CHAPTER 3b

Decreasing Nitrogen and Phosphorus Excretion by Dairy Cattle

T. Q. Sudduth and M. J. Loveless

INTRODUCTION

In 1996, the Council for Agricultural Science and Technology (CAST) published a report entitled *Integrated Animal Waste Management*. One of the recommendations in that report was to "change animal diets to decrease nutrient outputs" (CAST 1996, 1). Since that time, concentration of animal production units has continued, public concern about the environmental effects of animal manure has increased, and the Environmental Protection Agency (EPA) has proposed more restrictive requirements for concentrated animal feeding operations (CAFO regulations).

Progress has been made since 1996 to decrease nutrient outputs by animals through diet modification and nutrition. The current study describes the existing technological advancements, the decrease in nutrient outputs possible, the degree of acceptance by poultry and livestock producers, and the potential for further technological advancements.

This study focuses on two nutrients and addresses two environmental concerns. The nutrients are nitrogen (N) and phosphorus (P). Nitrogen is a part of amino acids (AAs) that form *proteins* required by all animals; animals consume protein and AAs and then excrete various forms of N. Phosphorus is a mineral nutrient required for bone growth and many important bodily functions. But these nutrients, if directly discharged into surface water in runoff or deposited in water from aerial emissions, can cause significant water pollution.

The first environmental concern is the *volatilization* of N in the form of ammonia (NH_3) from animal manures. Volatilized ammonia returns to the land or water via rainfall, *dry precipitation*, or direct absorption. Volatilized ammonia also can contribute to odor problems. Although ammonia may be beneficial as a fertilizer for agricultural fields, it may not be beneficial in other ecosystems. Manure in the form of a slurry when injected into the soil will have minimal losses of ammonia. The higher the N content of the manure, the greater the risk of ammonia loss. For example, most beef cattle are produced in open feedlots. Ammonia losses can represent as much as 70% of the N excreted by those cattle.

The second environmental concern is manure nutrient distribution. Manure is an excellent fertilizer for crop production. If manure nutrients are applied at rates equivalent to plant needs, then environmental impacts are minimal. If manure is applied at higher rates, however, N can leach into groundwater and P can build up in the soil and contaminate the surface water, harming the environment. As livestock and poultry units have increased in size, it has become more expensive to return manure to the cropland where the feed for the animals originated. The manure distribution problem can be local, regional, national, or even international. For example, approximately one-half of the corn grown in Nebraska is exported to other states or to foreign countries. Although there are many cattle feedlots in Nebraska, there is more than enough land on which to spread manure. Conversely, if Midwestern corn is exported to Texas for cattle production, to North Carolina for swine production, or to Delaware for broiler production, it is difficult to return the nutrients to the land where the crops originated.

Decreasing the N and P excreted by poultry, swine, or cattle can minimize these two concerns. In the past, there has been little pressure to decrease excretion, so livestock and poultry producers have typically overfed protein (N) and P. Researchers have made key advances in this field during the past decade. Source reduction is the logical starting point to lessen the environmental impact. Significant changes are occurring, but more can be accomplished.

NITROGEN

Nitrogen on dairy farms can be a threat to air and water quality when more manure nutrients are applied per acre than can be recycled through grain and forage production, as well as when manure nutrients are stored incorrectly or applied to the land improperly (Hutson et al. 1998; Wang et al. 1999). Studies have shown that on the typical dairy farm, N imported in feed, fertilizer, and N fixation in legumes exceeds that exported as protein in milk or meat by 62 to 79%; of this excess N, 62 to 87% comes from imported feed (Klausner 1993). Approximately 70% of the excess N escapes into the off-farm environment through volatilization, *denitrification*, and *leaching* into groundwater (Hutson et al. 1998).

