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A 100-Year Review: Regulation of nutrient partitioning to support lactation[1]

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ABSTRACT

We have seen remarkable advances in animal productivity in the last 75 years, with annual milk yield per cow increasing over 4-fold and no evidence of nearing a plateau. Because of these gains in productive efficiency, there have been dramatic reductions in resource inputs and the carbon footprint per unit of milk produced. The primary source for the historic gains relates to animal variation in nutrient partitioning. The regulation of nutrient use for productive functions has the overall goal of maintaining the cow's well-being regardless of the physiological or environmental challenges. From a conceptual standpoint, it involves both acute homeostatic controls operating on a minute-by-minute basis and chronic homeorhetic controls operating on a long-term basis to provide orchestrated adaptations that coordinate tissues and body processes. This endocrine regulation is mediated by changes in circulating anabolic and catabolic hormones, hormone membrane receptors and intracellular signaling pathways. The coordination of tissues and physiological systems includes a plethora of hormones, but insulin and somatotropin are 2 key regulators of nutrient trafficking. Herein, we review the advances in our understanding of both conceptual and actual regulation of nutrient partitioning in support of milk synthesis and identify examples of the challenges and future opportunities in dairy science.
Key words: homeorhesis, homeostasis, somatotropin, insulin, metabolic regulation

INTRODUCTION

Domesticating dairy animals played a critical role in the development of human society. Dairy products were recognized as nutritious foods as early as 4,000 BC, and today milk and dairy products are key components of dietary recommendations by governmental agencies and public health organizations around the world. Cow's milk contains more of the essential vitamins and minerals required by humans than any other single food (Patton, 2004). Advances in lactation physiology during the last century have increased our understanding of the biological processes that allow dairy cows to use feed nutrients for the biosynthesis of milk (Appendix Table A1). Annual milk yield per cow was relatively constant over the first part of the 20th Century. However, beginning in the early 1940s, the application of scientific principles to nutrition, management, and genetics initiated a progressive improvement in milk production that continues to this day. Whereas annual milk per cow averaged about 2,000 kg from the 1920s through the early 1940s, the US dairy herd currently annually averages over 10,000 kg (Figure 1). Indeed, the annual herd average on some US dairy farms is >14,000 kg of milk per cow, and the current US record holder is a Wisconsin cow named Ever-Green-View My Gold-ET ("My Gold"), who had a 365-d milk production of 35,144 kg (906 kg of fat, 934 kg of true protein; http://www.dairyherd.com/news/industry/new-national-milk-production-record-set). Equally impressive, the Guinness World Records recently recognized a 15-yr-old Canadian cow, Guillette E Smurf, as the lifetime record holder in milk production; Smurf's production of 216,891 kg in 10 lactations represents an impressive average of over 38 kg of milk for every day of life (http://www.guinnessworldrecords.com/world-records/greatest-milk-yield-by-a-cow-%E2%80%93-lifetime).

Historic gains in milk yield originate partly from selection and genetic improvement (50–66%) and the remainder from advances in nutrition and management (VanRaden, 2004; Shook, 2006). Progress from applying genetic selection requires sound practices in nutrition and overall management for a cow to achieve her production potential. Likewise, production advances resulting from technology developed from basic dairy cow biology require an adequate genetic base. Examples explaining the historic gains include a better understanding of nutrient requirements, improvements in diet formulation and mixing, utilizing AI and

