# OPTIONS IN MANAGING MANURE PHOSPHORUS

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## Introduction

Nutrient loading, i.e., the amount of a nutrient applied to cropland, is critical because excessive applications may escape to become a pollutant of ground or surface waters. To determine the amount of loading that is acceptable, farmers will be asked to develop whole-farm nutrient budgets that predict manure nutrient excretions, losses of nutrients, especially N, during storage, fertilizer use for predicted yields of crops to be grown, and supplemental fertilizer needs that will be supplied from commercial fertilizer. In the future most farms will have to keep records to document nutrient accountability and to justify changes that may be needed in nutrient budgets. We have developed approaches to whole-farm nutrient budgeting previously based on manure nutrients (Van Horn et al., 1994, 1996, 1998a, 1998b) that include considerations of:

Manure nutrient excretion,
Expected, environmentally acceptable losses of manure nutrients in storage,
Crop fertilizer needs,
Supplemental needs of commercial fertilizer, if any, and
Amounts of manure nutrients that need to be exported from the farm, if any.

In confined animal production units like the milking cow component of most dairy farms, it may be difficult to utilize all manure nutrients on-farm. Almost certainly, the cost of manure management will be lessened if the budgets can be balanced on-farm with utilization of all nutrients critical to water quality considerations. Otherwise, processing and transportation costs become greatly inflated. It would be ideal if the fertilizer value of the manure nutrients recovered and utilized could equal or exceed the cost of manure collection, storage, and distribution. Usually, the primary economic objective is to make this enterprise as near to a profitable unit as possible while meeting all environmental objectives.

Priority considerations in the whole-farm nutrient budget usually are first to make certain that manure nutrients are utilized to supply all or as many as possible of the fertilizer needs of crops produced on the farm, secondly to increase crop production on the available acreage if possible and if fertilizer requirement of the current crop production plan does not utilize all manure, and thirdly to reduce manure nutrient production as much as economically possible before developing systems to export manure nutrients from the farm. When critical nutrients are in excess, a first regulatory suggestion might be to reduce cow numbers or export nutrients but a better business approach for the dairymen usually is to first reduce the amounts of critical nutrients in cows rations and, hence, excretion as much as possible without forcing lower milk production. Most dairies have some potential to reformulate in ways that will reduce N in manure from 10 to 20% and P from 20 to 50%. These changes may reduce ration cost as well as facilitate the balancing of the whole-farm nutrient budgets.



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**Input-Output Relationships Affecting Manure Quantity and Quality**

Manure is what is excreted in the form of urine and feces after the animal has digested and utilized all that it could from the ration provided to it. Knowing digestibility and, hence, indigestibility of the ration dry matter (**DM**) and organic matter (**OM**) permits us to estimate the amounts of DM and OM excreted, components that determine manure volume. Urine contributes significantly to wet manure weight or volume, perhaps 30 to 50%, but contributes much less to dry volume, usually only 10 to 15%. Urine, however, is the major excretion pathway for rapidly available fertilizer-N (urea or uric acid), K, and Na. Excreted P, Ca, and slower-released N from undigested protein primarily are in feces (Morse et al., 1992; Tomlinson et al., 1996).

If animals are consuming dietary nutrients at maintenance levels, e.g., N, P, and K, they will excrete, on-average over time, the same amount of N, P, and K they consumed except for small amounts of nutrients in shed hair and sloughed tissues; and those usually are collected with manure. When animals are accumulating N, P, and K in body weight gain, offspring, milk, eggs, or wool produced, the amount of those nutrients excreted in manure (feces plus urine) differs from what is fed by the amounts in products produced. Thus, nutritional data coupled with estimates of the contents of the same nutrients in animal gains and food products permit accurate estimation of total nutrient excretions in feces plus urine (Tomlinson et al., 1996; Watts et al., 1994; Patterson and Lorenz, 1996).

Table 1 presents data from a nutrition-based approach to estimate manure N, P, and K excretions from inputs minus outputs in milk, meat, or eggs. Not all calculations of amounts of DM, N, P, and K input and output are shown in Table 1 but the data are provided from which the excretion estimates shown can be derived. Note that P and K excretion estimates here and throughout this paper are actual P and K and not $P_2O_5$ or $K_2O$ as used in fertilizer nomenclature. The rations shown in Table 1 for the different food animal species are representative of rations fed to these animals nationally to produce expected yields of milk, eggs, and body weight gain (lb/d) for dairy cows, hens, and beef steers and the gain/life cycle grow-out for broilers, turkeys, and hogs. Note that production units for hens in Table 1 are per 1000 hens.