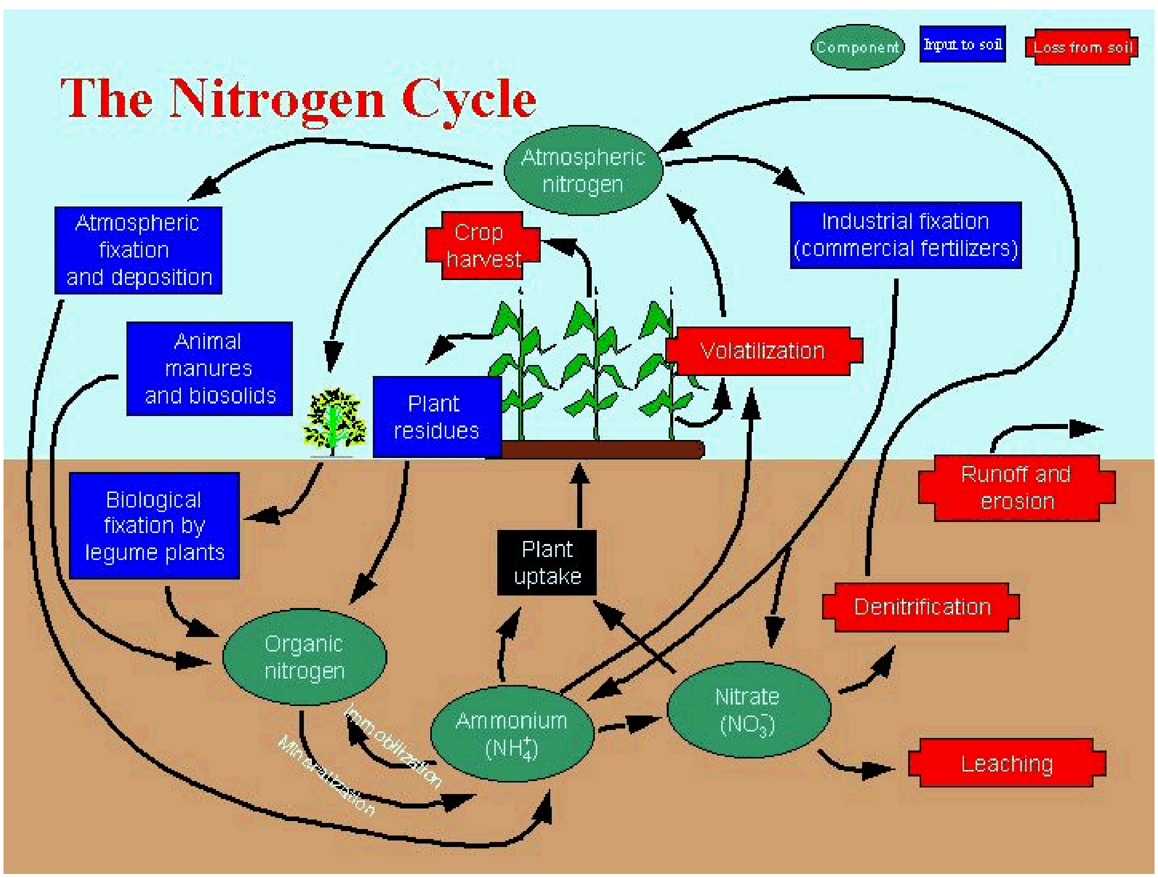
Precision Feeding

Dairy cattle require protein for maintenance and for production (pregnancy, growth, and lactation). In addition, microorganisms are present in the digestive system of cattle that require N for microbial growth during ruminal fermentation of feeds. The N from protein supplied in excess of required amounts is excreted primarily as urea in the urine, and much of the excreted N is volatilized because of urease activity in feces (Hutson et al. 1998; Rotz et al. 1999). Precision feeding is needed to minimize excess N. The first step in precision feeding is to group lactating cows in the herd according to their requirements based on the amount of milk produced. The next step is to determine accurately the requirements of each group to ensure optimum production while minimizing excess N.

Protein imported to meet dairy cattle requirements can be minimized by optimizing the amount of *rumen degraded protein*, which is used to synthesize microbial protein, and *rumen undegraded protein*, which can supply AAs directly to the intestine. The key to optimizing microbial protein production is to supply the rumen with fermentable carbohydrates, which stimulate microbial growth, along with N sources that meet microbial N requirements. Two primary groups of bacteria ferment feed in the rumen: those that ferment sugars and starches and those that ferment fiber. Microbes that ferment sugars and starches prefer peptides and AAs as their N source, and adequate concentrations of ruminally degradable dietary protein act as a growth stimulant to this group. Fiber-fermenting microbes rely solely on NH3 as their N source; the NH3 comes primarily from nonprotein N sources in forages and urea, as well as from the degradation of feed protein. An imbalance of protein or feed N sources in the diet can cause excess ruminal NH3 that is absorbed through the rumen wall and excreted in urine and milk as urea.

