Dairy Cattle Diets, Manure Chemistry, & Soil Nutrient Cycles: How Do They Relate?

J. Mark Powell and Lori Bocher, U.S. Dairy Forage Research Center, USDA-ARS

Milk is only about half of what a cow produces from her diet. Manure is produced in nearly equal amounts. And while most milk leaves the farm as a desirable end product, manure has different fates – both desirable and undesirable. The desirable outcomes are those in which nutrients stay on the farm to help produce more feed and milk; and the undesirable outcomes are those in which nutrients enter the environment where they may have detrimental effects.

In the past, the emphasis mainly has been on conserving manure nutrients through manure and crop management practices – how to collect and store, when to spread, where to spread, how to spread, and so on. But relatively little is known about relationships among the types and amounts of forages fed to dairy cows, manure chemistry, and soil nutrient cycles. Can changes in the diet improve the utilization of manure nutrients in the field? This article will look at the nitrogen component of diets and manure.

The nitrogen contained in dairy feces can be divided into two general pools: (1) endogenous nitrogen consisting of microbial products and microorganisms from the rumen, the intestine and the hind gut, plus the nitrogen originating from the digestive tract itself; and (2) undigested feed nitrogen (or fiber nitrogen).

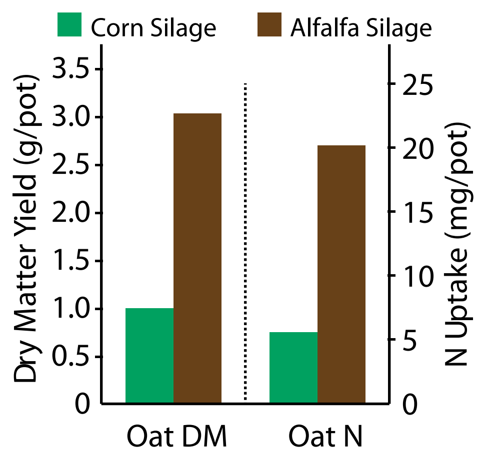
After land-application, each chemical component of dairy manure has differential impacts on soil nitrogen and carbon cycles. For example, whereas endogenous nitrogen in feces may make a significant contribution to crop nitrogen requirements the year following manure application, fecal fiber nitrogen mineralizes much more slowly in soil and is, therefore, unavailable to plants over the short term.[abcd]

The following sections of this article provide a synopsis of integrated dairy nutrition/soil science research aimed at quantifying relationships among dairy cattle diets, manure chemistry, nutrient cycles, and the environmental impacts of milk production.

Forage Type & Amount . . .

Over the past decade, the most significant shift in dairy diets has been an increase in the amount of corn silage fed to dairy cows with a subsequent decrease in the amount of alfalfa fed. The reasons for feeding more corn silage are clear to most producers and consultants: high dry matter yield, higher energy content, more uniform quality, and fewer required harvests. But relatively little is known about whether or not this change in forage type is having a detrimental effect on the fertilizer value of manure and/or soil quality on dairy farms; little is known about relationships among the types and amounts of forages fed to dairy cows, manure chemistry, and soil nutrient cycles.

Figure 1. Plant yield (left axis) and plant N uptake (right axis) when oats received manure from dairy cattle fed corn silage versus dairy cattle fed alfalfa silage.



Research has determined positive relationships between dietary crude protein in dairy cow diets and slurry nitrogen mineralization in soil; high nitrogen content in the diet increases nitrogen in manure, mostly as urinary nitrogen, which is hydrolyzed then mineralized readily by soil microorganisms into plant-available nitrogen forms. This same research showed a negative relationship between the fiber contained in slurry and mineralization of slurry nitrogen in soil; high fiber diets increased the fiber content in manure, so the manure is mineralized very slowly by soil microorganisms.[e]

Research in Wisconsin determined that the types and relative proportions of forages fed to lactating dairy cows impact the chemical composition of feces.[f] Highest concentrations of total nitrogen and fiber nitrogen (not readily available) were found in feces from cows fed birdsfoot trefoil-based forage diets. An intermediate level of fiber nitrogen (not readily available) was determined in feces from cows fed corn silage-based diets, and the lowest concentrations were determined in feces from cows fed alfalfa silage-based diets.

