Designing Feeding Systems for Robotic Milking

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Summary

Feed, is the primary motivation for the cow to visit the robotic milking stall. Highly motivated cows will visit voluntarily, thereby decreasing the need to expend labor fetching cows, and they will visit more frequently and regularly, leading to higher milk production. Forced cow traffic makes it possible to use forage at the bunk to provide motivation, and while it reduces the number of fetch cows, it decreases the number of meals, decreases feed intake in some studies,, and decreases cow welfare because of increased standing time. Free cow traffic provides greater cow comfort and is preferred, but motivation to visit the robot is provided solely by the concentrate fed in the milking box. Hard, dust free pellets made of palatable ingredients, such as barley and oats, fed at a rate of 5 to 17 lb/day result in the highest visit frequency and highest milk production. Limiting the energy density and starch level in the mixed ration fed at the bunk also increases the motivation provided by the concentrate. Current recommendations suggest feeding a partial mixed ration formulated for a production level 15 lb below the mean of the group, combined with 5 to 17 lb of pelleted concentrate fed according to production in the robotic milking stall. While the need to use feed to stimulate milking visits creates additional challenges for the nutritionist and feed advisor, the ability to collect a great deal of data on the individual cow and to feed and supplement her individually also creates many new opportunities for more precise and individualized ration delivery.

Introduction

Robotic milking is being accepted as a viable alternative to milking parlors throughout the developed world. In areas such as Western Europe and Scandinavia where labor costs are high and farms sizes are moderate, robotic systems have become the favored choice for new milking equipment purchasers. As labor costs and the complexity of labor management increase in North America and as the cost and challenges of managing robotic systems decline, robotic milking is earning its place as a viable option here as well. Currently, an estimated 500 dairy farms in North America are milking with either the Lely Astronaut (Lely USA Inc., Pella, Iowa) or the DeLaval VMS (DeLaval Inc., Kansas City, Missouri) system, in herds ranging in size from 40 to 1200 cows. Both of these systems use a single milking stall, which the cow visits voluntarily. In both systems, the primary motivation for cows to visit the stall is her desire and need to eat. The feed that attracts her can be in the concentrate feeder in the milking box, or with forced traffic, from this concentrate in combination with the feed at the bunk which is only accessible en route through or past the milking stall. Health concerns, particularly problems with locomotion, reduce visits to the milking stall and may be influenced by the diet. Greater milking frequency and more uniform milking times resulting from more visits to the milking stall increase milk production. Hence, feeding management takes on a more complex and important role in the robotic dairy farm than it had with conventional parlor milking. A

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completely different approach to feeding is required. When nutrition advisors fail to recognize this, new robotic milking herd start ups often have very disappointing results.

Goals in Feeding the Robotic Dairy

The goals of traditional dairy feeding programs include meeting the nutritional requirements of the cow in a way that ensures that she stays healthy, using feed ingredients that are economical, and using labor efficient and cost effective feed delivery systems. With robotic milking, there is a very important fifth goal: enticing the cow to visit the robotic milking stall regularly and frequently.

The Performance Spiral When Milking is Voluntary

Interactions among the activity or behavior of the dairy cow; her diet and feed consumption; her health; and her milk production are complex and become even more complex with voluntary milking. Part of the complexity among these relationships is that none can claim to be distinctly "cause" and none is distinctly "effect". For example, standard feeding management advice encourages producers to provide fresh feed more often, to stimulate a change in behavior, in the form of more frequent meals. This change in behavior is predicted to "cause" a change in diet, in the form of higher feed intake, which subsequently "causes" higher milk production. Alternatively, diet may drive behavior; when a low fiber, high grain ration is blamed for a high incidence of lameness, "causing" a change in behavior in the form of fewer trips to the feed bunk, it subsequently "caused" lower feed intake and lower production. But, when 3x milking elicits an 8 to 12 lb production response, higher production "causes" greater feed intake. In these examples, each of the 4 attributes (behavior, diet, health, and production) is "cause" in some cases and effect in others. When cows are milked at fixed intervals, external control of the "milking frequency" variable may limit variation in the other attributes. For example, under conditions of heat stress, cows reduce their activity and reduce their feed intake. Production suffers, but twice daily milking provides a baseline stimulus for production. Robotic milking is voluntary and variable, adding a new dimension to these interactions. If hot weather reduces activity, it results in both lower feed intake and reduced milking frequency. Without a fixed, milking interval, heat stress in the robotic herd could start a downward spiral of reduced interest in feed, leading to less frequent milking, leading to lower production, and in turn, even less interest in feed, etc. Based on this example, feeding management and an understanding of the interactions between diet, behavior, health, and production take on a greater importance when robotic milking is considered.

