The ration we create, the ration we make, and the ration the cows eat

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The dairy industry has achieved remarkable transformation during the past century. A recent volume of the Journal of Dairy Science highlighted several of the areas of progress (McNamara and Lucy, 2017). Advances in genetics and reproduction management has continued to provide the US dairy industry with animals capable of producing milk production at levels that challenge long held beliefs about the biological limits of dairy cattle. The increased genetic capacity has been translated into steady increases in milk produced per cow through significant advances in several other areas of dairy science. Immune function and mammary gland health improved over the past 100 years supporting higher milk yield, leading to decreased use of antimicrobials, and a higher quality source of dairy products for consumers. The industry has continued to evolve in areas of animal welfare as we develop a better understanding of animal behavior and stress.

A key nexus of the advances achieved in the dairy industry has been our deeper understanding of nutrition, nutritional metabolism and feeding management of the dairy cow. The advanced understanding applies to all phases of the life cycle of the dairy cow including new-born calves and colostrum management, development of digestive system, heifer development and growth, nutritional requirements of the periparturient cow and nutritional management of lactating cows that produce more and more milk year after year.

When considering specific details of nutritional management of dairy cows, we now have a more elaborate understanding of mineral and energy metabolism of cattle transitioning during the periparturient period. Research has led to metabolic transitions at the cellular level, leading to more strategic nutritional management strategies to prevent metabolic disorders (Overton et al., 2017). Research has advanced nutritional management of high producing cows from a crude protein system based on nitrogen to nutritional models that balance for metabolizable amino acids (Schwab and Broderick, 2017). Nutritional models also account for the complex characteristics of carbohydrates including digestion and metabolism (Hall and Martens, 2017). The complexity of diet formulation, digestion and metabolism have been modeled to provide platforms to predict supply of metabolizable nutrients in support the increasing level of milk produced by the lactating dairy cow (Van Amburgh et al., 2015). These models have been refined to compensate for the environmental conditions, the animals' responses and the benefits of increased frequency of diet formulation (White and Capper, 2014). In summary, the system of formulating diets fed to dairy cattle has become more complex, more precise and more effective in supporting the genetic potential of the modern dairy cow. We have greatly advanced the ration we create using modern formulation software. The software programs are driven by complex algorithms that utilize more than 100 years of research. As we continue to refine our ability to formulate diets, we also continue to refine the feeding systems we use to deliver the diets created for dairy cattle.

Formulations use available feedstuffs and consider the composition of the feeds that will be used to formulate the diet. Some models incorporate environmental conditions that are understood to influence factors like feed intake as well as changes in rate of passage and nutrient partitioning. Adjusting diets based on changes in nutrient make up of feeds is a key step in controlling variation in diets delivered to the herd. Cherney et al. (2021) surveyed variation that occurred in silages and TMRs on commercial dairy farms in New York. These authors found that haylage exceeded the 7 percentage-unit limit for variation in DM 42% of sample weeks, with corn silage and TMR samples out of range 14% and 25% of the weeks, respectively. McBeth et al. (2013) conducted a study to model the impact of a short-term change in silage dry matter. The study design was to replicate changes in silage DM due to a rain event. The authors concluded the short-term changes in silage DM had limited effects on DMI, milk yield and milk composition. St-Pierre and Weiss (2015) conducted an extensive project involving dairy farms located in nine states to study the source of variation in nutrient composition of feeds and diets used on commercial dairy farms. This research provides guidance on how often feed samples should be collected to optimize the accuracy for assessing composition of feeds used on farms. On farm handling of feeds is also a source of variation. This is especially important with ensiled feeds that can undergo aerobic decay resulting in the production of elevated temperatures that can impact DMI (Kung et al., 2018).

The design and operation of feeding systems also advanced (Schingoethe, 2017). Schingoethe (2017) provided a timeline for the advances made in dairy cattle feeding systems starting with grain feeding recommendations first reported in 1931. Dairy cattle feeding systems have been designed and integrated into the housing, milking and feeding centers that are unique to each farming operation. The component feeding systems delivered concentrate during milking in the parlor. In theory, grain was allocated to individual cows based on milk production. Forages were fed separately with ensiled forages provided in a feed bunk and dry hay in hay feeders. Rakes (1969) as cited by Schingoethe (2017) presented the concept of a complete ration. The concept of the complete ration or total mixed ration was that each bite provided the cow with a balanced diet (Bach, 2014). The adoption of computer feeders allowed grain to be allocated throughout the day reducing the impact of slug grain feeding on ruminal fermentation (Schingoethe, 2017). The computer feeding systems continued to utilize the forage feeding systems commonly used with parlor feeding systems. Feeding systems continued to evolve in part due to nutritional sciences but have also been linked to changes in the size and facilities of dairy operations that provided economic advantage of size and scale (Spain et al., 1991). Moallem and Lifshitz (2020) studied the variation of TMR by comparing trailer mounted mixers compared to self-propelled mixers (SPLM). The SPLM mixer performed better than the TM. This research reminds how important performance and operation of the TMR mixers is in achieving an accurately mixed diet. Bach (2014) suggested an alternative approach through dynamic concentrate parlor feeders (DCPF), an example of how dairy feeding systems continue to evolve to provide the ideal platform for nutritionally supporting the genetic potential of the modern dairy cattle, while simultaneously supporting optimal animal health and ultimately providing opportunity for profit.

