Energy Use in Digestion, and Increasing the Digestibility of Forages with Processing Technologies

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Francis L. Fluharty, Ph.D.
Department of Animal Sciences
The Ohio State University

Feed costs are rising, and corn price projections are currently maintaining between $4.95 and $5.35 per bushel on corn futures through December 2010 (Source: http://www.card.iastate.edu/iowa_ag_review/winter_08/article4.aspx). This equals $.088 to $.095 per pound, or $176 to $190 per ton. Dried distillers grains and corn gluten feed are currently in this same price range, and the prices of other alternative feeds are keeping pace on an energy and protein basis, so there are no cheap supplemental feeds for cow-calf producers, stocker cattle operations, or feedlots. Therefore, forage-based operations must utilize cost effective management tools that maximize forage digestibility.

All nutrients (energy, protein, vitamins, minerals, and water) are used in a hierarchy that goes from maintenance → development → growth → lactation → reproduction → fattening. This means that an animal's maintenance needs must be met before any other functions can occur. For example, a cow that has calved and is in lactation will take longer to re-breed if her nutrient requirements are not being met. If she is three years old, or younger, and still growing, her nutrient requirements will be even higher. Considerable evidence has shown that a large proportion of an animal's maintenance energy requirements can be attributed to the visceral organs, especially the liver and gastrointestinal tract, and appear to be associated with the high rates of protein synthesis in these tissues (Ferrell and Jenkins, 1985). The maintenance energy requirements of organs change with the relative weights of the organs and are affected by the level of nutrition (Ferrell et al., 1986). Burrin et al. (1989) fed lambs a high-concentrate diet either at a maintenance level of intake, or were offered as much feed as they could consume (ad libitum). They reported that the O_2 consumption, a measure of energy expenditure, in the portal-drained viscera and liver of the lambs fed at maintenance intake was 37 and 63% lower, respectively, than in the lambs offered feed ad libitum. Later, Burrin et al. (1992) reported that the level of feed intake affected visceral organ mass without changing the DNA mass of the organ. They concluded that changes in visceral organ mass due to changes in the level of feed intake result from changes in cellular hypertrophy (cell size) rather than changes in cell number. Differences in intestinal mass, and differences in energy source could have rather large implications in metabolic efficiency and growth. The energy sparing effects of restricted feeding on visceral organs occur primarily through reductions in organ size (Fluharty and McClure, 1997).

Fluharty et al. (1999) reported on the effects of limit-feeding a high-concentrate diet that was formulated to provide daily energy and protein intakes equal to lambs grazing alfalfa, resulting in the same ADG between the two groups. The lambs fed the high-concentrate diet had lower intestinal organ weights, and retained more than twice as much nitrogen (a measure of protein status) on a daily basis compared with lambs that grazed alfalfa, resulting in carcasses with a larger loin-eye area and more lean yield, demonstrating the large energy and protein requirements of the intestinal organs. Therefore, dietary manipulation can be used to alter nutrient utilization and muscle and fat deposition through altering tissue requirements. These reductions in maintenance energy and protein requirements are the basis for the enhanced feed efficiencies achieved with most limit-fed, grain-based feeding systems, are partially responsible for the greater feed efficiency and average daily gain which occur when growing cattle are taken from forage-based grazing systems to grain-based feedlot diets. These same principles offer potential with harvesting or post-harvest processing technologies that reduce the particle size of forages, thereby increasing their digestibility and increasing microbial protein.

In contrast to cattle being fed grain-based diets, the size of the rumen limits the amount of energy that can be consumed with forage-based diets, and digestible energy intake decreases with increasing forage maturity. As explained by Zinn and Ware (2007), the terms digestibility and digestion are often misused. "Digestibility is qualitative, referring to the susceptibility to degradation. In contrast, digestion refers to the extent of degradation." Ruminal fiber digestion is a function of the rate of digestion of the forage and the rate of passage of the forage particles from the rumen. From a practical standpoint with unprocessed forages, the large particle size of mature forage reduces the energy available to the animal. For digestion to occur, the microorganisms in the rumen must first be associated with the forage, and then attach to the forage. Digestion normally occurs from the inside of the forage to the outer layers. Limitations to the speed at which this occurs include the physical and chemical properties of the forage, the moisture level of the forage, time for penetration of the waxes and cuticle layer, and the extent of lignification (Varga and Kolver, 1997). Undigested feed is broken down through the process of rumination and re-chewing until it is either digested, or small enough to pass from the reticulo-omasal orifice. Most particles leaving the rumen are smaller than 1mm, although particles as large as 5 cm may leave the rumen (Welch, 1986). It is, therefore, not hard to understand how reducing the large particle size of many mature forages to 1mm to 5 cm can increase maintenance energy expenditures due to an increase in visceral organ mass and the energy expenditure of rumination and re-chewing. Furthermore, the conversion of fibrous forages to meat and milk is not efficient, with only 10 to 35% of the energy intake being captured as net energy to the animal, because 20 to 70% of the cellulose may not be digested (Varga and Kolver, 1997).

