12 Dairy Cattle Nutrition and the Environment

The dairy industry is developing intensive management systems in which cows are fed and housed in large groups. Consolidation of large numbers of dairy cattle into small land areas to improve the efficiency of milk production may contribute to environmental problems unless animals are fed and managed properly. However, any size dairy herd that does not have proper nutrition, feeding, management, and waste-disposal programs has the potential to pollute the environment. If cows are fed excessive amounts of dietary nutrients that are not used efficiently for milk production, large amounts of the nutrients will be excreted in feces and urine, resulting in pollution of the environment and increased cost of milk production (Chandler, 1996).

Developments in dairy cattle nutrition will be important in determining the ability of the dairy industry to produce a nutritious, wholesome product at an economic cost without polluting the environment (Clark and Overton, 1995). Dairy cattle should continue to be fed and managed to increase the production and the efficiency of production of milk and milk components because this will require fewer cows to produce the same quantity of milk and milk components; this will increase the efficiency of nutrient use and decrease the excretion of waste products. Although high-producing dairy cows are the ruminants most efficient at converting nutrients in feed to food for human consumption, not all nutrients consumed by dairy cows are secreted in milk. Dairy cattle must be fed to meet their requirements with minimal excesses of nutrients in the diet if the efficiency of nutrient use and milk production by dairy cows are to be maximized and nutrient losses to the environment reduced. The most successful feeding regimens will be the ones that supply nutrients in amounts required to optimize synthesis of milk and milk components, maximize ruminal fermentation and growth of ruminal microbes, and minimize nutrient losses to the environment. Development and adoption of improved dairy cattle feeding systems driven by the concept of nutrient management to meet nutrient requirements and to prevent environmental pollution will result in increased efficiency of nutrient use.

The U.S. Environmental Protection Agency has issued its definition of the term "concentrated animal feeding operation" for purposes of permit requirements and specifying limits on pollutant discharges from feedlots (Meyer and Mullinax, 1999; Meyer, 2000). The U.S. Environmental Protection Agency and the U.S. Department of Agriculture have drafted national guidelines that suggest comprehensive nutrient management plans for concentrated animal feeding operations. Users should become informed to be sure they are in compliance with all federal and state regulations. These activities have taken place because of the quantity and odor of the solid, liquid, and gaseous waste products produced when waste from large numbers of animals concentrated in a small area is not well managed (Lanyon, 1994; Miner, 1997; Van Horn et al., 1994). Large amounts of waste can create disposal problems and odors and result in more strict actions for waste disposal unless the cows are fed to meet but not exceed the required amount of nutrients and waste is properly managed to prevent environmental pollution. Components of voluntary guidelines and future plans, if implemented by the government, are concerned with feed management to reduce excreted nutrients, manure handling and storage, the application of manure and other wastes to crops and land, and recordkeeping.

From an environmental standpoint, nitrogen and phosphorus are the nutrients of primary concern, and ammonia, carbon dioxide, hydrogen sulfide, and methane are the gases of primary concern (Tamminga, 1992; Chase, 1994; Van Horn et al., 1994; Chandler, 1996; Johnson et al., 1996; Koelsch and Lesoing, 1999; Kuipers et al., 1999; Nelson, 1999). The loss of other mineral nutrients in animal waste might become important in the future. Successfully defining nutrient requirements of dairy cattle will minimize nutrient losses in feces, urine, and gases. Reducing nutrient losses in waste from cattle and developing good waste management practices will decrease the concerns about the effects of waste disposal on the environment.