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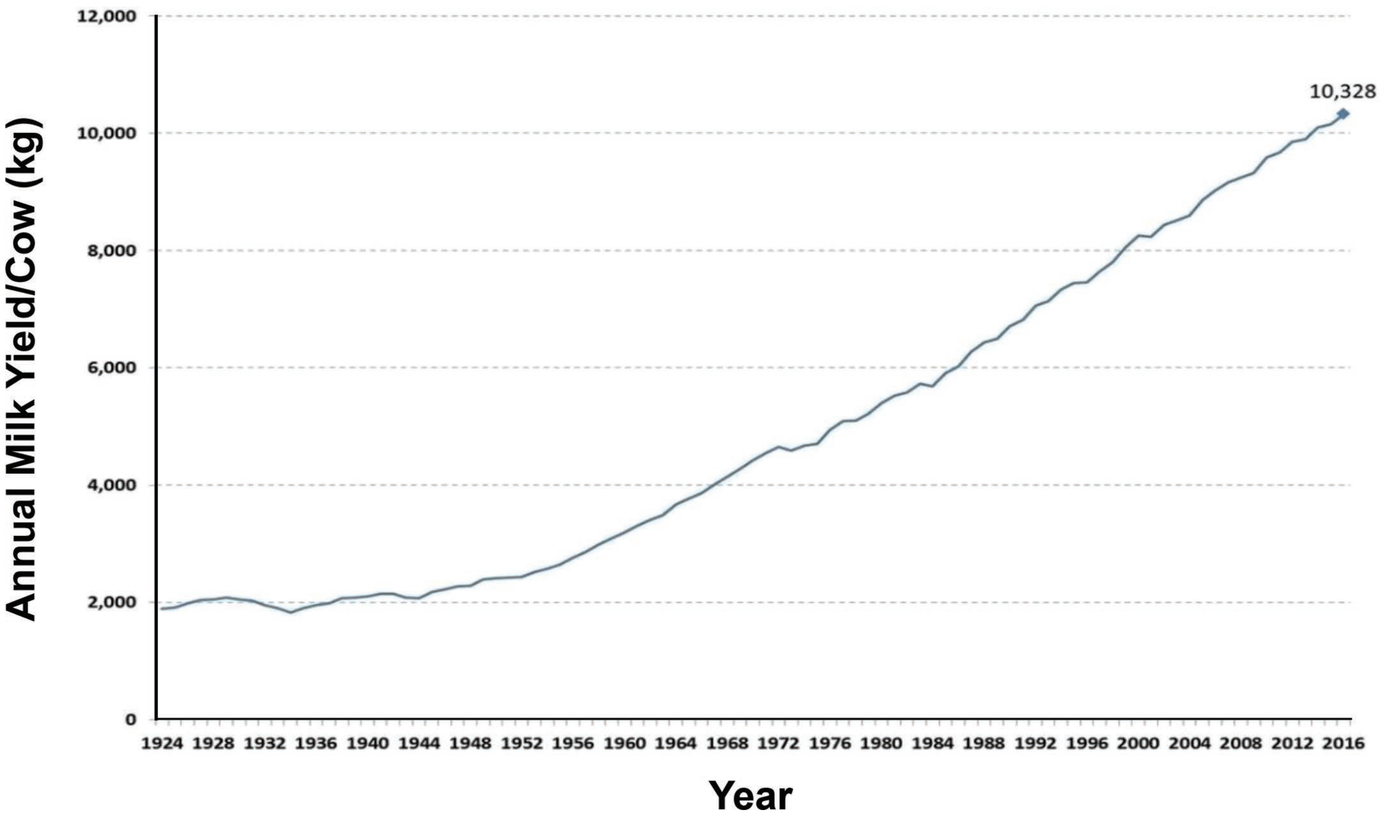

Figure 1. Average annual milk production in the United States per cow (https://quickstats.usda.nass/gov/; accessed February 20, 2017). Color version available online.

applying more accurate genetic selection methods, improved milking management practices and mastitis control, and the effective use of herd health programs to prevent disease (Collier et al., 2005). Furthermore, new technologies and management tools such as estrus synchronization, pregnancy detection, and bovine somatotropin have enhanced the production potential of dairy cows and allowed them to more nearly achieve their genetic capacity.

Lactation represents a substantial reorganization in the hierarchy of nutrient partitioning, and a dairy cow's metabolism is exquisitely coordinated to support the metabolic demands of milk synthesis. The mammary gland's synthetic capacity is so impressive that in the context of nutrient use and metabolism, Brown (1969) proposed the cow should be considered as an appendage to the udder, rather than vice versa. Herein, we will consider the cycle of life and advances in productive efficiency, review the broad concepts of regulation, and characterize specific tissue adaptations and mechanisms to support lactation (Appendix Table A1). Finally, we will speculate on upcoming challenges and opportunities for future discoveries in productive efficiency in dairy cows.

PRODUCTIVE EFFICIENCY

The continued increase in dairy cow productivity is a key component for the sustainability of the global dairy industry. Productivity or productive efficiency, defined as milk output per resource input, is improved as milk yield increases (Bauman et al., 1985; VandeHaar and St-Pierre, 2006). When the increase in milk yield/cow during the last 75 years is combined with improved crop productivity, feed use by the US dairy herd per unit of milk produced has been reduced by about 80% and carbon footprint has decreased by two-thirds (Capper and Bauman, 2013). Animal biology includes a series of processes in which dietary feed components are transformed and used to support body tissues and activities (Kleiber, 1961). Feed is consumed and digested products are assimilated and partitioned in a process governed by a physiological echelon; meeting maintenance requirements is top priority and secondary uses of absorbed nutrients are for productive functions such as milk synthesis or fetal development. Further, on a short-term basis, body reserves can be replenished or mobilized to support the hierarchical goals of nutrient trafficking.