With mature forages, and crop residues such as wheat straw, or corn stover that are harvested for feed, lignin content can be a limiting factor. Wheat straw is approximately 14% lignin, and corn stover is approximately 7% lignin. However, in many parts of the world, straw is fed as a roughage source to ruminant animals. While long-stem straw has a very low digestibility, varying between 35% and 55%, Dr. M.G. Jackson, Professor of Animal Nutrition at the G.B. Pant University of Agriculture and Technology, Pantnagar, India, reported 'the grinding of straw increases consumption leading to higher digestible energy intakes of the order of 30%. In terms of net-energy intake the increase is somewhat more than this because the net-energy value of straw is increased by grinding.' (Source: http://www.fao.org/DOCREP/003/X6510E/X6510E02.htm).

Dr. Steven Loerch, at The Ohio State University, investigated the potential of using processing technologies to improve the utilization of prairie hay. Dr. Loerch reported that "One effective option producers rarely consider is hay chopping. Chopping hay allows the cows to eat 25-30% more energy. Costs of chopping hay (equipment, labor, etc.) should be compared to costs of purchasing supplemental energy. For some producers, this may be a cost effective option. I came to realize the potential of hay chopping from an observation at the OARDC Beef Center in Wooster. Steers fed a chopped hay based diet gained 2.5 lbs/day while those fed round baled hay (same hay source) in a rack gained less than 1.5 lbs/day." (Source: http://beef.osu.edu/library/AltFeedSuplong.pdf). This can be explained on the basis of more surface area being available for degradation, allowing for a more rapid rate of digestion; a faster rate of passage of indigestible components from the rumen allowing for an increase in feed intake, and the possibility that these factors allowed for an increase in propionate production due to a faster rate of digestion, and an increased rate of passage of indigestible components (Hintz et al., 1999).

Finally, harvesting techniques have been found to result in improvements in forage digestibility. Williams et al. (1995) harvested wheat forage with a mower conditioner, at an early head stage of maturity, and allowed it to wilt for either 0, 6 or 20 hours prior to being cut with a forage chopper and ensiled. They reported that wilting for 20 hours resulted in lower fermentation acids, a higher concentration of water-soluble carbohydrates, and improved fiber digestibility compared with either direct-cut or wilting for 6 hours. Finally, Hintz et al. (1999) reported that maceration, an intensive forage conditioning process that shreds forage thus reducing rigidity and increases field drying rates by as much as 300% by disrupting the waxy cuticle layer of the plant and breaking open the stem, resulted in an increase in surface area available for microbial attachment in the rumen, a decreased lag time associated with NDF digestion, an increase in NDF digestion, while having a decrease in the acetate:propionate ratio, which would be positive for growing and finishing animals.

If forage is evaluated on a price per pound, rather than a price per ton, the necessity to maximize digestibility becomes apparent. If corn is $5.04 per bushel, it is $.09 per pound. Likewise, if dried corn gluten feed or distillers dried grains are $180 per ton, they are $.09 per pound. If hay is $180 per ton, it is $.09 per pound. Normally, the digestibility of corn, corn gluten feed, and distillers dried grains are all much higher than even the highest quality hay. Therefore, in order for forages to be economically competitive, they must be managed, harvested, and potentially processed to their optimum digestibility. In summary, high prices for all feeds will necessitate that beef producers adopt grazing practices and forage harvesting and processing technologies that reduce the animal's energy and protein requirements through reducing visceral organ mass; increase the digestibility of forages through providing more sites for bacterial attachment; and use technologies and products that increase the microbial protein yield.

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