NITROGEN

Nitrogen is of primary environmental concern because of losses of ammonia in the air and because of nitrate contamination of surface water and groundwater (Tamminga, 1992; Van Horn et al., 1994). Large amounts of nitrogen are brought onto dairy farms in purchased feeds. Much of this nitrogen remains on the farm rather than being incorporated into milk, animal tissue, and crops that are sold from the farm (Korevaar, 1992; Aarts et al., 1992; Klausner, 1993). Klausner (1993) indicated that purchased feeds supplied 62–87 percent of the total nitrogen on farms and that the percentage of total nitrogen taken to farms in feeds increased as herd size increased because a larger percentage of the feeds was purchased rather than grown on the farms. The percentage of the total nitrogen inputs that remained on the farm ranged between 64 and 76 percent but was not related to herd size (Klausner, 1993). The fraction of total nitrogen that remained on Dutch farms was 85 percent (Korevaar, 1992). To prevent environmental pollution and ensure efficient nutrient use, a nutrient management plan should be developed for the farm that will determine the movement and quantity of nutrients entering, leaving, and remaining on the farm; a nutrient application schedule that ensures that the rate and timing of manure and fertilizer applications are in concert with crop requirements while minimizing loss; and a crop selection and rotational sequence that provides quality feed, improves nutrient recycling, and reduces runoff and erosion (Klausner, 1993).

Dairy cows on average secrete in milk 25–35 percent of the nitrogen that they consume (Chase, 1994; Chandler, 1996), and almost all the remaining nitrogen is excreted in feces and urine. Van Horn et al. (1994) indicated that total excretion of nitrogen in waste products can be determined by subtracting the amount secreted in milk from the amount consumed. Feeding nitrogen in excess of requirements, feeding excessive amounts of ruminally degradable protein, or feeding diets not properly balanced for ruminally degradable and undegradable protein, amino acids, or energy may increase nitrogen excretion in feces or urine (Pell, 1992; St-Pierre and Thraen, 1999). As milk production increases, nitrogen excretion in feces and urine per unit of milk produced decreases (Chandler, 1996; St-Pierre and Thraen, 1999).

Ammonia and organic nitrogen are the major forms of nitrogen in manure (Van Horn et al., 1994). This nitrogen is from undigested feed, microbial protein, endogenous nitrogen, and urea and ammonia nitrogen excreted in urine. Some 40–50 percent of the total nitrogen excreted in manure is from urea and ammonia nitrogen excreted in urine (Van Horn et al., 1994). Urea is rapidly converted to ammonia in the presence of urease. In an acidic environment ammonia (NH_3) reacts with H^+ to form the nongaseous ammonium ion (NH_4^+); this reaction prevents the loss of NH_3 to the atmosphere. However, most dairy cow manure provides little acid for converting NH_3 to NH_4^+, and it releases large amounts of NH_3 into the atmosphere. In fact, 50–75 percent of the nitrogen can be lost from manure mostly as NH_3 before nitrification to nitrate (NO_3^-) (Van Horn et al., 1994). Excessive concentrations of NH_3 in closed buildings can lower animal performance and pose a potential health hazard for cows and people. In addition, NH_3 emitted into the air can cause acid rain. If excessive nitrogen is applied to land in manure, NO_3^- can contaminate surface water and leach into the groundwater.

Many aspects of dairy cattle nutrition will probably contribute to improving the efficiency of nitrogen use in the future, including optimizing the intake of nitrogen, ruminal fermentation, the synthesis of microbial protein, and the passage of ruminally protected amino acids to the small intestine; absorption and postabsorption metabolism of nitrogen; and the further development of integrated computer models, feeding systems, and waste-management systems based on new scientific information generated from research to determine nutrient requirements, increase efficiency of nutrient use, and decrease excretion of nutrients into the environment (Clark and Overton, 1995).

It will be difficult to determine an exact amount of crude protein to include in the diet that will provide optimal performance in all situations. The amount of crude protein needed in the diet will be influenced by milk yield, milk protein percentage, growth rate, body size, amount and type of energy in the diet, and amino acid composition and degradability of dietary protein. Feeding diets that do not meet requirements of ruminal microbes and dairy cows decrease nutrient digestibility and production of milk and milk components. An adequate supply of nitrogen is essential for maximizing carbohydrate digestibility in the rumen (Oldham, 1984). Carbohydrate makes up the largest percentage of diets fed to dairy cattle, and anything that increases carbohydrate digestibility increases energy availability to cows, decreases the volume of manure produced, and reduces concerns about waste disposal. In contrast, feeding a diet that contains too much crude protein is wasteful, detrimental to the environment, inefficient for dairy cattle because energy must be used to synthesize urea that is excreted in urine, and costly to dairy farmers because the protein is not used for productive functions by dairy cows.