Accumulated scientific knowledge about ruminal and animal requirements and available nutrients in feeds has aided in the development of computer models for on-farm precision feeding of dairy cattle (Fox et al. 2000; NRC 2001). These programs use actual farm information to predict animal requirements and diet energy, ruminally available energy and N, and AA available to the animals from the diet in each production situation. To meet the specific AA demands of high-producing cows, the computer model will suggest that certain feeds be included with low protein degradability in the rumen, which will increase the needed AA supply to the small intestine.

In a study reported by Klausner and colleagues (1998), precision feeding decreased N excretion by 34% while improving milk production. Milk production increased 13% and economic returns improved by more than $40,000 per year for a 320-cow dairy herd. Similar results were reported in other studies (Rotz et al. 1999; Tylutki and Fox 2000).



Adoption

There are several reasons why precision feeding and whole-farm nutrient planning have not been adopted on a widespread basis. The emphasis in feeding is on maximizing animal production and profits rather than on minimizing excretion of nutrients. Least-cost ration balancing and the growing use of byproduct feeds results in excess N in many diets. In addition, diets typically are formulated to have a margin of safety to minimize production risk due to variation in the composition of the diet delivered to each animal group. Increased knowledge of requirements, coupled with improved analytical methods for feeds and improved accuracy in delivery of the formulated diet to the intended group of animals, should result in producers and nutritionists using smaller safety margins.

Potential for Decreasing Excess Nitrogen

Studies have shown that implementing whole-farm plans that integrate nutrient management across herd, crop, soil, and manure components can decrease nutrient concentrations on dairy farms while increasing economic returns (Rotz et al. 1999; Tylutki and Fox 2000; Wang et al. 2000). Implementation of these changes must not compromise milk production, growth, reproduction, or animal health. These plans
focus on two goals: decreasing protein inputs brought on the farm by more accurately formulating diets as described previously and improving the efficiency of nutrient use through improved feed and crop management strategies.

Suggested actions to meet these goals include the following:

1. **Obtain accurate and representative feed assays for feeds used in the dairy operation to allow precision feeding with minimum margins of safety**. Inadequate forage analysis and lack of control of the ingredient dry matter content of feeding were predicted to increase both annual variation in nutrient excretion (242 lbs of N excretion and 63.8 lbs of P excretion) and feed inventory required (60.5 tons of corn silage) and to decrease income over feed costs ($21,792) per 100 cows (Tylutki et al. 2000).

2. **Use high-quality forages**. To increase the amount of forages in the diets, forage quality must be high. For example, maximum intake from forages was expected when the neutral detergent fiber (NDF) content was as follows: alfalfa, 40%; grasses, 55%; and corn silage, 40 to 45% (Tylutki and Fox 2000). Many dairy farms do not have an adequate land base to produce their own grains; therefore, farmers should maximize forage quality and then choose purchased concentrates that accurately supplement their forages.

3. **Improve feeding accuracy**. The addition of feeding error was predicted to increase both annual variation in P excretion (17.6 lbs) and corn silage inventory (9.02 tons) and to decrease income over feed costs ($19,148) per 100 cows (Tylutki et al. 2000).

4. **Reformulate rations to improve accuracy as intake changes**. Chase (1999) calculated that by increasing intake 5%, it is possible to decrease diet *crude protein* about one percentage unit to achieve the same pounds of protein intake.

5. **Control the amount of refusals**. On most farms, feed refusals from the lactating herd are fed to replacement heifers, a practice that can result in excess N in the heifers' diet. The amount of refusals should be adjusted to achieve maximum *dry matter intake*; however, extremely high refusals need to be avoided.

6. **Use milk production, milk components, and milk urea N to track the impact of changes in diet formulation and feeding management**. Milk urea N can be used as an indicator of diet protein deficiency or excess (normal range is 12 to 18 milligrams/deciliter).

7. **Obtain manure analysis so land application can account for N and P concentration alterations due to diet modifications**.

PHOSPHORUS

Recent surveys conducted in the United States indicate that producers typically formulate dairy diets to contain 0.45 to 0.50% P (dry basis). This amount is approximately 20 to 25% in excess of the NRC suggested requirement (NRC 2001). This excess P supplementation costs $10 to $15 per cow annually (approximately $100 million annually in the United States) and may contribute to excessive P loading of soils through manure application.

There are several reasons why dairy producers feed more P than is required. Until recently, research information has been lacking on the P requirement of high-producing cows, particularly research that clearly identifies the minimum amount of P required to avoid deficiency symptoms. This lack of information, coupled with inconsistent feeding standards in Europe and North America, contributed to uncertainty about the dietary P requirement. Perhaps the most important factor contributing to excessive P supplementation of dairy cows, however, is the prevailing belief that adding P to the dairy diet will improve the herd's reproductive performance. Aggressive marketing of P supplements also has contributed to unrealistic margins of safety in diet formulation programs.

