Feed Intake and Feed Efficiency: Can We Make More With Less?

Heather M. White[1]
Department of Animal and Dairy Sciences
University of Wisconsin-Madison

Summary

Feed costs contribute to half of the cost of dairy production and thus improvements in feed efficiency are essential to maintaining and improving economic, environmental, and social sustainability. As a part of a large national and international effort focused on improving feed efficiency, we have focused on measuring phenotypic feed efficiency both to contribute to the genetic reference population and in order to better understand individual animal variance. This proceeding focuses on three primary efforts: 1) predicting individual cow feed intake, 2) elucidating individual animal variation in post-absorptive nutrient use efficiency, and 3) understanding the effects of feeding behavior and competition on feed efficiency. Models constructed to predict feed intake over a six-week period have used cow descriptive data, milk yield and components, sensor activity data, and basic blood energy metabolites, with body weight being the most essential variable. Using only one-week of data marginally reduced model performance. Incorporation of genetic parameters and milk fatty acids, limiting data to single-timepoint for on-farm application, resulted in models that predicted feed intake reasonably well. Further improvements in prediction models, and in feed efficiency, will likely reflect knowledge being gained in individual animal variance in post-absorptive nutrient use efficiency. In a global exploration, metabolites associated with fatty acid oxidation and amino acid metabolism differed between the most and least feed efficient cows, making the associated pathways promising targets for future research. Finally, the large database generated in this research has allowed for analysis of feeding behavior and feed competition. Interesting findings, including that more efficient cows had a slower eating rate on a daily, meal, and temporal basis and that cows with a shorter latency to feed tended to have decreased feed efficiency, may provide on farm proxies for feed efficiency. Competition between primiparous and multiparous cows also tended to reduce feed efficiency which can inform on-farm grouping strategies. The overall goal is to determine strategies to improve feed efficiency with the current national dairy herd, while making progress towards genetically improving feed efficiency of milk production.

Introduction

On farm, feed represents approximately 50% of the total cost of dairy production over the last ten years (USDA-ERS, 2020a); therefore, identifying cows that are more feed efficient can pay dividends for dairy farmers and improve economic, environmental, and social sustainability of dairy production. The need to improve efficiency of production is underscored by the need to feed the growing world population, predicted to be 9.3 billion

---

[1] Contact at: 1675 Observatory Dr., 934B Animal Sciences Bldg., Madison, WI, 53706-1205, (608) 263-7786, Email: heather.white@wisc.edu.

people by 2050, which will take 60% more food with less available land and natural resources.

Historic progress in feed efficiency across production animal species has been primarily through dilution of maintenance. For any animal of a given size, the maintenance cost remains constant, despite their production amount. This means that the proportion of energy or nutrients dedicated to maintenance is smaller, relative to the total, for an animal that is producing more. For example, the maintenance energy for a 1430 lb (650 kg) cow that is making 15 lb milk/day (7 kg/day) is 69% of the total energy requirement while 13% of total energy is dedicated to milk production. If the same animal is making 64 lb milk/day (29 kg/day), only 33% of her daily energy requirement is used for maintenance and 67% is used for milk production (adapted from Capper et al., 2009). The concept of diluting maintenance requirement and having each animal produce more has been the primary driver in improved efficiency across species in the last 100 years; however, we are not likely to have the same exponential improvements through this mechanism over the next 50 years. Instead, additional improvements in feed efficiency will be more marginal and will likely require determining sources of individual animal variance in feed efficiency and capitalizing on it through genetics, management, and nutrition.

How Do We Quantify and Compare Feed Efficiency?

In the broadest terms, feed efficiency is how much feed it takes to generate a unit of milk (lb milk / lb dry matter intake **[DMI]**), but this does not account for the energetic differences in feed intake or milk output. Given this, there are many different ways to express feed efficiency from energy corrected milk per DMI, milk nitrogen per feed nitrogen, or value of milk per cost of feed, to name a few. While these are all applicable metrics on farm, these metrics do not always allow us to directly compare cows to determine which cow is more efficient than the others. This is due to the fact that these do not fully account for milk energy output or cow variables such as body size, body weight change, and parity. In a research setting, we are able to compare cows on equivalent bases by determining residual feed intake **(RFI)**, defined as the amount of feed she consumes compared to what we predict she should consume when we account for the aforementioned energy sinks. Cows are compared within a cohort, of which DMI, milk yield, milk energy output, and body weight are all measured concurrently so that external factors, such as diet, environmental conditions, and management practice, remains constant on the cohort. When a negative RFI is obtained, it means the cow is more efficient than other animals in the cohort. This residual represents heritable variation in efficiency of 0.17 based on 4,900 cows(Tempelman et al., 2015) and more recent analysis of the top 100 net merit progeny-tested sires yielded a similar (0.16) heritability (Li et al., 2020).

