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Harnessing the genetics of the modern dairy cow to continue improvements in feed efficiency[1]

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ABSTRACT

Feed efficiency, as defined by the fraction of feed energy or dry matter captured in products, has more than doubled for the US dairy industry in the past 100 yr. This increased feed efficiency was the result of increased milk production per cow achieved through genetic selection, nutrition, and management with the desired goal being greater profitability. With increased milk production per cow, more feed is consumed per cow, but a greater portion of the feed is partitioned toward milk instead of maintenance and body growth. This dilution of maintenance has been the overwhelming driver of enhanced feed efficiency in the past, but its effect diminishes with each successive increment in production relative to body size and therefore will be less important in the future. Instead, we must also focus on new ways to enhance digestive and metabolic efficiency. One way to examine variation in efficiency among animals is residual feed intake (RFI), a measure of efficiency that is independent of the dilution of maintenance. Cows that convert feed gross energy to net energy more efficiently or have lower maintenance requirements than expected based on body weight use less feed than expected and thus have negative RFI. Cows with low RFI likely digest and metabolize nutrients more efficiently and should have overall greater efficiency and profitability if they are also healthy, fertile, and produce at a high multiple of maintenance. Genomic technologies will help to identify these animals for selection programs. Nutrition and management also will continue to play a major role in farm-level feed efficiency. Management practices such as grouping and total mixed ration feeding have improved rumen function and therefore efficiency, but they have also decreased our attention on individual cow needs. Nutritional grouping is key to helping each cow reach its genetic potential. Perhaps new computer-driven technologies, combined with genomics, will enable us to optimize management for each individual cow within a herd, or to optimize animal selection to match management environments. In the future, availability of feed resources may shift as competition for land increases. New approaches combining genetic, nutrition, and other management practices will help optimize feed efficiency, profitability, and environmental sustainability.
Key words: dairy cattle, feed efficiency, genetics

INTRODUCTION

Modern taurine cattle were likely first domesticated from wild aurochs in the Middle Euphrates River Valley about 9000 BCE, and they arrived in northern Europe around 4000 BCE (Bollongino et al., 2012; Scheu et al., 2015). The wild auroch became extinct approximately 400 years ago, but its phenotype is documented (van Vuure, 2005). In comparison to the auroch, modern dairy breeds are likely more docile, thinner, and less muscular, and have greater milk-secretory capacity. Until modern times, selection was generally not purposeful, or if selection was based on observation and scientific thinking, it was generally based on observations of an animal's own phenotype. Paintings from almost 400 years ago, such as Aelbert Cuyp's *Cows in a River* (c. 1654), indicate that the external phenotype of the modern dairy cow predated modern scientific selection and management. Thus, without the aid of modern science, humans produced cattle that were essentially "modern."

In the last 100 yr, the productivity of dairy cattle has risen considerably due to scientific advances in many

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disciplines. Chief among these was the science of quantitative population genetics, which began in the 1930s and greatly accelerated the rate of change (Shook, 2006; Gianola and Rosa, 2015). Other advances were also important. Technological developments in milking equipment and computerized record-keeping enabled accurate identification of those cows producing the most milk. Advancements in reproductive technologies, such as artificial insemination, enabled the selected animals to produce multiple offspring. Advances in nutrition and management enabled animals to reach their genetic potential so that genetic differences could be detected. Modern computing enabled development of breeding values, more accurate ration balancing, and sophisticated management systems. Finally, developments in methods for research, education, and outreach enabled these scientific advances to occur and provided an effective means for dissemination and application on farms.

The bovine genome was first published in 2009 (Bovine Genome Sequencing and Analysis Consortium, 2009), the same year in which genomic selection began in the US dairy industry (Wiggans et al., 2011). On the one hand, the science of genomics is just one more step in a series of developments, and yet genomics has revolutionized animal breeding. Genotyping and genomic selection have already enabled more accurate selection with a dramatically reduced generation interval compared with conventional selection systems based on daughter performance (Hayes et al., 2009; VanRaden et al., 2009). Superior genotypes can be identified at birth, and through advanced reproductive techniques, multiple offspring can be produced in less than 2 yr. By increasing the accuracy and intensity of selection and shortening the generation interval, the rate of genetic progress for economically important dairy traits can be approximately doubled (Schefers and Weigel, 2012). Genomics also enables selection for new traits such as feed efficiency (Hayes et al., 2013; Pryce et al., 2014a). Eventually, management practices might be tailored specifically for genotypes or genotypes might be selected to match environments. In the past 20 yr, multitrait selection indexes have been developed and evolved, and now include not only productivity but also traits such as longevity, udder health, and fertility (VanRaden, 2004). Clearly, changes in the genetics of dairy cattle are now occurring faster than at any time in history. Undesirable side effects from intense selection for productive efficiency may occur without adequate forethought (Rauw et al., 1998). The critical question to consider is, "What animal traits should be selected to match future demands?"

Feed efficiency matters on farms because it has a major influence on farm profitability and environmental stewardship in the dairy industry. Dairy feed efficiency in North America has doubled in the past 50 yr, largely as a byproduct of selecting and managing cows for increased productivity (VandeHaar and St-Pierre, 2006; Capper et al., 2009). Increasing productivity results in a greater percentage of total feed intake being used for milk instead of cow maintenance. The USDA National Agricultural Statistics Service show that current average milk production of dairy cattle in the United States is 10,100 kg/cow per yr. Elite dairy cattle in the United States currently partition >3 times more feed energy toward milk than toward maintenance over their lifetime (VandeHaar and St-Pierre, 2006). Most of the gain in feed efficiency from increasing productivity, especially from selecting for production, has already occurred in well-managed herds with superior genetics, and the dairy industry must begin to focus more directly on increasing the amount of milk from each unit of feed or each unit of land. Several excellent reviews have been published recently on dairy feed efficiency and possible selection mechanisms to improve it; among them are Berry and Crowley (2013), Pryce et al. (2014b), and Connor (2015). In this paper, we will describe the views of our group of nutritionists and geneticists on the most important considerations for improving feed efficiency of the modern dairy cow. These include (1) selection for efficient genetics and (2) management to take advantage of the genetic potential of superior cattle.

DEFINING FEED EFFICIENCY

Feed efficiency is a complex trait for which no single definition is adequate. Generally, feed efficiency describes units of product output per unit of feed input, with the units generally being mass, energy, protein, or economic value. For dairy cattle, the major product is milk, but the energy or value of tissue captured cannot be neglected. Losses or gains of body tissue can result in misleading values for feed efficiency if the only product considered is milk. Feed efficiency should be considered over the lifetime of a cow and include all feed used as a calf, growing heifer, and dry cow and all products including milk, meat, and calves. The factors that could be used to define efficiency in the dairy industry are shown in Figure 1.

At the farm level, feed efficiency also should account for feed that is wasted by the cow or during harvesting, storing, mixing, or feeding and for products that are not suitable for human consumption. In addition, we should consider that feed efficiency is more complicated than just feed and product. At the farm level, economic efficiency is clearly a priority. Feed is a major expense for any dairy farm, so biological feed efficiency affects economic efficiency, but so does the economic value of