Using Feed as an Enticer for Robotic Milking

Early research with robotic milking showed that without a feed incentive, voluntary attendance at the milking stall is poor and highly variable. Feeding concentrate in the milking box, or forage or concentrate after passing through the milking box (forced cow traffic), improves attendance for milking. Although all commercial robotic systems currently offer concentrate in the milking box, and some use a form of forced cow traffic, failure of some cows to attend voluntarily remains a concern. The number of cows which must be fetched has been reported to be as low as 6% (Van't Land et al., 2000) on Dutch farms and as high as 19% on commercial farms in Ontario (Rodenburg and Wheeler, 2002). In recent years, design improvements that have made the cow more comfortable in the milking stall, such as more space and the removal of the butt plate and adjustable manger in some models, has improved milking frequency and reduced the number of cows fetched. In systems that still use these space limiting devices, adjusting them properly is an important factor in improving voluntary attendance.

A general understanding of eating behavior is useful for assessing how eating is altered by robotic milking feeding strategies. Dado and Allen (1994) reported that cows in a tiestall barn spent 300 min/day eating, and 11 meals of 5.1 lb for high producers and 3.7 lb for low producers. These cows drank water 14 times per day, while cows in loose housing (Andersson, 1987) drank 6.6 times per day. In a freestall setting, cows consumed 12.1 meals of TMR daily (Vasilatos and Wangsness, 1980).

Forced Versus Free Cow Traffic

Numerous studies have shown that attendance, while no longer "voluntary" in the pure sense, can be improved by forcing the cow to enter the robotic milking stall or an associated selection gate en route from the resting area to the feed manger or on her return from the manger to the resting area. This is commonly referred to as "forced" cow traffic. There are at least 4 common variations of "cow traffic" strategies used in robotic milking herds today: (1) Free cow traffic, where cows can access feeding and resting areas of the barn with no restriction; (2) Forced cow traffic with one- way gates blocking the route from the resting area from the feeding area so cows leaving the resting area must enter the milking box to be milked if the interval since the last milking makes her eligible or "refused" if the milking interval is too short. After passing through the milking stall, the cow is released to the feeding area and can only return to the resting area through a one-way gate; (3) Forced cow traffic with "pre-selection" adds an entry lane where a sort gate directs cows eligible for milking to the holding area and ineligible cows to the feeding area. This reduces waiting times for milking and for feed because only cows eligible for milking pass through the milking stall. Pre-selection can also be provided by selection gates in crossovers away from the robot, which open only for cows ineligible for milking; and (4) Feed first forced traffic is a reversal of (2) which allows cows access to the manger from the resting area via one-way gates, but they can only return to the resting area through the robotic milking stall or through pre-selection gates that direct cows ineligible for milking directly to the free stalls or bedding pack.