Table 1 also shows estimated composition of excreted manure which was derived by dividing amounts of N, P, and K excreted (from Table 1) by the predicted amounts of dry matter excreted. Additionally, manure composition was estimated by assuming that 60% of the N was lost through volatilization (see later subsection on Ammonia Volatilization) and that 20% of original dry matter is lost through anaerobic or aerobic fermentation after excretion. The originally excreted P and K were assumed to be fully recovered and concentrated in the remaining DM.

The manure composition estimates in Table 1 illustrate that there is little difference expected on a dry matter basis between species when animals consume diets of similar nutrient composition and digestibility. Water content of collected manure usually is the biggest variable affecting wet-weight composition and total volume. Expressing manure nutrient composition on a DM basis reduces variation.

Literature reviewing analyzed compositions of manures collected from farms shows much greater variation in composition than shown in Table 1. The reason is that there are greater variations in dry matter losses or ammonia volatilization or leaching losses, etc., etc., etc. Table

**Table 1. Estimates of N, P, and K excretions and manure composition based on ration and products produce**

| Herd or Flock information | Units | Dairy cows | Beef steer | Hens | Broilers | Turkeys | Hogs |
|---|---|---|---|---|---|---|---|
| | | Numbers below expand from daily averages to years | | | Numbers below based on life cycle grow-out | | |
| Animals/day or animals/grow-out | No. | 1 | 1 | 1000 | 1 | 1 | 1 |
| Average DMI/day or grow-out = | lb | 48.0 | 21.0 | 209.0 | 8.63 | 53.50 | 657 |
| Average diet CP % (DM basis) = | % | 15.5 | 12.0 | 16.4 | 20.0 | 20.0 | 16.5 |
| Average diet N % = CP % x .16 = | % | 2.48 | 1.92 | 2.624 | 3.2 | 3.2 | 2.64 |
| Average diet total P % (DM basis) = | % | 0.35 | 0.40 | 0.65 | 0.80 | 0.80 | 0.57 |
| Average diet K % (DM basis) = | % | 1.20 | 0.80 | 0.60 | 0.60 | 0.60 | 0.66 |
| Milk yield or egg yield/d (lb) = | lb | 60 | | 105 | | | |
| Milk or egg protein percentage | % | 3.2 | | 10.4 | | | |
| Milk or egg N% | % | 0.496 | | 1.664 | | | |
| Milk or egg P% | % | 0.10 | | 0.21 | | | |
| Milk or egg K% | % | 0.15 | | 0.12 | | | |
| Average body weight gain/day or grow-out | lb | 0.20 | 3.10 | 1.85 | 4.80 | 23.80 | 254 |
| Average N % of weight gain | % | 1.20 | 1.60 | 2.20 | 2.60 | 2.10 | 2.32 |
| Average P % of weight gain | % | 0.70 | 0.70 | 0.60 | 0.60 | 0.60 | 0.72 |
| Average K % of weight gain | % | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 |
| Average diet DM digestibility % | % | 65 | 80 | 82 | 83 | 83 | 83 |
| Ratio: Feed DM:(milk, doz eggs, or gain) | Ratio | 0.80 | 6.77 | 3.16 | 1.80 | 2.25 | 2.59 |
| N lb excreted yearly or per animal grow-out | lb | 325 | 129 | 1349 | 0.151 | 1.212 | 11.45 |
| P lb excreted yearly or per animal grow-out | lb | 38.91 | 23 | 411 | 0.040 | 0.285 | 1.916 |
| K lb excreted yearly or per animal grow-out | lb | 177 | 59 | 410 | 0.042 | 0.273 | 3.828 |
| Excreted N recovered (40% of excreted) | lb | 130 | 52 | 540 | 0.061 | 0.485 | 4.581 |
| Manure N% of DM (excreted) | % | 4.64 | 6.74 | 7.69 | 7.97 | 10.30 | 7.92 |
| Manure P% of DM (excreted) | % | 0.56 | 1.19 | 2.34 | 2.12 | 2.42 | 1.33 |
| Manure K% of DM (excreted) | % | 2.53 | 3.08 | 2.34 | 2.22 | 2.32 | 2.65 |
| N% if 40% N recovered, 20% DM reduction | % | 2.32 | 3.37 | 3.84 | 3.99 | 5.15 | 3.96 |
| P% of DM if 20% DM reduction | % | 0.69 | 1.48 | 2.93 | 2.65 | 3.03 | 1.66 |
| K% of DM if 20% DM reduction | % | 3.16 | 3.85 | 2.92 | 2.78 | 2.90 | 3.31 |
| N:P ratio predicted in recovered manure | ratio | 3.34 | 2.27 | 1.31 | 1.50 | 1.70 | 2.39 |

1 and additional data emphasize that manure composition can vary at time of excretion and that concentration after excretion, especially with respect to N, is a moving target.