A number of studies have demonstrated that adding P to diets containing large amounts of low quality roughage can improve reproductive performance in cattle. A study in England by Hignett and Hignett (1951) is cited widely on this topic. What is often overlooked, however, is that the diets in these studies typically contained 0.10 to 0.25% P before P supplementation. At these low dietary concentrations, P is likely to be deficient for rumen microorganisms (Durand and Kawashima 1980), resulting in decreased diet digestibility and lowered *microbial protein synthesis*. Decreasing both available energy and protein with these low-quality diets could indeed decrease reproductive efficiency. Thus, the P effect on reproductive performance is a secondary one, expressed through a decreased supply of protein and energy. There is no evidence of a direct effect of P on reproductive performance. Modern dairy diets seldom contain less than 0.30 to 0.35% P before the addition of a P supplement. This amount of P is more than adequate for rumen microorganisms. A review of lactation studies using more typical dairy diets shows no relationship between dietary P content and reproductive performance (Satter and Wu 1999).

Requirement for Phosphorus

The recent publication *Nutrient Requirements of Dairy Cattle* (NRC 2001) provides an excellent summary of the literature on P feeding of dairy cows. The recommended P concentration of diets for cows producing 55 or 121 lbs of milk daily is 0.32 and 0.38% (dry basis), respectively. A study appeared after the NRC publication (Wu et al. 2001) that measured bone strength and P content of cows fed diets containing approximately 0.31, 0.39, or 0.47% dietary P for two or three consecutive lactations. The study indicated that the 0.31% P diet was borderline deficient for cows producing more than 25,960 lbs of milk in a 305-day lactation. Results of this study and a study by Valk and Sebek (1999) establish that high-producing dairy cows will begin to show signs of P deficiency when the diet contains less than 0.30% P. Knowing this amount allows calculation of a reasonable margin of safety rather than guessing, as has been the practice. Although the NRC (2001) described requirements, they used conservative estimates to determine P availability in feedstuffs; so, in fact, a modest safety margin is already included in the NRC requirements.

Decreasing Dietary Phosphorus

Phosphorus fed in excess of a cow's requirement is excreted in the feces, with only small amounts excreted in the urine. Storage of P in the body is limited to the amount present in normal bone mass, but bone P and calcium are mobilized in early lactation to meet the sudden demands of lactation. As much as 500 to 1000 grams (g) of P may be mobilized from bone in early lactation; this P, of course, must be replaced later in lactation. Milk contains approximately 0.09% P; so P mobilized from bone can support a significant amount of milk production in early lactation, which avoids the need to have enriched dietary concentrations of P in early lactation when feed intake lags behind milk production.

Dietary phosphorus recommendations usually are discussed on the basis of *percent of dietary dry matter (% of DM)* while requirements really are for a quantity that needs to be absorbed from the digestive tract. Thus percentages can be misleading. For example, 69 grams of dietary phosphorus (P) is an amount that might be considered a requirement for cows producing 100 lbs. of milk per day (Nutrient Requirements of Dairy Cattle, National Research Council (NRC), 2001). The amount of dry matter that cows are eating in which 69 grams of P is incorporated has a big effect on the needed percentage of dietary P. This is illustrated in the following table.

Lb DMI	% Phosphorus in diet to supply 69 grams intake
59	.360%
58	.366%
57	.373%
56	.379%
55	.386%
54	.393%
53	.400%
52	.408%
51	.416%
50	.425%
49	.433%
48	.443%
47	.452%
46	.462%
45	.472%
44	.483%

Implications

High-producing dairy cows consuming diets containing 0.31, 0.39, or 0.47% dietary P excreted 43, 66, and 88 g fecal P/day, respectively (Wu et al. 2001). Essentially all of the P fed in excess of the 0.31 % treatment was excreted in the feces. Feeding high-P diets increases not only the P content of the manure but also the vulnerability of the manure P to surface runoff. When manure collected from cows fed diets containing 0.31 or 0.49% P was surface applied to plots at equal manure application rates, concentrations of dissolved reactive P in water runoff were almost ten times higher with manure from cows fed the higher-P diet Ebeling et al. 2002). Most P is insoluble and is associated with soil, but the dissolved reactive P is soluble in water and with rainfall or snowmelt will be in the water runoff. When manure was applied at equivalent P rates, runoff of dissolved reactive P was approximately four times higher with manure from cows fed the higher-P diet. One might expect, therefore, that decreasing dietary P from an industry average of 0.45 to 0.50% to the NRC requirement of 0.38% P (high-producing cows) could decrease surface runoff from manure by a minimum of 50%. The plots used in this study had recently been harvested for corn grain that had been no-tilled.