Numerous studies report slightly higher milking frequency and a much-reduced need to fetch cows with forced traffic (Hogeveen et al., 1998; Van't Land et al., 2000). Harms et al. (2002) reported 2.29, 2.63, and 2.56 milkings and 15.2, 3.8, and 4.3 fetching acts per day with 49 cows in free, forced, and forced with pre-select traffic, respectively. The number of meals was higher at 8.9 with free cow traffic than with either forced or forced with pre-select, when cows consumed 6.6 and 7.4 meals, respectively. Forage intake decreased when cows were switched to forced traffic and went back up in the forced with pre-select phase. Thune et al. (2002) reported 1.98, 2.56, and 2.39 milkings and 12.07, 3.86, and 6.46 feeding periods with free, forced, and forced with pre-selection traffic, respectively. On 7 Ontario farms with forced cow traffic (Rodenburg and Wheeler, 2002), the average number of daily visits per cow, and therefore visits to the manger to consume TMR, was 3.40 ± 0.44. This is many meals fewer than the 12.1/day reported in a trial with free access and parlor milking (Vasilatos and Wangsness, 1980). Fewer meals are associated with lower dry matter **(DM)** intake (Dado and Allen, 1994), and forced cow traffic has been shown to have this effect (Prescott et al., 1998). Pre-selection systems result in some improvement in feed access, but the number of meals remains lower than with free traffic. Cows in a forced traffic situation also spend more time waiting for milking and less time lying down (Winter and Hillerton, 1995). It is also of some concern that when a cow is in pain from a clinical case of mastitis or when she is lame, she will avoid milking in a free traffic situation, and this alerts the herdsman to her plight. Faced with the choice of starvation or milking, this cow is more likely to go unnoticed in a forced traffic setting.

In the most recent comprehensive comparison for the 2 traffic systems (Bach et. al., 2007), cows were fed a partial mixed ration and up to 6.6 lb of concentrate in the milking stall. The results summarized in Table 1 illustrate that milking behavior, eating behavior, and milk composition were all influenced by the choice of traffic system, but total DM intake and milk production were similar.

From a feeding standpoint, forced traffic reduces the need to provide highly palatable feed in the robotic milking stall. As long as there is no alternative, most cows will go through the robotic milking stall out of sheer need to consume the ration at the feed manger, but reduced number of meals, reduced feed intake, reduced resting time, and longer waiting times, especially for timid cows, make this system less desirable from the stand point of cow welfare and long-term productivity.

With current technology, there are numerous examples of robotic milking herds with free traffic that report over 3 milkings per day and very few fetch cows, and there are also numerous examples of forced traffic herds that report high feed intake, good production, and few health issues. This demonstrates that both systems can work successfully under ideal circumstances. But, when less than ideal conditions prevail with a free traffic system, the dairy farmer suffers the consequences in the form of fewer milkings and more fetch cows. With forced traffic, the cows suffer the consequences with lower feed intake and longer waiting times. Since problems are much more likely to be resolved quickly when the dairy farmer suffers, free cow traffic is the preferable management system.

Feeding Concentrate in the Milking Box

The typical eating rate for pelleted concentrates is 0.45 to 0.65 lb/min. Since cows spend 6 to 8 minutes in the stall per milking, maximum concentrate fed during milking is 2.5 to 3.5 lb, or 7.5 to 10.5 lb/day for a cow visiting 3 times. Some herds are successfully increasing pellet delivery rates in the robot to as much as 1 lb/min. and 18 lb/day without seeing feed left behind. Additional grain is usually fed as part of a mixed ration in the manger or in individual feeders in the barn. The use of computer feeders with robotic milking can be organized strategically so that cows that require additional concentrate can receive it in computer feeders. These feeders can be linked to the milking software so that cows can only use them while they are ineligible for milking, or they can be located in a special exit area from the robot to further encourage traffic to the milking stall.

The concentrate fed in the milking stall is the "candy" that attracts the cow to come to the stall frequently for milking. More frequent milking shortens milking intervals and decreases variation in milking interval. Both of these outcomes increase milk production. Having fewer cows to fetch reduces labor for the operator.