**Nutritional Strategies Help Balance Total Farm Budgets**

The major advantage of showing that manure nutrient production is a function of ration and performance (Table 1) is that it is easy to visualize the importance of ration management to minimize excretions. For every percentage unit that dietary protein can be reduced, Table 1 calculations predict that excretion of N by different species would be reduced by 8 to 10% (average of 8.5%) which would reduce manure N to manage nationally (assuming 40% recovery of excreted N) by 137,000 tons actual N.

Nutritionists that balance rations for amino acids help to producers to reduce total dietary protein and, hence, reduce excretion of N (e.g., Carter et al., 1996). This is done regularly for poultry and often for swine. Ruminant nutritional physiology models, for instance the Cornell Net Carbohydrate and Protein Model (Fox et al., 1995), now can evaluate the potential of ration changes to improve amino acid balance, and reduce protein intake and nutrient excretions. An example application of the Cornell Model in a New York dairy herd (Fox and Berry, 1995) utilized a herd that averaged 24,100 lb milk/cow annually when they started using the model in June 1992. Dietary changes made by using the model were estimated to save $74,600 the first year and the herd increased milk production to over 26,000 lb/cow in 1995. Additionally, manure analyses suggested that N excretion had been reduced by about one-third.

Another change that takes place when N excretions are minimized by reducing excess dietary N down to required amounts is that urinary N (urea) is decreased much more than fecal N. For example, reducing dietary CP% for dairy cows from 18 to 15 to 12% reduced urinary N excretion from 228 to 138 to 99 g/d and fecal N from 199 to 179 to 158 g/d (Tomlinson et al., 1996). Additionally, by reducing urea (urinary) excretion, the percentage of excreted N lost to ammonia volatilization also will be reduced.

Thus far most total farm nutrient budgeting has concentrated on N. Most dairy farms and many swine farms have adequate crop production potential to utilize manure N, especially when ammonia losses are 60% or greater. Additionally, denitrification losses after application can be more than 100 lb N/acre annually when soils are wet (several references cited by Van Horn et al., 1996). However, there is great potential to reduce N excretion on many farms with benefit to farm profits and reduction in N excretion.

Because manures become more and more P-rich as more N volatilizes, ration management to minimize dietary P concentrations will become especially important. Utilization of phytase enzymes in poultry and swine rations makes organic P available to those animals and permits reduction of dietary P (Yi et al., 1996; Kornegay, et al., 1996; Carter et al., 1996). Hopefully, it will become even more cost effective in the future. Phytase enzyme is inherent in ruminant rations because ruminal microorganisms provide it so dietary addition is not necessary (Morse et al., 1992a). However, surveys indicate (e.g., Shaver and Howard, 1995; Watts et al., 1994) that dairy and beef producers usually feed more dietary P than animals require (e.g., NRC, 1989, for dairy cattle) and, thus, excretions can be reduced by dietary reduction. For example, if ration P as percent of dry matter were reduced 0.1% in all rations in Table 1, P excretions for different species in Table 1 would be reduced by 19 to 35% (average of 29.5%) and the amounts of P in manures from confined livestock operations nationally could be reduced by 213,000 tons actual P.

Reducing P excretions also helps to improve the N:P ratios in manure to more nearly match those needed in complete fertilizers for plants. For example, the N:P ratios for manures represented in Table 1 (range 1.31 to 2.39) illustrate that manures are P-rich relative to N because N:P ratios recommended in plant fertilizers usually are much wider, e.g., 8:1 N to actual P. Note that calculated ratios in freshly excreted manure (not shown in table) range from 3.3 (hens) to 6.0 for hogs. These ratios, although still P-rich, are much closer to plant needs and point out that if N volatilization losses could be eliminated or greatly reduced and P excretion reduced, manures would be much closer to a complete fertilizer.