Given the impact of the diets on animal health, production and ultimately the profitability of the dairy farm enterprise, approaches for evaluating and managing the diets and feeding systems have been developed. Oelberg and Stone (2014) and Oetzel (2014) have provided extensive summaries for evaluating the nutritional management systems. Evaluating diets and feeding systems can be divided into factors that include animal performance metrics and factors that are sources of variation that impact animal performance metrics. When evaluating factors, one consideration is to separate factors are leading indicators or predictors of a successful nutritional management system (diet + feeding system) and factors are the lagging indicators or the results of the nutritional management system. The factors of milk yield, milk composition and animal health are lagging indicators that reflect how well the nutritional management system is meeting the needs of the cows. Leading indicators are factors that influence the outcomes (lagging indicators). Leading indicators are also sources of variation in the system that contribute to the outcomes of the nutritional management system.

One leading factor that has received extensive attention has been particle size and diet sorting. Sova et al. (2014) reported decreasing variation in long particles in the TMR was associated with an increase in daily milk yield (1.2 kg/d) and a concurrent increase in efficiency of milk yield. Khorrami and coworkers (2021) conducted an extensive meta-analysis and concluded subacute ruminal acidosis was linked to dietary levels of physically effective NDF and starch. Feed sorting has been linked to consumption of dietary ingredients in amounts that reflect the formulated or balanced diet. As Miller-Cushon and DeVries (2017) reported, feed sorting is a complex combination of factors that include but are not limited to ration composition, feeding system, forage to grain ratios, and forage particle size. DeVries et al. (2005) evaluated investigated the effect of number of feedings per day on sorting behavior. Sorting behavior was evaluated by measuring the change in NDF concentration which increased post feeding. However, sorting was decreased by increasing the frequency of feeding. The authors concluded that having feed readily available during “peak feeding periods” with fresh feed reduced feed sorting.

Associated with feed delivery is feed push up. Lunak (2023) outlined several recommendations for managing feed delivery including the timing of pushing feed up. Dairy cattle eating behavior includes sorting through the total mixed ration that results in feed being pushed away from the cows. Another factor is the uneven eating pressure that occurs along the feed bunk. TMR disappearance can vary along the feed bunk. When considering ‘push ups’, a system should be used that ‘redelivers’ the feed by pushing residual ration back to the feedline and also ‘redistributes’ the feed along the feedline. By redistributing the feed along the length of the feed bunk, availability of the feed is optimized. Attention should be given to areas of the feed bunk close to water sources and areas that are along walkways cattle use when returning from the milking parlor. Turning the feed over in the bunk during the redelivery can also help remix the feed and reduce the sorting that was described by DeVries et al. (2005).

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A critical feature of the nutritional management system involves the delivery of water. Murphy (1992) noted:

"*Water is of paramount importance both physiologically and nutritionally; therefore, it is not surprising that its metabolism indirectly may affect many feeding and management decisions. Ample water of acceptable quality must be provided to maximize production.*"

Lactating dairy cows producing 100 pounds of milk per day with an average DM intake of 60 pounds consume an estimated 34 gallons or 282 pounds of water per day. In an invited review by Jensen and Vestergaard (2021), noted that research on water systems and the impact on water intake is limited. In order to manage water as a nutrient, systems should be designed to measure water consumption in a manner similar to how dry matter intake is measured and managed. Rate of water disappearance and water refill should be monitored to assure water delivery optimizes water consumption. Optimizing water consumption is linked to optimization of feed intake and milk production. During periods of elevated air temperatures, water consumption allows cattle to utilize thermoregulatory mechanisms. Avoiding the negative impacts of heat stress supports feed intake, milk production and reproductive performance. Singh and others (2022) reported water nutrition is becoming a pressing issue for the global dairy industry.

In summary, diet formulation software systems provide the dairy industry with an ability to balance diets with great precision. The diet formulas allow animal nutritional requirements to be met while also optimizing the health of the animal. Whole farm nutrient management plans rely on diet formulation to minimize nutrient losses to the be managed within the waste management system. Ultimately, these diets are designed to support profitability of the dairy farm enterprise. In order to realize the value of precise diet formulations, the feeding management systems must be managed to minimize the variation between the formulated diet and the diet delivered to the cows. This aspect of nutritional management system requires the variation in ingredients to be controlled. This is especially important for ensiled forages. Maintaining optimal function and operation of feeding equipment is important, including validating accuracy of scales. Feed mixers have unique features that must be used to deliver a diet that is well mixed. Well mixed diets will provide adequate levels of peNDF that limits feed sorting. Pushing feed up is not only redelivering the feed but also allows the ration to be redistributed to provide an even supply along the entire feed bunk. Remixing the ration during the push up process can help control the impact of feed sorting. Finally, greater attention should be given in managing the water supplied and consumed by lactating dairy cows. Controlling the variation in the leading indicators will increase the likelihood of achieving the goals that are recognized as the lagging indicators of the dairy farm enterprise.

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