The importance of feeding palatable concentrate in the milking stall is illustrated by a case study on one Ontario farm (Rodenburg and Wheeler, 2002). Initially, a low cost pellet formulated with lower palatability ingredients, and including gluten meal, canola, and tallow were fed. Poor pellet strength caused a build up of fines in the bottom of the feeders. A stronger pellet of high palatability containing 3 (vs. 0) % molasses and 96 (vs. 65) % high palatability ingredients was substituted. Voluntary visits increased from 3.40 to 4.04 and voluntary milkings from 1.72 to 2.06/cow/day. Canadian robotic milking system owners describe cows that they have to fetch for milking as "lazy" when there is no clear reason, such as inexperience, clinical mastitis, or lameness for not attending voluntarily. Using this definition, "lazy milkings" and "lazy cows" declined from 27.3% and 16.0% to 12.7% and 7.1%, respectively, when the stronger pellet replaced the weaker one. In another study (Rodenburg et al., 2004), we formulated a concentrate for what we thought was maximum palatability. Ingredients included corn, soya hulls, wheat shorts, barley, bakery meal, soybean meal, corn distillers, extruded soy meal, wet molasses, animal vegetable fat blend, vitamin mineral premix, sodium bicarbonate, salt, pellet binder, and fenugreek flavor. In comparisons to commercial concentrates on 4 farms in trials with 3 consecutive 15-day crossover/switchback feeding periods, we found that visits (3.95 vs. 4.80) and milkings (2.69 vs. 2.81) were fewer ($P < 0.05$) for the experimental pellet when compared to a stronger commercial pellet (shear strength of 91.2 vs. 96.0 pdi) in Trial 1. In Trial 2, the experimental pellet was compared to a different commercial product of equal shear strength, and in this trial, attendance was unaffected. In Trial 3, conducted in the same herd as Trial 2, the pellet was reformulated to exclude all mineral ingredients, but no difference in attendance was found. In Trial 4, a mixture of 50% commercial pellets and 50% high moisture corn was compared to our experimental pellet, adjusted to make it isonitrogenous with the control. As in Trial 1, number of visits (3.06 vs. 3.33) and milkings (2.34 vs. 2.49) were lower ($P < 0.05$) for the experimental pellet. In this trial, shear strength of the experimental pellet was weaker, 86.9 vs. 97.7 pdi, than the commercial pellet, and there was evidence of fines in the feeder when it was fed. One of the other herds volunteered to test a mixture of 49% dried corn distillers, 49% cracked corn, 2% molasses, and 0.1% flavoring agent fed in a mash form, but during a 6-day feeding period, the number of visits decreased from 3.93 to 3.57 and number of milkings from 2.50 to 2.35. Milk production declined from 57.2 to 53.6 lb, and the trial was discontinued. These studies clearly demonstrate that the concentrate fed in the robot should be pelleted, and the pellets should be of high quality and free from fines. Feed delivery systems should be designed to minimize pellet breakdown during handling.

More recently, Danish researchers (Madsen et al., 2010) compared 7 pellet formulations and found substantial differences in the number of visits, the number of milkings, the number of fetch cows, and in milk production, linked to the ingredients used in the pelleted concentrates (Table 2). As illustrated, cows preferred a barley and oats combination, followed by a wheat based concentrate, both of which resulted in more milkings and visits without milking than a standard pellet. Pellets made from corn or only barley was slightly less palatable and resulted in a similar number of visits as the standard pellet, while a fat enriched pellet and one based on dried grass resulted in significantly fewer visits and lower milk production. Danish workers have also demonstrated a preference for barley/oat mixtures over corn in other studies with computer feeders. The term "refusals" used in Table 2 may be confusing to a nutritionist unfamiliar with robotic milking. A "refusal" is a visit to the milking stall by a cow that is not yet eligible for milking because the time elapsed since the last milking is shorter than the minimum interval programmed into the milking software. Since cows are only fed in the stall during milking, a refusal is not rewarded with feed. A high number of refusals indicate cows are eager to visit the milking stall and are returning shortly before their minimum milking interval criteria is met. The sum of milkings and refusals represents the total number of visits by the cow to the milking stall.