Calculated RFI is useful in a research setting; however, it only indicates if a cow is relatively more or less efficient within a cohort. In order to put RFI on a practical basis, we use it to calculate a trait known as "Feed Saved", which is the amount of feed (on a dry matter basis) that is saved by more efficient cows. Across a 6,000-cow database collected over 7 years by a team of nutritionists and geneticists collaborating on a 2010 USDA NIFA grant, it was determined that RFI had sufficient heritability to result in decreased feed needs of dairy cattle. Contrasting the bottom and top 20% of cows for RFI in a population of ~3,500 cows (1999-2013; 10 North American research stations), the cows with the lowest RFI (more feed efficient) ate 400 kg less feed dry matter per year than those with highest RFI (less feed efficient) to support the same level of milk production at the same body weight. When combined with variation in body weight, which is used as an estimate for maintenance, the most efficient cows produced the same amount of milk with 8% less feed (635 kg) per lactation than the least efficient cows. These results have collectively yielded the Feed Saved trait, released in December 2020 from the US Center for Dairy Cattle Breeding (CDCB, see www.uscdcb.com/news/), which has already been incorporated into the Holstein Association Total Performance Index and is included in the US Net Merit Index.

Feed Intake Predictions

Determination of feed efficiency for individual cows requires precise feed intake measurement capabilities, which limits the number of research facilities that can generate RFI phenotype data and how many records can be collected each year. If there were a lower barrier method to determine individual cow feed intake, collection of RFI phenotypes could be higher throughput since it is the phenotype, not the genotype, that is limiting. Knowing individual cow feed intake is also a limiter on farm since we assume that all cows in a pen are consuming the average calculated daily intake. Having individual cow feed intakes could allow for a better understanding of individual cow feed efficiency on farm by allowing for strategic grouping of cows and higher throughput research. In the past, feed intake prediction models functioned well to formulate rations for groups of cattle but were not precise at the individual cow level. These models utilize basic cow descriptive factors, such as milk production, body weight, stage of life, breed, and parity. There has been a recent effort to strengthen feed intake prediction models with new data sources that are becoming available on dairy farms (Souza et al., 2019; Martin et al., 2021a), and predicting feed intake accurately will likely utilize additional data streams.

Metabolism and smart technologies

Technological advancements in the dairy industry have given dairy farmers access to a variety of precision management technologies, including activity monitoring systems and real-time blood analysis devices. These technologies generate information that could be useful as predictive variables. Recently, we examined the potential value of adding sensor-derived behavior variables and blood metabolites as novel data streams to traditional feed intake prediction models (Martin et al., 2021a) to predict feed intake over a 6-week period. Models were generated using data collected from a commercial ear tag sensor system (SMARTBOW; Zoetis) that provided activity, rumination, lying time, and location. We also used blood metabolite concentrations, milk yield, milk components, and descriptive cow variables (parity, body weight, etc.). Using a sequential approach to add different predictor variables to the models based upon the ease of obtaining each predictor type and different statistical model types, we were able to generate models with different types of variables. The best models predicted actual DMI reasonably well ($R^2 = 0.82$; CCC = 0.90). Notably, body weight was essential and increased R^2 from 0.64-0.67 to 0.77-0.80 across statistical modeling approaches. Adding the sensor-derived behavioral variables to the traditional predictor variables explained an additional 2% of the variation in intake. While nominal, this improvement highlights a unique contribution that alternate data streams may provide on explaining variation in intake. Addition of blood metabolites that are relevant to body energy status (fatty acids, glucose, and beta-hydroxybutyrate) neither improved precision nor accuracy of the predictions. These models would be useful in a research setting; however, 6-weeks of data is still impractical outside of a research purpose. When we selected a week worth of data for any cow, model accuracy was only marginally reduced which was encouraging.

Single-timepoint models using milk fatty acids and predicted transmitting abilities

In order to reduce the models described above to be built on a practical amount of data input, we used a larger data set that had 350 single-day DMI observations. We also added data that would be available from on-farm DHIA milk testing programs. Milk fatty acid analysis is growing in popularity and availability through milk testing organizations. Milk fatty acids are indicative of nutritional and metabolic status and may present a snapshot of the cow's feed intake patterns. Preformed and de novo fatty acids improved prediction of feed intake over traditional predictor variables by 4 to 8% (Brown et al., 2022a). Similar results were obtained by other researchers using the milk mid-infrared spectroscopy wavelengths from which the fatty acid groups are derived (Dórea et al., 2018). The other data streams incorporated into the single-timepoint models were predicted transmitting abilities **(PTA)**. While traditional PTA for milk production and components have been available for decades, recent work has enabled the development of new PTA related to feed efficiency – notably, PTA for RFI and body weight composite. When offering these PTA for inclusion in prediction models, the PTA for milk and RFI were routinely retained in the final models (Brown et al., 2022a) and increased precision of prediction by 3 to 12% over traditional predictor variables.

