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In Appreciation of Dr. Larry D. Satter—How a Career-Long Effort in Nutrition Research Will Serve Livestock Production in the Future*

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ABSTRACT

Dr. Satter's main research accomplishments rest in the central role that he played in developing the current understanding of nitrogen utilization by ruminant animals, especially dairy cattle. Dr. Satter's willingness to constantly reassess strongly held dogmas has led to a series of breakthroughs. This article highlights 6 areas of his research program that have become classics or benchmarks in the field of protein nutrition of ruminants, as well as his latest effort in revisiting phosphorus requirements in dairy cattle. Dr. Satter's work has contributed substantially to more accurate dietary recommendations for nitrogen and phosphorus, with invaluable economic and environmental benefits to the U.S. dairy industry. Serendipity does not explain the success and impact of his research. Dr. Satter is also a "relevant generalist" who is committed to communicating research results to a broad audience. Because he broadened the definition of "proper" nutrition to include nutrient excretion in manure, his work has contributed to reduction in environmental risks associated with manure management on farms and has propelled nutrition research into the area of nutrient management of animal feeding operations.
(**Key words:** career achievement, agricultural sustainability, nitrogen, phosphorus)

INTRODUCTION

Dr. Satter's 39 yr of service as a researcher and administrator are truly remarkable. Over the years, Dr. Satter has held responsibilities as professor in the Department of Dairy Science, University of Wisconsin—Madison; co-lead research scientist and, for 11 yr, director of the USDA Dairy Forage Research Center, president of the American Dairy Science Association, and first president of the Federation of Animal Science Societies (FASS) Board of Directors.

Shortly after Dr. Satter announced his retirement, a group of colleagues discussed how to best recognize the accomplishments of his career. The idea of organizing a symposium at the national meeting was received with enthusiasm by a rapidly growing number of people who had known and worked with Larry over the years. The theme of the symposium would have to do with nitrogen, an uninterrupted focal point of his research effort; it would have to relate to phosphorus also, because of his recent contribution in this area; and the symposium would highlight his scientific contribution in the context of the environmental challenges that face the livestock industry today and in the years ahead.

Covering all areas of Dr. Satter's research interest and his contribution to the scientific literature would be enormous and remains outside the scope of this paper. However, given the aforementioned premises, the primary objective is to highlight Dr. Satter's contribution to nitrogen and phosphorus nutrition of ruminants, in the context of improving the economic and environmental sustainability of livestock operations, and in particular dairy operations.

Protein Nutrition

The 6 research areas described below represent only a fraction of Dr. Satter's research effort of the last 3 decades. However, they have been chosen as a way to highlight the contribution of Dr. Satter to the field of protein nutrition and to illustrate how, directly or indirectly, his work has laid the foundation for current efforts in reducing manure nitrogen excretion and associated environmental risks.

Determination of Minimal Concentration of Ammonia inRumen Fluid for Maximal Microbial Growth

In a series of experiments in the early 1970s, Dr. Satter demonstrated that rumen microbes can scavenge ammonia from very dilute solutions to meet their nitrogen requirements. In a publication that earned a "Cita-

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tion Classic" from the Science Citation Index, Dr. Satter and his coworkers demonstrated that 2 m*M*, or 5 mg NH3-N/100 mL of ruminal fluid support maximal microbial growth and that higher concentrations were without effect on microbial yield (Satter and Slyter, 1974). Although these values are to be adapted for today's high-producing cow diets, this original work and other work that followed (Roffler and Satter, 1975) spurred nutritionists all over the world to revise the prevalent ruminant protein utilization concepts of the time. It also led to much more rational use of nonprotein nitrogen supplements in dairy and beef diets.

Development of a New Approach for Expressing Protein Requirements and Protein Utilization by Dairy Cows

At about the same time, Dr. Satter's effort also focused on developing a more accurate system of predicting protein supply in ruminants. With collaborators, he developed a protein system that accounted for microbial protein synthesis in the rumen, nitrogen recycling into the gut, average degradability of protein sources, and other aspects of nitrogen metabolism (Roffler and Satter, 1975; Roffler et al., 1976). The main publication outlining this approach also went on to become a "Citation Classic" (Satter and Roffler, 1975). This effort, along with those of others in the forefront of the scientific community, lead to the demise of the crude protein and/or digestible protein systems that had been in vogue until then. There is no doubt that the work of Dr. Satter and his colleagues deserve credit for the development of the now familiar concepts of rumen degradable protein and rumen undegradable protein that are built in current feeding systems of North America and Western Europe.