In studies of feed palatability, higher intake for flavored concentrates (Arave et al., 1989) and sweeteners (Weller and Phipps, 1989; Nombekala et al., 1994) has been reported in some trials but not in others (Murphy et al., 1997). Published palatability ratings for feed ingredients tend to be based on field experience rather than controlled studies (Amaral-Phillips and Hemken, 1993; Maiga et al., 1997). Highest palatability is assigned to brewers grains, distillers grains, hominy, molasses, and beet pulp. Soybean meal, roasted soybeans, corn, barley, and wheat midlings rank intermediate; raw soybeans and canola meal are ranked low, and corn gluten meal, blood meal, meat meal, fish meal, tallow, bypass fats, mineral mixes, buffers, and niacin rank very low. Pellets are clearly favored over mash, and heat-treated rapeseed meal or barley with 10% rapeseed fatty acids,10% palm oil, or 10% glycerol were all preferred over ground expeller palm kernel (Sporndly and Asberg, 2006). DeLaval robotic specialists suggest that caramel flavoring added at 0.5 lb/ton to the robot pellet is thought to enhance palatability (Futcher, 2011).

The amount of pellets fed in the robotic milking stall appears to have less influence on visiting behavior than the composition and pellet strength. Feeding 6.6 or 17.6 lb of pellets in the robotic milking stall to cows fed a high corn silage diet at the manger did not result in any difference in the number of milkings or the number of cows that required fetching (Bach et al., 2007). In this study, the ration fed was quite energy dense, and it is likely that this reduced the attraction offered by higher levels of concentrate in the milking stall. A study at the University of Ghent (Hauspie, 2008) summarized in Table 3 revealed that visits and milk production increased when the amount of concentrate in the mixed ration in the manger was reduced by 30% or 4.0 lb/cow, and the amount of concentrate fed in the milking stall was increased by 12% or 1.54 lb. Despite lower grain feeding, milk production went up in response to more frequent milking.

Varying the amount of concentrate fed in the milking stall according to production can also decrease grain feeding and associated feed cost. Since the concentrate dispenser in the robotic milking stall delivers feed on a volume basis, it is essential that it be calibrated after each new load of feed is delivered and on a regular basis between deliveries as well. Pellet ingredients, pellet strength, and quantity fed can all affect visit behavior, and visits and milkings drive production, so nutritionists need to pay careful attention to pellet formulation, manufacturing, and handling. This product is the "candy" for robotic milking units.

Grazing and Automatic Milking

Grazing and automatic milking have been successfully combined in research studies (Sporndly and Wredle, 2002; Ketelaar-DeLauwere et al., 2000) and on commercial farms (Jagtenberg and VanLent, 2000). When distances to pasture increase, especially beyond 400 meters (Wiktorsson and Sporndly, 2002; Sporndly and Wredle, 2004), milk production, milking frequency, and grazing time for late summer pasture declined, suggesting pastures close to the barn are preferred. Providing more supplementary forage in the barn did not increase milk yield in cows grazed 260 meters (868 ft) from the robotic milking system (Sporndly and Wredle, 2004). With distances to pasture of up to 330 meters (1089 ft), no differences in milking frequency or milk production were found when water was offered only in the barn vs. in the barn and in the pasture (Sporndly and Wredle, 2005).

Traffic management strategies that offer water and supplementary feed prior to milking and direct cows back to pasture are suggested as a way to encourage frequent attendance. The Lely company recommends strip grazing and directing cows to new pastures twice daily using a selection gate at the barn exit that directs cows ineligible for milking to a new pasture twice daily (Van Mourik et al., 2008a; Van Mourik et al., 2010).