When combined, traditional predictor variables in addition to milk fatty acids and PTA in feed intake prediction models explained 67% of the variation in daily feed intake (Brown et al., 2022a). The unique aspect about these models is that they were derived from data on a single day rather than the usual approach of averaging data over a period of weeks or months. Accuracy of models using only single-timepoint data hold potential for higher throughput feed intake determination on-farm, although the precision would need to be further improved to be useful in a research setting.

Post-Absorptive Differences in Nutrient Use Efficiency

In order to continue improving feed efficiency, and predictions of both feed efficiency and feed intake, we must understand the individual animal sources of variance in these metrics. Individual cow variance in RFI can be primarily attributed to six different energy uses: protein turnover and tissue metabolism (51%), heat increment and fermentation (12%), digestibility (14%), body composition (7%), feeding patterns (3%), and physical activity (14%) (Herd and Arthur, 2009). The greatest of these, tissue metabolism, serves as a central metabolic point in conversion of fermentation products to animal nutrient needs. For example, volatile fatty acids and amino acids that are absorbed from the rumen are often converted to end products needed by the animal, including other amino acids, synthesized proteins, glucose, and others. This metabolism represents nutrient use metabolism and efficiency, but the outcomes and byproducts of these pathways can also be used as markers of those pathways. Therefore, our interest in this area of individual cow variation in nutrient use is two-fold: 1) to explain how some cows are more efficient than others at the same body size, energy status, and environmental conditions and 2) as a source of potential markers of efficiency. Our first look at this was at a global level using metabolomics to identify metabolites, or types of metabolites, that differed between the most and least efficient cows in a cohort (Martin et al., 2021b). Metabolites associated with fatty acid and amino acid oxidation were identified as differing between high and low efficient cows, which supports more research in understanding differences in individual animal efficiency related to fatty acid and amino acid metabolism, use of these metabolites in predictions models, and potential nutritional strategies that will maximize feed efficiency by optimizing protein and fat metabolism.

Feeding Behavior, Feed Competition, and Feed Efficiency

There are many non-dietary influences of feed efficiency, including environmental temperature, management practices, cow comfort, and feed competition. Within the feeding system at the University of Wisconsin-Madison, roughage intake control system (**RIC**; Hokofarm Group, The Netherlands) feeders are used to monitor feed intake and feeding behavior with real time data on meal size, frequency, competition, and feeding rate. Across a dataset of 592 multiparous and 304 primiparous cows from 17 cohorts, we compared feeding behavior to RFI (Brown et al., 2022b). Overall, more efficient cows (negative RFI) had a slower eating rate on a daily, meal, and temporal basis for both primiparous and multiparous cows, which may account for the lower DMI of more efficient cows. Future research could work to identify markers of these behaviors as proxy measures of DMI or feed efficiency.

Feed competition within group housed cows is another potential contribution to feed intake. By assigning primiparous and multiparous cows to bins that either allowed for them to eat with same parity group cows or with opposing parity group cows, we were able to determine if this potential competition influenced feed efficiency. Interestingly, cows that were assigned to feeders in a mixed-parity group were less efficient, regardless of their parity group (Reyes et al., 2022a,b). It was also observed that cows with a shorter latency (cows that go immediately to the bunk after first feeding) have more competitive interactions and a greater percentage of first visits to the same feeding bin. Although these cows had a greater eating time during the first 30 minutes after first feeding, they tended to have a decreased duration of the first visit. Overall, cows with shorter latency tended to have decreased feed efficiency.

Conclusions

Progress continues to be made in improving dairy cattle feed efficiency. Continual addition of new records to the database is important; given the pace of genetic improvement, the reference population can quickly become outdated and irrelevant. While genetic selection for Feed Saved is key, obtaining more high-quality phenotypes that can contribute to the Holstein Association Total Performance Index and US Net Merit Index is of the upmost importance to be able to accurately predict, identify, and retain more feed efficient cows over less feed efficient cows. Other external factors such as improving our management practices and underlying factors such as understanding metabolic efficiency will allow us to feed and manage the current and future dairy herd for improved feed efficiency.