Feeding high-quality forages that are produced on the farm will improve nutrient management and increase dry matter (DM) intake. Maximizing DM intake will allow dairy producers to feed diets that contain a lower percentage of crude protein and that will improve the efficiency of nitrogen use by dairy cows and decrease the amount of protein supplement that must be purchased (Chase, 1994). A 5 percent increase in DM intake decreases the percentage of crude protein required in diets by about 1 percentage point (Chase, 1994). Feeding total mixed rations formulated from feeds analyzed to supply the exact amount of nutrients required by dairy cows on the basis of milk production, milk composition, body size, and pregnancy status will be essential for maximizing efficiency of nitrogen use and minimizing environmental pollution.

Optimizing ruminal fermentation, microbial protein synthesis, and passage of selected nutrients to the small intestine of dairy cattle offers potential for improving nutrient management (Clark and Davis, 1983). During ruminal fermentation, dietary protein is degraded to a mixture of peptides, amino acids, and ammonia, and this supplies precursors for synthesis of microbial protein. Excess ammonia is absorbed through the ruminal wall and transported to the liver to be detoxified by synthesizing urea. Any urea that is not recycled to the gastrointestinal tract is excreted in urine; this represents a nitrogen loss from cows to the environment. Both nitrogen and carbohydrates are required for microbial growth; synchronization of carbohydrate and protein degradation should increase incorporation of nitrogen into microbial protein (Hoover and Stokes, 1991; Clark et al., 1992). Digestibility of dry matter, efficiency of microbial protein synthesis, and synthesis of microbial protein in the rumen were maximized when diets contained 10–13 percent of the dietary DM as ruminally degradable protein and 56 percent of the total carbohydrate as nonstructural carbohydrate (Hoover and Stokes, 1991); however, further refinement of these estimates is needed. Increasing feed intake and the amount of organic matter digested in the rumen will supply additional energy to fuel microbial growth if both protein and carbohydrates are in adequate supply and their degradation is synchronized (Clark et al., 1992). Faster growth of microorganisms coupled with faster passage of microorganisms to the small intestine resulting from increased feed intake should decrease recycling of energy and nitrogen in the rumen because of decreased cell lysis; this will decrease maintenance requirements and trap more nutrients for growth of the microorganisms (Clark et al., 1992; Russell et al., 1992).

Microbial protein supplies a large quantity of the total amino acids passing to the small intestine; therefore, differences in passage of individual amino acids to the small intestine when different diets are fed often are small (Clark et al., 1992). From a nutrient-management perspective, it is essential that use of amino acids be optimized for production of milk and milk protein if dairy cows are to use crude protein from the diet most efficiently. Schwab (1994) reported that methionine and lysine were limiting for production of milk and milk protein when they made up less than 5 and 15 percent respectively of the total essential amino acids passing to the small intestine. Feeding protein supplements of low ruminal degradability to cows has not consistently increased the passage of methionine and lysine to the small intestine, probably because synthesis of microbial protein often is decreased (Clark et al., 1992). Even though passage of methionine and lysine to the small intestine can increase in some situations, passage of other amino acids to the small intestine probably will increase also, and the desired ratio of amino acids will not be correctly balanced; the imbalance will result in inefficient use. Feeding diets that contain lower concentrations of crude protein supplemented with balanced quantities of rumen-protected amino acids should minimize excretion of nitrogen in the urine.

The contributions of small peptides to microbial growth in the rumen have not been quantified in dairy cattle. Ruminal bacteria might transport peptides more rapidly and efficiently than single amino acids (Chen et al., 1987), and growth and efficiency of growth of ruminal bacteria are improved when amino acids or peptides are supplied, as opposed to ammonia (Maeng and Baldwin, 1976a, b; Maeng et al., 1976). Therefore, the potential exists to improve the efficiency of microbial protein synthesis by manipulating the quantity and composition of peptides supplied to the ruminal microorganisms.

Few data are available to quantify the absorption and metabolism of amino acids by splanchnic tissues of lactating dairy cows, but the use of many amino acids by the portal-drained viscera is substantial (Reynolds et al., 1994). Furthermore, the contribution of peptides to amino acid absorption and transport is relatively unknown (Reynolds et al., 1994). Substantial quantities of amino acids are probably absorbed from the gut as short peptides (Webb et al., 1992, 1993), but research is needed to provide a better understanding of absorption and metabolism of amino acids and peptides by tissues of lactating dairy cows. Data on the effects of amount and composition of peptides on ruminal microorganisms and tissues of dairy cattle could unlock mechanisms that will improve the efficiency of nitrogen use and decrease nitrogen output in urine and feces.