High Grain Diets and Automatic Milking

In North America, the more continental climate favors diets of whole plant corn and alfalfa silages, which are more easily fed from storage. Because grain is inexpensive and investment in housing is high, diets with a high concentration of grain, which support high milk production, are favored. Mixing all grain, forage, and supplement ingredients into a TMR provides the accuracy of formulation and control of fiber level needed to minimize the risk of digestive disturbance with these diets. The need for concentrate in the milking box conflicts with traditional feeding practices in the US and Canada. Purchased pelleted concentrates cost more than the high moisture grains they replace. Feeding grain separate from the TMR can lead to situations where the maximum concentrate to forage ratio is exceeded when TMR intake is depressed. Field data (Rodenburg and Wheeler, 2002) suggest that in robotic milking herds where a high grain TMR is fed at the manger, frequency of voluntary milking is lower and more cows must be fetched as illustrated in Figure 1. Measures of voluntary milking appear impaired in diets with more than 1.66 Mcal Ne_L per kilogram DM (0.75 McalNE_L/lb DM) or more than 48% concentrate.

High grain diets are associated with laminitis (Manson and Leaver, 1988), and perhaps the 3 farms above 1.66 Mcal Ne_L/Kg in Figure 1 suffer from a level of "subclinical" laminitis, which is decreasing the mobility of cows. Carbohydrate level and fermentation rates; matching rumen availability of protein; and the level and form of dietary fiber are key factors which influence rumen acidosis and laminitis. Limits of 25 to 35 % NDF, with 75% from forage, 35 to 40% nonstructural carbohydrates, 30 to 40% starch in the dietary DM, and a ratio of forage NDF to ruminally degradable starch of > 1:1 have been recommended (Nocek, 1997).

An Israeli trial assessing the impact of replacing pellets made with high starch grains with isocaloric pellets made with soy hulls and corn gluten feed high in digestible fiber revealed higher milk production (94 vs. 86 lb/day), but milking frequency at 3.12 and 3.16 visits per day was not different (Halachmi et. al., 2009).

According to NRC (2001), predicted DM intake for a cow fresh 11 days producing 90 lb of 3.5% fat and 3.0% protein is 36.8 lb or 35% less than for the same production at 90 days in milk. When a portion of the grain is fed separately in the milking box, TMR intake depression in early lactation means that a small amount of grain can cause the above guidelines to be exceeded. Grain fed in the milking box should be limited to 4.4 lb/day at calving and increased slowly over several weeks while appetite and TMR intake stabilize.

Cows on high grain diets may also be less aggressive due to a direct metabolic effect. Cows on high grain diets spend less time eating and ruminating and more time resting (Robinson and McQueen, 1997), and consume fewer meals (Friggens et al., 1998). With fewer meals, directed cow traffic becomes less effective.

The type of diets described as high grain and high energy in this paper are typical of programs commonly used with high producing TMR herds in North America. If these diets result in poorer voluntary attendance for milking and lower milking frequency, understanding this relationship better will be an important area of future research.

The current trend in herds with an automatic milk system in Canada is toward less grain feeding. The standard recommendation from Lely (VanMourik et. al., 2008b) is to balance the partial mixed ration **(PMR)** fed in the manger for a production level that is 15 lb below the average production of the group and to selectively feed pelleted concentrate at a rate of 5 to 17 lb/day according to production for all cows fresh more than 4 weeks. When a new herd is started on robotic milking, cows should be acclimatized to the pellets by feeding them at the manger until the robotic milking stalls are installed. Switch the concentrate to the milking stall at start up. DeLaval recommends a default value of 8 lb of concentrate per cow in the milking stall at start up, combined with a mixed ration in the manger (Futcher, 2011). After start-up, concentrate feeding can be adjusted using tables with a range of 4 to 14 lb/cow/day with free traffic. More moderate upper limits are suggested for forced traffic applications. Grain feeding in the first 2 to 3 weeks of lactation is very conservative. In the past, it was common for rations to be formulated to provide 110 to 115% of the nutrient requirements of the average cow. These diets are now being evaluated for "feeding efficiency", which the feed advisor defines as the measure of how closely the feed provided supplies the nutrients required at the current production level. Response to this shift in emphasis appears to be positive as producers report higher forage intakes, steady production, and higher attendance. In many herds, the stimulus of increased milking frequency has increased milk production, despite lower levels of grain feeding.

