ADSA Production Division Symposium: The rumen and beyond—Nutritional physiology of the modern dairy cow

488 Harnessing the physiology of the modern dairy cow to continue improvements in feed efficiency. Michael VandeHaar*[1], Diane Spurlock[2], and Louis Armentano[3], [1]*Michigan State University, East Lansing, MI,* [2]*Iowa State University, Ames, IA,* [3]*University of Wisconsin, Madison, WI.*

Feed efficiency, as defined by the fraction of feed energy captured in products, has more than doubled for the US dairy industry in the past 100 years. This increased feed efficiency resulted from increased milk production per cow achieved through genetics, 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. The dilution of maintenance has been the overwhelming driver of enhanced feed efficiency in the past, but its impact diminishes with each successive increment in production relative to body size. In the future, we must 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 energy to net energy more efficiently, or have lower maintenance requirements than expected based on BW, use less feed than expected and thus have lower 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. Helping all farms achieve the efficiency of the best farms would have a major effect on feed efficiency for the industry. Management practices such as TMR-feeding and grouping improve rumen function and efficiency, but they have decreased our attention on individual cows. Perhaps new computer-driven technologies will enable us to optimize efficiency 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, environmental sustainability, and profitability.

Key Words: efficiency, dairy cow, genetics

489 Development and physiology of the rumen and the lower gut: Targets for improving production efficiency. Michael A. Steele*[1], Greg B. Penner[2], Frédérique Chaucheyras-Durand[3], and Leluo Guan[1], [1]*Department of Agricultural, Food and Nutritional Science, University of Alberta, Edmonton, AB, Canada,* [2]*Department of Animal and Poultry Science, University of Saskatchewan, Saskatoon, SK, Canada,* [3]*Lallemand Animal Nutrition, Blagnac, France.*

It has been estimated that the gastrointestinal tract accounts for 30% of metabolic and protein synthesis activities of the cow and calf, and thus, plays an important role in animal energetics. Diet and microbiota can positively and negatively affect gut function and the ability to modulate gut function has created an applied interest relevant to improved dairy cow and calf productivity. The mechanisms that govern growth and barrier function of gut tissues have received particular attention, especially with the advancements of molecular based techniques over the past decade. The rumen has been the focal point of dairy cow and calf nutritional physiology research, yet the intestinal tract has received less attention. Three key areas requiring more discovery-based and applied research: (1) early-life intestinal gut barrier function and growth; (2) how the weaning transition affects gut health of rumen and intestine; and (3) gastrointestinal adaptations during the transition to high energy diets in early lactation. Nutrients are not only seen as substrates, but also as signals that can alter gastrointestinal growth and barrier function. Nutrients can act directly, affecting epithelial cell gene expression, and in concert with somatotropic axis hormones, insulin-like growth factor (IGF) and growth hormone where they have been shown to play a pivotal role in gut tissue growth. For example, IGF-1 can mediate other hormones involved in cell growth, such as glucagon-like peptide 2 (GLP-2), whereas, intestinal GLP-2 is secreted upon nutrient ingestion causing a stimulation of intestinal growth. The latest research suggests that total-tract barrier function in calves and cows in early life, at weaning and in early lactation is compromised. A major factor for gut health is maintaining proper gastrointestinal barrier function, which is highly influenced by the presence of metabolites (butyrate) and resident microbiota and/or direct fed microbials within the gut. In the first studies that investigated barrier function in cows and calves, it was determined that the expression of genes encoding mucin and tight junction regulating proteins, such as claudins, occludins and desmosomal cadherins, are regulated by diet. Additionally, recent evidence suggests that the upper and lower gut can communicate, but the exact mechanisms of gastrointestinal cross-talk have not been studied in detail. A deeper understanding of how diet and microbiota can affect growth and barrier function of the intestinal tract would provide knowledge of what specific management regimens could effectively impact gut function.

490 The contribution of the lower gut to altered nutrient partitioning during stress. Lance H. Baumgard*[1], Sara K. Stoakes[1], Mohannad Abuajamieh[1], and Robert P. Rhoads[2], [1]*Iowa State University, Ames, IA,* [2]*Virginia Tech University, Blacksburg, VA.*