PHOSPHORUS

In some parts of the United States and in many other countries, the amount of waste that can be generated by a farm operation is regulated and limited by law. For instance, in the Netherlands in 1987, laws were enacted that limited the amount of phosphorus that could be applied to the land to 55 kg/hectare. That corresponded to limiting agriculture to about three cows or 17 pigs per hectare (Korevaar and den Boer, 1990). Regulatory agencies usually give special attention to the role of phosphate as an environmental pollutant, because it is relatively easy to measure and does not volatilize or leach away, as does much of the nitrogen excreted into manure and applied to the land. Phosphate in manure that is applied to the land is usually adsorbed onto soil particles, so it does not leach into water tables or into waterways; therefore, it builds up in the soil (Pierzynski et al., 1994). It will erode into waterways with soil and causes environmental concern because it is considered to be the nutrient that limits growth of most aquatic plants (Sharpley et al., 1994). From a regulatory standpoint, it is also felt probable that if an excessive amount of phosphate is being excreted and applied to the land, an excessive amount of nitrogen is also being lost to the environment.

Nearly two-thirds of the phosphorus found in common feedstuffs is unavailable to nonruminant animals because it is bound to the organic acid phytate. In contrast, ruminal microorganisms effectively break down phytate, making a greater proportion of dietary phosphorus available to ruminant animals. In the subcommittee's model the coefficients of absorption of phosphorus from the diet are 64 percent for forages, 70 percent for concentrates, and $>$ 70 percent for most of the inorganic sources of phosphorus.

Once the phosphorus needs of cows have been met by the diet, most of the extra phosphorus will be excreted in the feces and urine. Morse et al. (1992) fed lactating Holstein cows diets that contained phosphorus at 0.30, 0.41, and 0.56 percent, which supplied 60, 82, and 112 g of phosphorus/day, respectively. On the basis of the 1989 National Research Council requirements, the cows were fed 79, 108, and 147 percent of their phosphorus requirement. According to the current model in this publication, the cows required a diet that provided 58–62 g of phosphorus/day. Cows fed 60 g/day of phosphorus in the diet, which provided less than required, excreted 42.1 g of phosphorus in feces and urine. Cows fed 82 g/day of phosphorus excreted 50.6 g/day of phosphorus in feces and urine, or 5 g for each 22 g of phosphorus fed in excess of requirements. Cows fed 112 g/day of phosphorus excreted 79.9 in feces and urine. Increasing dietary phosphorus intake from 82 g/d to 112 g/d (a 30 g/d increase) increased phosphorus excretion in feces and urine by 29.3 g/d. Wu et al. (1998) and Satter and Wu (1999) showed that the loss of fecal phosphorus increased greatly once the needs of the animal were met, which occurred at about 0.35 percent dietary P in their experiment. They also showed that the dietary requirement for phosphorus can be met with diets that are below the requirement suggested in the 1989 National Research Council publication which was 0.48 percent in diets for cows in early lactation and 0.41 percent in diets for cows in later lactation. Many dairy rations contain phosphorus in excess of the needs of cows. A survey of nutritionists indicated that the average concentration of phosphorus in diets fed to commercial herds was about 0.52 percent for high-producing dairy cows (Sansinena et al., 1999).

SUMMARY

Dairy cattle should be fed to meet but not to exceed their nutrient requirements. Feeding diets that are deficient in any nutrient will decrease production of milk and milk components; however, feeding excessive amounts of a nutrient will decrease the efficiency of nutrient utilization, which results in increased nutrient excretion into the environment, increased cost of milk production, decreased profits for dairy producers, and increased costs for the consumers of dairy products. Production of milk by dairy cows causes losses of nutrients in feces and urine that can not be prevented. Because nutrients accumulate on dairy farms, nutrients should be managed to ensure efficient nutrient cycling with a minimum impact on the environment.

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