Identification of the Limiting Amino Acids for Milk Production

In the late 1970s, Dr. Satter and his students experimented with abomasal infusion of individual or mixtures of amino acids and eventually demonstrated unequivocally that lysine and methionine were the 2 most limiting amino acids for milk production in cows fed primarily corn grain and corn silage (Schwab et al., 1976). Subsequently, several manufacturers have proceeded to develop lysine and methionine products that are protected from rumen degradation. This research has been carried on by a number of researchers around the country and continues to be of interest in the context of precision feeding.

Measuring Extent of Dietary Protein Degradation in the Rumen and Intestinal Digestion of Protein

Dr. Satter's research program continued with an intense effort to measure the extent of protein degradation and protein synthesis by rumen microbes and intestinal digestibility of protein in the early 1980s. During this period, Larry's research utilized at any one time as many as 20 intestinally cannulated cows. While some of his students experimented with rare earth elements to characterize digesta flow and residence time in distinct compartments of the gastro-intestinal tract (Hartnell and Satter, 1979), others developed quantitative information on protein degradation of feedstuffs (Stern, Rode et al., 1983; Santos et al., 1984; Stern et al., 1983). This work was cited extensively in the National Research Council publication on Ruminant Nitrogen Usage (1985) that Dr. Satter coauthored (NRC, 1985).

Determining Optimal Heat Processing of Soybeans to Increase their Nutritional Value for Lactating Cows

In the early 1990s, proper heat treatment of soybeans to increase their value as a protein supplement for lactating dairy cows was studied in a series of experiments involving in vitro protein degradation measurements, rat growth studies to measure heat damaged protein (Falder et al., 1992), and in vivo experiments with cattle. Larry's laboratory not only defined the proper temperature but also standardized a quality control test for heat-processed soybeans (the Protein Dispersibility Index, PDI; Hsu and Satter, 1995), and quantified the expected milk production response to roasted soybeans (Faldet and Satter, 1991). The impact of this work on the dairy industry was illustrated by informal surveys indicating that the roasting of soybeans for inclusion in dairy diets rose from an estimated 40,000 t per year (1.5 million bushels) in the late 1980s to about 610 million metric tons per year (22.4 million bushels) in the late 1990s.

Identifying Protein Rather than Energy as First Limiting in Alfalfa Silage

Also in the early 1990s, another series of experiments involving abomasal infusion of glucose or casein demonstrated that protein was more limiting than energy when cows were fed high quality alfalfa silage supplemented with minerals and vitamins only (Cadorniga and Satter, 1993; Dhiman et al., 1993; Dhiman and Satter, 1993). This research challenged the traditionally held view that dairy diets containing a high proportion of alfalfa would have inadequate energy and that

protein would be in excess of the lactating cow's requirements. A follow-up trial was aimed at optimizing the proportion of alfalfa silage and corn silage in dairy rations to sustain high levels of milk production, while minimizing manure nitrogen excretion (Dhiman and Satter, 1997).

Phosphorus Nutrition

Dr. Satter has played a major role in the last 7 yr in determining the phosphorus requirements of high producing dairy cows. When this research was started, there was little confidence in the National Research Council recommendation for phosphorus feeding (0.36 to 0.49% of diet DM). After survey data showed that producers were feeding about 0.48% phosphorus, long-term lactation trials were conducted to evaluate the minimum concentration of dietary phosphorus required for high levels of milk production (Wu and Satter, 2000). Results demonstrated no impact of high dietary phosphorus levels (0.48 to 0.49% of ration DM) on milk production, but high dietary concentration of phosphorus greatly increased phosphorus excretion in manure compared to diets containing 0.31 or 0.40% phosphorus (Wu et al., 2000). At the lower end of the scale, early signs of phosphorus deficiencies (measured using bone phosphorus and ash concentrations) began to show up, but milk production remained unaffected, when dietary phosphorus was reduced to 0.30 to 0.32% of diet DM (Wu et al., 2001).

In his latest effort, Dr. Satter and his collaborators followed hundreds of cows to dispel a long-held belief by skeptics that dietary phosphorus should be kept high in order to maintain good reproductive performance of the herd. Overall, results showed that dietary phosphorus of 0.38% of ration DM (which has a "safety factor" already built into it) does not lower milk production nor reproductive performance in high producing dairy cows (Wu and Satter, 2000; Lopez et al., 2002).