Increased animal productivity and production variability are due to changes in nutrient partitioning. The coordination of nutrient trafficking is an incredibly complex system and how tissues/systems are reprioritized or de-emphasized during different physiological states is controlled by homeostatic and homeorhetic adaptations that probably incorporate every tissue and physiological system. There are a variety of situations in an animal's life-cycle that challenges homeostasis. The metabolic adaptations that cows utilize to copiously synthesize milk following parturition are unfortunately often referred to as "metabolic stress." Metabolic maladaptation to lactation results in ketosis and this is in part either caused by inadequate feed intake or causes reduced feed intake. Regardless, although heavily researched for the last 3 decades the specific etiology of periparturient ketosis remains elusive as it unclear why a small percentage of cows are susceptible (or predisposed?) to metabolic imbalances following calving. Heat stress (HS) compromises efficient animal production and jeopardizes animal welfare and HS animals also have a unique metabolic and physiological fingerprint that is uniquely different than their nutritional status predicts. The origin of both ketosis and HS issues may lie at the gastrointestinal tract. Increased intestinal permeability to lipopolysaccharide (LPS) and other luminal contents results in local and systemic inflammatory responses. LPS interferes with hepatic lipid trafficking, stimulates insulin secretion and influences systemic fuel selection. We demonstrated that both ketotic and HS animals have markedly increased circulating markers of leaky gut. We have also shown that reduced feed intake (a conserved response to stress) compromises intestinal integrity in both thermal-neutral monogastrics and ruminants. Thus, stressors that physically prevent ad libitum feed intake or cause voluntarily reductions in feed take may share a common mechanism(s). Defining the physiology and mechanisms that underlie how intestinal barrier dysfunction jeopardizes animal performance is critical for developing approaches to ameliorate current production issues.

Key Words: nutrient partitioning, intestine

491 Nutritional strategies to optimize dairy cattle immunity. Lorraine M. Sordillo*, *Michigan State University, East Lansing, MI.*

Dairy cattle are susceptible to increased incidence and severity of both metabolic and infectious diseases during the periparturient period. Health problems occurring around the time of parturition are especially problematic because they greatly affect the productive efficiency of cows in the ensuing lactation. A major contributing factor to increased health disorders is alterations in bovine immune mechanisms. Indeed, uncontrolled inflammation is a major contributing factor and a common link among several economically important diseases including mastitis, retained placenta, metritis, displaced abomasum, and ketosis. The nutritional status of dairy cows and the metabolism of specific nutrients are critical regulators of immune cell function. There is now a greater appreciation that certain mediators of the immune system also can have a reciprocal impact on the metabolism of nutrients. Thus, any disturbances in nutritional or immunological homeostasis can provide deleterious feedback loops that can further enhance health disorders, increase production losses, and decrease the availability of safe and nutritious foods for a growing global population. This review will discuss the complex interactions between nutrient metabolism and immune functions in periparturient dairy cattle. Details of how either deficiencies or overexposure to macro- and micronutrients can contribute to immune dysfunction and the subsequent development of health disorders will be presented. Specifically, the ways in which altered nutrient metabolism and oxidative stress can interact to initiate and promote uncontrolled inflammatory responses in transition cows will be discussed. Understanding more about the underlying causes of dysfunctional inflammatory responses may facilitate the design of nutritional regimens that will reduce disease susceptibility in early lactation cows. Given the critical role that nutrition plays in supporting all immune functions, nutritional-based management strategies should have a central position in any disease prevention program.

Key Words: immunity, inflammation, oxidative stress

492 Managing complexity: Dealing with systemic cross-talk in bovine physiology. Barry J. Bradford*, *Kansas State University, Manhattan, KS.*

Dairy producers rely heavily on advisors with deep expertise in nutrition, reproduction, and health. However, a shift is occurring, driven by both farm size and advances in biology. Larger dairy businesses can investigate management options with a degree of precision never before possible; simultaneously, the lines between the metabolic, immune, and reproductive systems are becoming blurred. For example, new research has revealed a surprising role for immune cells in regulating metabolism and documented the nutrient requirements of the immune system. The gut epithelium has garnered new attention as a tissue that actively manages the commensal microbiome, entrains the responses of the neonatal immune system, and provides a barrier limiting movement of molecules from the gut lumen. New hormone discoveries have added adipose tissue, bone, and muscle to the list of endocrine organs. Finally, nutrients are now seen not only as substrates and cofactors, but also as signals that can alter cellular function. What does all of this mean for the dairy industry? Consultants increasingly need to reach across disciplinary boundaries to best support the physiology of the cow. However, research is needed to move beyond proof-of-principle findings toward applications in dairy cattle. Key unanswered questions include: the degree to which roles of the hindgut in monogastrics translate to ruminants; whether host/microbe crosstalk also occurs in the rumen; whether hormone release by storage organs during a catabolic state affects reproductive function; and the degree to which immunostimulation by dietary signals enhances or disrupts health and productivity. It is critical to address these questions with a 2-pronged approach. Mechanistic studies provide a nuanced understanding of signal interactions, but large-scale commercial studies are also needed to evaluate effects on multiple production outcomes in the environment of interest. Incorporating all aspects of animal health and productivity in management decisions will remain an art for the foreseeable future, but this should not dissuade the industry from pursuing a more holistic approach to management of the cow.

Key Words: physiology, endocrinology, dairy cow