Acknowledgements

Current members of our feed efficiency collaborative team are: University of Wisconsin-Madison: Kent Weigel, Heather White, Francisco Peñagaricano

Contributors to UW-Madison work included in this proceedings include Billy Brown, Malia (Martin) Caputo, Ligia Cavani, Sophia (Erb) Kendall, and Faith (Baier) Reyes,

Michigan State University: Mike VandeHaar, Rob Tempelman
Iowa State University: James Koltes
University of Florida: José E. Santos
USDA Animal Genomics Improvement Lab: Randy Baldwin, Paul Van Raden
US CDCB: Kristen Gaddis

References

Brown, W.E., M.J. Caputo, C. Siberski, J.E. Koltes, F. Peñagaricano, K.A. Weigel, and H.M. White. 2022a. Predicting dry matter intake in mid-lactation Holstein cows using point-in-time data streams available on dairy farms. J. Dairy Sci. 105:9666–9681. doi:10.3168/jds.2021-21650.

Brown, W.E., L. Cavani, F. Peñagaricano, K.A. Weigel, and H.M. White. 2022b. Feeding behavior parameters and temporal patterns in mid-lactation Holstein cows across a range of residual feed intake values. J. Dairy Sci. 105:8130–8142. doi:10.3168/jds.2022-22093.

Capper, J.L., R.A. Cady, and D.E. Bauman. 2009. The environmental impact of dairy production: 1944 compared with 2007. J. Anim. Sci. 87:2160–2167. doi:10.2527/jas.2009-1781.

Dórea, J.R.R., G.J.M. Rosa, K.A. Weld, and L.E. Armentano. 2018. Mining data from milk infrared spectroscopy to improve feed intake predictions in lactating dairy cows. J. Dairy Sci. 101:5878–5889. doi:10.3168/jds.2017-13997.

Herd, R.M., and P.F. Arthur. 2009. Physiological basis for residual feed intake. J. Anim. Sci. 87:E64–E71. doi:10.2527/jas.2008-1345.

Li, B., P.M. VanRaden, E. Guduk, J.R. O'Connell, D.J. Null, E.E. Connor, M.J. VandeHaar, R.J. Tempelman, K.A. Weigel, and J.B. Cole. 2020. Genomic prediction of residual feed intake in US Holstein dairy cattle. J. Dairy Sci. 103:2477–2486. doi:10.3168/jds.2019-17332.

Martin, M.J., J.R.R. Dorea, M.R. Borchers, R.L. Wallace, S.J. Bertics, S.K. DeNise, K.A. Weigel, and H.M. Weigel. 2021a. Comparison of methods to predict feed intake and residual feed intake using behavioral and metabolite data in addition to classical performance variables. J. Dairy Sci. In Press. doi:10.3168/jds.2020-20051.

Martin, M.J., R.S. Pralle, I.R. Bernstein, M.J. VandeHaar, K.A. Weigel, Z. Zhou, and H.M. White. 2021b. Circulating metabolites indicate differences in high and low residual feed intake Holstein dairy cows. Metabolites 11:868. doi:10.3390/metabo11120868.

Reyes, F.S., K.A. Weigel, H.M. White, and J.M.C. Van Os. 2022a. Feeding patterns and efficiency in same- and mixed-parity groups. J. Dairy Sci. 105(Suppl. 1):283. (Abstr.)

Reyes, F.S., K.A. Weigel, H.M. White, and J.M.C. Van Os. 2022b. Preference for competing against same vs. mixed parity cows and relationship to feed efficiency. J. Dairy Sci. 105(Suppl. 1):283. (Abstr.)

Souza, R.A. de, R.J. Tempelman, M.S. Allen, and M.J. VandeHaar. 2019. Updating predictions of dry matter intake of lactating dairy cows. J. Dairy Sci. 102:7948–7960. doi:10.3168/jds.2018-16176.

Tempelman, R.J., D.M. Spurlock, M. Coffey, R.F. Veerkamp, L.E. Armentano, K.A. Weigel, Y. de Haas, C.R. Staples, E.E. Connor, Y. Lu, and M.J. VandeHaar. 2015. Heterogeneity in genetic and nongenetic variation and energy sink relationships for residual feed intake across research stations and countries. J. Dairy Sci. 98:2013–2026. doi:10.3168/jds.2014.8510.

U.S. Department of Agriculture-Economic Research Service. Milk cost of production estimates. Available online: http://www.ers.usda.gov/data-products/milk-cost-of-production-estimates/ (accessed on 12 April 2021).