After application to soil, feces derived from cows fed a greater proportion of corn silage than alfalfa silage significantly reduced plant available nitrogen in the soil compared to soils amended with feces from diets that contained lower amounts of corn silage. And in a companion greenhouse trial, plant yield and nitrogen uptake were also significantly lower in pots amended with feces from corn silage-based diets than in pots amended with feces from alfalfa silage-based diets.[g] (Figure 1).

Overall, the long-term environmental impacts (such as soil erosion abatement and sequestration of carbon in soil) associated with forage production are likely more important than the short-term impacts on manure chemistry and manure nitrogen availability in soil. However, the differential mineralization of fecal nitrogen in soil due to forage consumption could enhance nitrogen uptake by crops and decrease nitrous oxide (N_2O, a greenhouse gas) losses from cropland.

Dietary Crude Protein Levels . . .

One of the easiest ways to put more nutrients into milk production, and less into manure, is to choose efficient crude protein levels for the diet. Of the total nitrogen consumed by cows on typical confinement-based dairy farms, a general range of 20-35% is secreted in milk and the remaining is excreted approximately equally in feces and urine (mostly urea, the most volatile form of nitrogen). Feed nitrogen use efficiency by the cow, and the 50:50 ratio of fecal to urinary nitrogen excretion, can be highly influenced by a wide range of feed management practices.

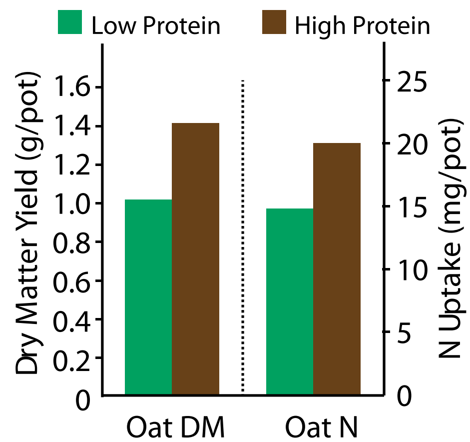
For example, well-balanced diets that contain about 16.4% crude protein maximize milk production and feed nitrogen use efficiency often making it a positive choice in terms of farm profitability. A well-balanced diet also minimizes urinary nitrogen excretion by dairy cows,[h i] making it a positive choice in terms of reducing ammonia emissions from dairy farms. On the flip side, as dietary crude protein increases above this requirement level, feed nitrogen use efficiency declines and excretion of urinary nitrogen increases.[j] An increase in dietary crude protein from 15.1 to 18.4% was found to decrease feed nitrogen use efficiency from 31 to 25% and increase the relative excretion of urinary nitrogen from 23 to 35% of the nitrogen consumed.[k]

About 75-80% of urinary nitrogen is in the form of urea. After excretion, urea is hydrolyzed rapidly to ammonium by urease enzymes found in feces and soil. Depending on pH, ammonium is transformed into ammonia gas and lost to the atmosphere. The increase in urea nitrogen excretions due to excessive feeding of dietary crude protein increases ammonia emission from dairy barns, manure storage, and after manure land application.

As detailed in the previous paragraphs, the impacts of dietary crude protein level on milk production, feed nitrogen use efficiency, urinary nitrogen excretion, and ammonia emissions from dairy barns and soils have been documented. While reduced urinary nitrogen excretion and ammonia emissions may lead to the desirable outcome of improved air quality, it has been suggested that lower dietary crude protein levels may also impact the amount of manure nitrogen available for crop uptake, crop yield, and manure nitrogen use efficiency.[l m]

For example, after application to soil, slurry from cows fed a higher (19.4%) crude protein diet emitted approximately four times more ammonia than slurry from cows fed a lower crude protein (13.6%) diet.[n] However, after ammonia volatilization subsides (48 hours after slurry application), plant available nitrogen levels are greater in soils amended with the higher crude protein slurry than in soils amended with the lower crude protein slurry.[o] Also, the application of feces from cows fed a high crude protein diet leads to higher levels of plant nitrogen uptake and plant yield than feces from cows fed a low crude protein diet (Figure 2). However, manure nitrogen use efficiency (percentage of applied manure nitrogen that is taken up by a crop) was found to be lower when dairy manure was derived from cows fed a high crude protein diet (18.2%) than when manure was derived from cows fed a low crude protein diet(13.6%).[p]

Figure 2. Plant yield (left axis) and plant N uptake (right axis) when oats received manure from dairy cattle fed low protein diet versus dairy cattle fed high protein diet.