Thus, decreasing dietary P has two important effects. First, the amount of P in manure decreases, and, therefore, the amount of cropland required using the manure decreases proportionately. Second, the risk of runoff of P from surface-applied manure is decreased when lower concentrations of P are fed. Decreased risk of runoff P is relevant for all dairy producers that surface-apply manure, regardless of the amount of land they have available for spreading manure. The majority of dairy diets formulated today contain 0.35 to 0.40% P before addition of a P supplement. Therefore, by eliminating some or all of the supplemental P, most producers will be able to reach appropriate dietary P concentrations. But producers that use large amounts of by-product feeds containing high concentrations of P may be feeding diets that contain 0.42 to 0.46% P without a P supplement. By-product feeds are often priced lower than grains or oilseeds, so their use in dairy diets is increasing, and it is difficult to minimize P feeding. Dairy producers who choose to include large amounts of byproduct feeds rich in P will need to consider injecting manure into the soil as well as using a larger landmass to accept the manure.

Future Benefits of Advances

A 20% decrease of dietary P can be achieved without decreasing animal performance, and this decrease will result in a 25 to 30% decrease in the P content of manure and a similar decrease in the amount of land required for manure application. Perhaps more importantly, runoff of dissolved reactive P from surface-applied manure can be decreased by more than 50% if dietary concentrations of P are decreased by 20%. The dairy industry has started to lessen dietary P concentrations, but progress to date may be characterized as simply a good beginning.

GLOSSARY

Bacterial protein (BCP). The crude protein in rumen bacteria, made up of amino acids and nucleic acids.

Bioavailability. The amount of nutrient in the diet that can be absorbed in a form that can be used in the body for metabolic functions of that nutrient.

Crude protein. A measure of dietary protein that is based on the assumption that the "average" amino acid in a protein contains 16% nitrogen. Thus, total chemically determined nitrogen x 6.25 (100 divided by 16) = crude protein.

Crystalline amino acid. Amino acid provided in its pure chemical form.

Cystine. A sulfur-containing amino acid that can supply up to one-half of the total sulfur amino acid (methionine + cystine) requirement.

Degraded intake protein (DIP). Crude protein that is degraded in the rumen by microorganisms.

Denitrification. The process whereby fixed nitrogen is converted to nitrogen gas ($N2$) and nitrous oxide and returned to the atmosphere.

Dry matter intake. The amount of completely dry feed consumed by animals.

Dry precipitation. Chemicals combining in the atmosphere and falling to the earth.

Ideal protein. A protein with a balance of amino acids that exactly meets an animal's amino acid requirements.

Leaching. The process whereby plant nutrients move down through soil into groundwater.

Lysine. A basic amino acid required for tissue maintenance and growth.

Metabolizable protein (MP). Protein (amino acids) absorbed from the small intestine of ruminants. Contains bacterial protein and undegraded intake protein.

Methionine. A sulfur-containing amino acid required for tissue maintenance and growth.

Microbial protein synthesis. The process whereby protein is synthesized in the rumen as microorganisms grow and multiply.

Near infrared spectroscopy. Feed analysis using near infrared lightwave reflectance.

Phase-feeding. Changing the nutrient concentrations in diets as animals age to meet their nutrient requirements more precisely.

Phytase. An enzyme that degrades phytate, making the phosphorus available.

Phytate. A complex, organic form of phosphorus.

Protein. A polymer composed mainly of amino acids, which contain the elements carbon, hydrogen, oxygen, nitrogen, and sulfur.

Rumen degraded protein. See degraded intake protein.

Rumen undegraded protein. See undegraded intake protein.

Sparing effect. The process whereby one chemical or metabolite decreases the need or requirement for another nutrient.

Undegraded intake protein (UIP). Feed protein that is not degraded in the rumen by microorganisms.

Volatilization. The process whereby chemicals evaporate at ambient temperature.

LITERATURE CITED

Council for Agricultural Science and Technology (CAST). 1996. *Integrated Animal Waste Management*. Report Number 128. Council for Agricultural Science and Technology, Ames, Iowa.