Dynamic Feeding and Other Opportunities for Greater Feeding Precision

Currently, software can be purchased for Lely robotic milking systems that automatically optimizes the robot grain allocation for each cow in the herd based on feed and milk prices, and yesterday's production, milk composition, and milking speed of each cow, using a dynamic linear model (VanHolder et al., 2010). Although the concept of adaptive feeding models that base today's feed allocation on how the cow has responded to feeding changes in the recent past is a valid one, the present model has not been verified under North American conditions. Farmers in Europe report that during the period of low milk prices in 2009, dynamic feeding reduced grain feeding levels for many cows and increased income over feed costs (Wesselink, 2011).

The concept of dynamic feeding illustrates that robotic milking provides a unique opportunity to feed cows individually. The evolution of TMR over the last 40 years has meant that the concept of feeding the individual cow according to her nutrient requirements, as well as her individual behavior and preferences, has fallen by the wayside. Robotic milking systems are available with the capability to offer several feed types in pellet, mash, or liquid form. These systems provide daily data on milk production, milk composition, milking and eating behavior, and a wide variety of other parameters. Additional precision management tools are available, such as DeLaval's Herd Navigator in line testing for milk urea nitrogen, and beta-hydroxybutyrate will add further information to enhance individual cow nutrition management. While the need to attract the cow to the stall with feed creates additional challenges for the nutritionist and feed advisor, the capability for gathering detailed information about individual cows and the capability to provide a wide variety of feeds and additives on an individual basis creates many new opportunities as well.

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Table 1. Feeding and milking behavior, and milk production and composition of cows with free vs. forced traffic.[1,2]

Item	Treatment			
(per cow per day)	Free Traffic	Forced Traffic	SE	*P*-value
Total milkings	2.2	2.5	0.04	<0.001
Fetched milkings	0.5	0.1	0.03	<0.001
Voluntary milkings	1.7	2.4	0.06	<0.001
PMR intake (lb DM)	41.0	38.8	1.34	0.24
No. of meals of PMR	10.1	6.6	0.30	<0.001
Concentrate intake (lb)	5.5	5.5	0.09	0.99
Milk production (lb)	65.7	68.1	1.74	0.32
Milk fat (%)	3.65	3.44	0.078	0.06
Milk protein (%)	3.38	3.31	0.022	0.05

[1]Taken from Bach et al. (2007).
[2]SE = standard error and PMR = Partial mixed ration.

Table 2. Effect of concentrate formulation on robotic milking behavior and milk production.[1]

	Standard	Barley	Wheat	Barley/Oats	Corn	Fat Rich	Dried Grass
Item	(Mean)	(Effect of test feed expressed as test feed minus standard)					
Milkings	2.95	-0.03	0.17	0.35**	0.02	-0.36*	-0.93***
Refusals[2]	2.09	-0.05	0.44	1.87	0.31	-0.39	-1.16
Fetchings	0.026	0.028	0.019	0.009	0.50	0.042	0.17
Milk (lb/day)	57.5	0.22	3.53*	2.65	0.44	-1.98	-9.04***

*P < 0.05, **P < 0.01, ***P < 0.001
[1]Taken from Madsen et al. (2010).
[2]Number of visits to a milking stall by cows that are ineligible for milking.

Table 3. Milking frequency and milk production response to feeding more of the concentrate in the robotic milking stall.[1]

Item	Control	Treatment	% Difference
Concentrate in the manger (lb/day)	13.2	9.3	-30%
Concentrate in the milking stall (lb/day)	12.8	14.3	+12%
Milkings	2.3	2.5	+8%
Refusals[2]	1.0	1.4	+27%
Milk production (lb/day)	60.4	65.0	+7%

[1]Taken from Hauspie et al. (2008).
[2]Number of visits to a milking stall by cows that are ineligible for milking.

