk ketone levels) than did conventional herds (21%). Those researchers also reported that multiparous cows in AMS herds were more likely to have SCK than in conventional herds (Tatone et al., 2017). Higher SCK prevalence may be the result of increased frequency of milking during early lactation or inadequate supplemental feeding of concentrates in the robot. In a field study King et al. (2018) reported that development of SCK in AMS cows was associated with greater production of milk relative to the amount of feed consumed in the AMS, suggesting that inadequate supplementation was potentially occurring at that time. This provides evidence that robot feed supplementation must be based on stage of lactation and production level. Alternative and additional energy sources may also be beneficial in early lactation. Specifically, alternatives to starch (to improve rumen conditions) including sugars and other gluconeogenic precursors may have benefits. As one example, 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).

Conclusions

The adoption of AMS systems continues to rise and sound feeding management practices are needed to support efficient and cost-effective milk production. Feeding strategy in AMS herds must take into account the stage of lactation and production level, as well as the behavioral capabilities of dairy cows. It is well established that the feeding strategy at the AMS will impact PMR consumption levels, thus this needs to be accounted for when formulating dietary plans. Finally, encouraging PMR feeding will help drive total intake and milking activity.

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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.

Beauchemin, K. A., M. Maekawa, and D. A. Christensen. 2002. Effect of diet and parity on meal patterns of lactating dairy cows. Can. J. Anim. Sci. 82:215–223.

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.

Deming, J.A., R. Bergeron, K.E. Leslie, and T.J. DeVries. 2013. Associations of housing, management, milking activity, and standing and lying behavior of dairy cows milked in automatic systems. J. Dairy Sci. 96:344-351.

DeVries, T. J., J. A. Deming, J. Rodenburg, G. Seguin, K. E. Leslie, H. W. Barkema. 2011. Association of standing and lying behavior patterns and incidence of intramammary infection in dairy cows milked with an automated system. J. Dairy Sci. 94:3845-3855

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.

Harper, M. T., J. Oh, F. Giallongo, J. C. Lopes, H. L. Weeks, J. Faugeron, and A. N. Hristov. 2016. Preference for flavored concentrate premixes by dairy cows. J. Dairy Sci. 99:6585–6589. http://dx.doi.org/10.3168/jds.2016-11001

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.

Henriksen, J.C.S., M.R. Weisbjerg, P. Løvendahl, T. Kristensen, and L. Munksgaard. 2019. Effects of an individual cow concentrate strategy on production and behavior. J. Dairy Sci. 102:2155-2172.

Johnson, J. A., K. S. Paddick, M. Gardner, G. B.Penner. 2022. Comparing steam-flaked and pelleted barley grain in a feed-first guided-flow automated milking system for Holstein cows. J. Dairy Sci. 105:221-230.

Kertz, A. F., B. K. Darcy, and L. R. Prewitt. 1981. Eating rate of lactating cows fed four physical forms of the same grain ration. J. Dairy Sci. 64:2388–2391.

Maekawa, M., K. A. Beauchemin, and D. A. Christensen. 2002. Effect of concentrate level and feeding management on chewing activities, saliva production, and ruminal pH of lactating dairy cows. J. Dairy Sci. 85:1165–1175

Madsen, J., M.R. Weisbjerg, and T. Hvelplund. 2010. Concentrate composition for automatic milking systems – Effect on milking frequency. Livest. Sci. 127:45-50.

Matson, R. D., M. T. M. King, T. F. Duffield, D. E. Santschi, K. Orsel, E. A. Pajor, G. B. Penner, T. Mutsvangwa, and T. J. DeVries. 2021. Benchmarking of farms with automated milking systems in Canada and associations with milk production and quality. J. Dairy Sci. 104:7971–7983.

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.

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.

Moore, S. M., M. T. M. King, A. J. Carpenter, and T. J. DeVries. 2020. Behavior, health, and productivity of early-lactation dairy cows supplemented with molasses in automated milking systems. J. Dairy Sci. 103:10506-10518. https://doi.org/10.3168/jds.2020-18649

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. 102: 2173–2187.

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.

Schwanke, A.J., K.M. Dancy, T. Didry, G.B. Penner, and T.J. DeVries. 2019. Effects of concentrate location on the behavior and production of dairy cows milked in a free-traffic automated milking system. J. Dairy Sci. 102:9827-9841.

Schwanke, A.J., K.M. Dancy, H.W. Neave, G.B. Penner, R. Bergeron, and T.J. DeVries. 2022. Effects of concentrate allowance and individual dairy cow personality traits on the behavior and production of dairy cows milked in a free-traffic automated milking system. J. Dairy Sci. 105:6290-6306.

Siewert, J.M., J.A. Salfer, and M.I. Endres. 2018. Factors associated with productivity on automated milking system dairy farms in the Upper Midwest United States. J. Dairy Sci. 101:8327-8334.

Sporndly, E. and T. Asberg. 2006. Eating rate and preference of different concentrate components for cattle. J. Dairy Sci. 89:2188–2199.

Tatone, E. H., T. F. Duffield, S. J. LeBlanc, T. J. DeVries, and J. L. Gordon. 2017. Investigating the within-herd prevalence and risk factors for ketosis in dairy cattle in Ontario as diagnosed by the test-day concentration of β-hydroxybutyrate in milk. J. Dairy Sci. 100:1308-1318. http://dx.doi.org/10.3168/jds.2016-11453

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.