Going from Nutrition to Environmental Management of Livestock Operations

The role of agriculture in preserving water and air quality is increasingly recognized in our society today. Excessive loss of phosphorus from over-fertilized agricultural fields to surface water has contributed to impaired water quality in countless watersheds around the country (Sharpley and Tunney, 2000; Heathwaite et al., 2000). Similarly, agriculture, and in particular the livestock industries, have been identified as major contributors of ammonia release in the atmosphere (Erisman et al., 1999) with negative impacts on human health, ecosystem imbalance and acid rain (EPA, 2000b). Agricultural nonpoint source pollution that degrades water and air quality has become a focal point of policy makers under the Clean Water Act (EPA, 2000a) and the Clean Air Act (EPA, 2002), respectively.

Under the Clean Water Act, the final rules released earlier in 2003 by the EPA will insure that Concentrated Animal Feeding Operations (CAFO's) manage manure effectively in order to protect the nation's water quality. The measures in place aim to reduce phosphorus release into the environment by 25,400 t and nitrogen release by more than 45,400 t (EPA, 2003).

One of the remarkable features of Dr. Satter's accomplishments is the natural fit between his career-long disciplinary research programs in nutrition with the multidisciplinary, systems-oriented research required in the context of nutrient management challenges facing livestock operations. In this broader context, Dr. Satter's research has contributed significantly to limiting nitrogen and phosphorus excretion in livestock manure with concomitant reduction in environmental risk, associated with manure management on farms.

Of his own account, Dr. Satter has estimated that diets balanced with regard to rumen degraded protein and rumen undegraded protein, and containing proper proportions of amino acids can result in a 10 to 15% reduction in dietary protein concentration with no loss in animal performance. This reduction can result in a 20 to 30% reduction in urinary nitrogen excretion, and a similar reduction in volatile ammonia loss from urine to the atmosphere. Similarly, reduction of dietary phosphorus from current levels (about 0.45% of diet DM in the nation's dairy herd) to an adequate amount that provides a margin of safety (0.38%) will reduce phosphorus excretion in manure of dairy cattle by 20%, and reduce potential for phosphorus runoff from surface applied manure by about two-fold. The results of Dr. Satter's research effort, and those of others who have altered diets of ruminants and nonruminant species to decrease potential for nitrogen and phosphorus pollution, have been included in a recent publication of the Council for Agricultural Science and Technology (CAST, 2002).

The *Relevant Generalist* Beyond the Focused Nutritional Scientist

Why has Dr. Satter's research made such an impact on the nutrition research community, the feed and consulting industry, and in the community of producers? Part of the answer to this question is found in his scientific achievements, part of it in him as a person, and part of it is because he has been relevant generalist. A relevant generalist is a person who sees the tree in a forest and knows which one needs attention next. In

other words, this is a person who uses the scientific method to answer specific questions, always keeping in mind the broader context, in this case, improving the sustainability of livestock farming systems. The research is rooted in a scientific discipline, but remains connected to current issues related to livestock production systems. A broad understanding of farming issues is an essential asset of a relevant generalist. Larry has been a relevant generalist in more than one way.

First, throughout his career, Larry has formulated hypotheses and designed key experiments that led to new insights that fundamentally improved the practice of feeding ruminants.

Second, Larry has never been satisfied with the status quo of the prevalent theories in his fields of interest. His work has challenged many dogmas and long-held views for the purpose of creating more effective and sustainable dairy production systems.

Third, Larry has been relentless in trying to communicate his results to those who could use them. Larry has always kept his fingers on the pulse of the industry and, armed with the power of scientific evidence, he changed the course and the discourse regarding protein and phosphorus nutrition of livestock ruminants.

CONCLUSIONS

Dr. Satter has constantly reassessed strongly-held nutrition dogmas throughout his career and his fundamental research has played a central role in developing our current understanding of how protein is uniquely digested in ruminant animals. Also, Dr. Satter's work has led to more accurate dietary recommendations for nitrogen and phosphorus in ruminant diets. The livestock industry, and in particular the dairy industry, has benefited tremendously from improved efficiencies in protein utilization and concomitant reduction in feeding costs.

In keeping with his nutritional area of expertise, but broadening the definition of proper nutrition in the latter years of his career to include nutrient excretion in manure, Dr. Satter without a doubt, has placed nutrition as a key component of research in the area of nutrient management of animal feeding operations. As illustrated in this paper, all along the more than 39 yr of his research career, Dr. Satter's work has laid the scientific foundation for our current efforts to reduce nitrogen and phosphorus excretion in manure.

Larry's career-long effort is a story that had to be told, and it is fitting that his outstanding contribution be acknowledged and honored as a way to introduce this symposium.

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