Results from various dairy nutrition trials, and the research reported in this article, lend strong evidence that diets can be formulated to meet the needs of healthy, high producing cows while at the same time producing manure that has more desirable impacts on the environment.

References

[a]Sørensen, P., E.S. Jensen, and N.E. Nielsen. 1994. Labeling of animal manure nitrogen with 15N. Plant and Soil 162:31-37.

[b]Somda, Z.C., J.M. Powell, S. Fernández-Rivera, and J.D. Reed. 1995. Feed factors affecting nutrient excretion by ruminants and fate of nutrients when applied to soil. p. 227-246. In J.M. Powell, S. Fernández-Rivera, T.O Williams, and C. Renard C. (ed.) Livestock and Sustainable Nutrient Cycles in Mixed-Farming Systems of Sub-Sahara Africa. Volume II: Technical Papers, Proceeding of an International Conference held in Addis Ababa, Ethiopia, 22- 26 November, 1993. ILCA International Livestock Center for Africa (ILCA), Addis Ababa, Ethiopia.

[c]Powell, J.M., F.N. Ikpe, and Z.C. Somda. 1999. Crop yield and fate of nitrogen and phosphorus after application of plant material or feces to soil. Nutri. Cycl. in Agroecosyst. 52:215-226.

[d]Powell, J.M., Kelling, K.A., Munoz, G.R and Cusick, P.R. 2005. Evaluation of dairy manure 15N enrichment methods on short-term crop and soil N budget. Agron. J. 97: 333-337.

[e]Sørensen, P., M.R. Weisbjerg, and P. Lund. 2003. Dietary effects on the composition and plant utilization of nitrogen in dairy cattle manure. J. Agric. Sci. 141: 79-91.

[f]Powell J.M., M.A. Wattiaux, G.A. Broderick V.R. Moreira, and M.D. Casler. 2006. Dairy diet impacts on fecal chemical properties and nitrogen cycling in soils. Soil Sci. Soc. Am. J. 70: 786-794.

[g]Same as "f."

[h]Broderick, G.A., 2009. New perspectives on the efficiency of nitrogen use in ruminants. Pages 165-178 in II Simposio Internacional Avancos em Techicas de Pesquisa em Nutricao de Ruminantes. L.F. Prada e Silva and F.P. Rennó (eds). University of Viscoso, Brazil

[i]Broderick, G.A. 2003. Effects of varying dietary protein and energy levels on the production of lactating dairy cows. J. Dairy Sci. 86: 1370-1381.

[j]Wattiaux, M.A., M. J. Aguerre and J. M. Powell. 2011. 3rd International Socioeconomic and Environmental Research on Livestock Farming, Morelia, Michoacan, Mexico. May 18-20, 2011.

[k]Same as "i."

[l]Paul, J.W., N.E. Dinn, T. Kannangarat, and L.J. Fisher. 1998. Protein content in dairy cattle diets affects ammonia losses and fertilizer nitrogen value. J. Environ. Qual. 27 (3): 528-534.

[m]Powell, J.M., M.J. Aguerre and M. A. Wattiaux. 2011. Dietary crude protein and tannin impact dairy manure chemistry and ammonia emissions from soils. J. Environ. Qual. (under review)

[n]Misselbrook, T.H., J. M. Powell, G. A. Broderick, and J. H. Grabber. 2005. Dietary manipulation in dairy cattle: Laboratory experiments to assess the influence on ammonia emissions. J. Dairy Sci. 88:1765-1777

[o]Same as "m."

[p]Wu, Z. and J.M. Powell. 2007. Dairy manure type, application rate, and frequency impact plants and soils. Soil Sci. Soc. Am. J. 71(4) 1306-1313.