Durand, M. and R. Kawashima. 1980. Influence of minerals in rumen microbial digestion. Pp. 375–408. In Y. Ruckebusch and P. Thivend (eds.). *Digestive Physiology and Metabolism in Ruminants*. MTP Press Ltd., Lancaster, England.

Ebeling, A. M., L. G. Bundy, J. M. Powell, and T. W. Andraski. 2002. Dairy diet phosphorus effects on phosphorus losses in runoff from land-applied manure. *Soil Sci Soc Am J* 66:284-291.

Ellenberger, H. B., J. A. Newlander, and C. H. Jones. 1950. Composition of the bodies of dairy cattle. *Vt Agric Exp Stat Bull* 588:1–66.

Fox, D. G., T. P. Tylutki, A. N. Pell, M. E. Van Amburgh, L. E. Chase, R. E. Pitt, L. O. Tedeschi, V. J. Durbal, and C. N. Rasmussen. 2000. The Net Carbohydrate and Protein System Version 4.0: A computer program for evaluating herd nutrition and nutrient excretion. Animal Science Department Mimeo 213. Cornell University, Ithaca, New York.

Hignett, S. L. and P. G. Hignett. 1951. The influence of nutrition on reproductive efficiency in cattle. I. The effect of calcium and phosphorus intake on the fertility of cows and heifers. *Vet Rec* 63:603–609.

Hutson, J. L., R. E. Pitt, R. K. Koelsch, and R. J. Wagnet. 1998. Improving dairy farm sustainability. II. Environmental losses and nutrient flows. *J Prod Agric* 11:233–239.

Klausner, S. D. 1993. Mass nutrient balances on dairy farms. Pp. 126-129. *Proceedings of the Cornell Nutrition Conference*. Animal Science Department, Cornell University, Ithaca, New York.

Klausner, S. D., D. G. Fox, C. N. Rasmussen, R. E. Pitt, T. P. Tylutki, P. E. Wright, L. E. Chase, and W. C. Stone. 1998. Improving dairy farm sustainability. I. An approach to animal and crop nutrient management planning. *J Prod Agric* 11:225-232.

National Research Council. 2001. *Nutrient Requirements of Dairy Cattle*. 7th ed. National Academy Press, Washington, D.C.

Rotz, C. A., L. D. Satter, D. R. Mertens, and R. E. Muck. 1999. Feeding strategy, nitrogen cycling, and profitability of dairy farms. *J Dairy Sci* 82:2841–2855.

Satter, L. D. and Z. Wu. 1999. Phosphorus nutrition of dairy cattle: What's new? Pp. 72–80. In *Proceedings of the Cornell Nutrition Conference for Feed Manufacturers*. Cornell University, Ithaca, New York.

Tylutki, T. P. and D. G. Fox. 2000. Quality control in herd nutrient management. Pp. 130–143. *Proceedings of the 2000 Cornell Nutrition Conference*. Animal Science Department, Cornell University, Ithaca, New York.

Tylutki, T. P., D. G. Fox, M. McMahon, and P. McMahon. 2000. Using the Cornell Net Carbohydrate and Protein System Model to evaluate the effects of variation in maize silage quality on a dairy farm. In J. P. McNamara (ed.). *Modeling Nutrient Utilization in Farm Animals*. CABI International, New York.

Valk, H. and L. B. J. Sebek. 1999. Influence of prolonged feeding of limited amounts of phosphorus on dry matter intake, milk production, reproduction and body weight of dairy cows. *J Dairy Sci* 82:2157–2163.

Wang, S. J., D. G. Fox, D. J. R. Cherney, S. D. Klausner, and D. Bouldin. 1999. Impact of dairy farming on well water nitrate level and soil content of phosphorus and potassium. *J Dairy Sci* 82:2164–2169.

Wang, S. J., D. G. Fox, D. J. Cherney, L. E. Chase, and L. O. Tedeschi. 2000. Whole herd optimization with the Cornell Net Carbohydrate and Protein System. III. Application of an optimization model to evaluate alternatives to reduce nitrogen and phosphorus mass balance. *J Dairy Sci* 83:2160– 2169.

Wu, Z., L. D. Satter, A. J. Blohowiak, R. H. Stauffacher, and J. H. Wilson. 2001. Milk production, estimated phosphorus excretion and bone characteristics of dairy cows fed different amounts of phosphorus for two or three years. *J Dairy Sci* 1738–1748.