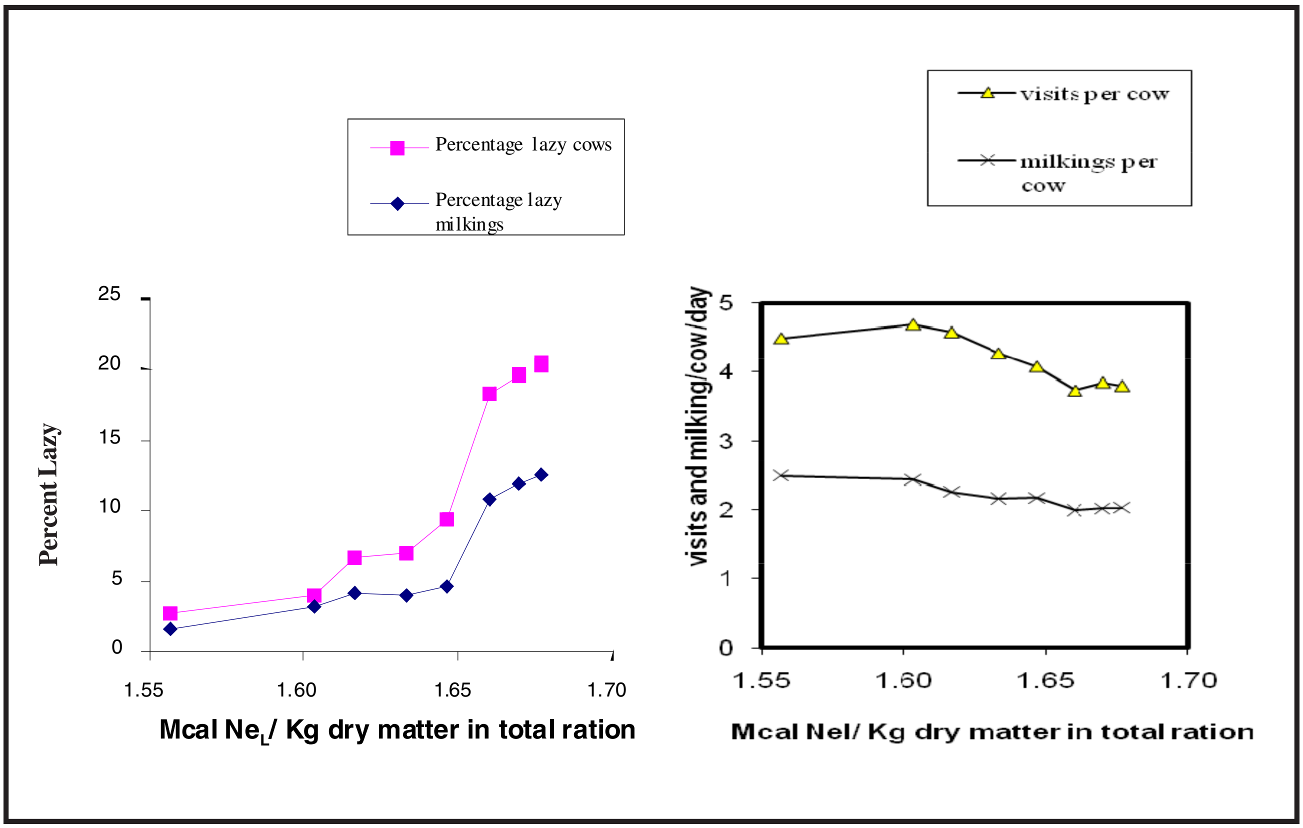

Figure 1. Energy level in diet dry matter and milking behavior (Rodenburg and Wheeler, 2002).