If it becomes possible to decrease dietary P while still meeting minimum animal requirements and to reduce N volatilization, production of manures with much higher N:P ratios, similar to ratios needed in plant fertilizers, could result. For example, preliminary analyses of current USDA research with dairy cattle (Satter et al., 1998a, 1998b) suggests that dietary P content might be able to be reduced to .35% of dietary dry matter without detriment to the animal. This is somewhat below the currently accepted dietary requirement (NRC, 1989). Changing the P content of ration dry matter for the average dairy cow in Table 1 to .35% of dietary dry matter lowers estimated P excretion from 0.179 lb/d to 0.107 lb/d, changes estimated P% in manure excreted from .93% to .56% of DM and P% in manure DM collected from 1.16% to .69%. If concurrently, we could assume a best-case-scenario for N recovery of 65% (Van Horn et al., 1998b), then the N% of DM in the manure collected would increase to 4.26% and the N:P ratio would increase to 6.13, much closer to ratios needed by plants.

The example of the importance of reducing dietary P is illustrated further in Table 2. Two ration scenarios are compared, the first is the dairy cow example from Table 1 that received 48 lb DM/day containing 17% crude protein and .5% P and the second is where P was reduced to .35% of DM and dietary formulation done so as to permit reduction in CP to 15.5% of DM.

**Table 2. Effect of dairy ration CP and P on yearly excretions, acreages needed per cow to utilize manure N or P, and amount of forage produced per cow with a standard fertilizer application rate[1]**

| Category | Cow fed 17% CP, .5% P | | Cows fed 15.5% CP, .35% P | |
|---|---|---|---|---|
| | N | P | N | P |
| Excretion, lb/cow/yr | 367 | 65 | 325 | 38.9 |
| Manure nutrients recovered, % | 40 | 90 | 40 | 90 |
| Manure nutrients recovered, lb | 147 | 59 | 211 | 35 |
| Crop removals, lb (BG, corn silage, rye) | 480 | 69 | 480 | 69 |
| N, P application (removals x 1.3 and 1.1) | 624 | 75.9 | 624 | 75.9 |
| Acres needed/100 cows | 23.5 | 77.1 | 33.9 | 46.1 |
| Forage DM/cow/d if total DM yield = 11.4 | 14.7 | 48.1 | 21.1 | 28.8 |
| Recovered manure N:P ratio | 2.5 | | 6.0 | |
| Crop application N:P ratio | 8.2 | | 8.2 | |

[1]The cropping system used in this example is a triple cropping program utilizing bermudagrass as a base crop, corn for silage harvested by July 1, two cutting of bermudagrass hay, and rye planted in late October and harvested as haylage by March 10.

Yearly excretion estimates reduce to 38.9 lb P/yr and 325 lb N. In the original scenario, it was assumed that 40% of N was recovered after volatilization losses to permit application of 147 lb N as fertilizer, P recovery was estimated to be 90% yielding 59 lb recovery. For this example, an intensive triple-crop production program was assumed in which a total of 11.4 tons of DM/acre were harvested removing 480 lb N and 69 lb P. Fertilizer application rates, or agronomic rates, were assumed to be 10% over removals for P which allows 10% for surface runoff and groundwater losses while N applications were 30% over removals which allows for 20% for volatilization and denitrification losses and 10% for losses to surface and groundwaters. Acreages required per 100 cows for recycling are 23.5 for N and 77.1 for P. Most Florida dairies have enough acreage, if they choose to use the land for intensive crop production, to utilize N with this scenario but most dairies do not have the amount of acreage and crop production potential to utilize P when applied at these rates. Another point is that the forage grown to utilize P would amount to 48.1 lb DM/cow daily if all was recycled back to the milking cows. About 20 lb of forage DM/cow daily may be about the maximum that most dairies can refeed to milking cows. And the dairy will not be able to use 20 lb/day effectively unless it is very high quality, a good argument in favor of keeping corn silage in the crop production plan. The additional 28.1 lb/cow daily is even more than could be fed to the complement of dry cows, calves, and heifers that likely would be kept on the farm. Therefore, this farm would find that it had to market forage to balance its P budget or to export manure P instead.

The second scenario reduced dietary P as far as likely will be feasible in order to and again assumed a the high P-utilizing crop production program that would permit 75.9 lb P application per acre annually. Additionally, dietary CP was reduced to 15.5% assuming that formulation to optimize ruminal protein production and bypass protein was economical. There is good likelihood that ration cost could be reduced modestly while doing this. Because manure are usually P-rich, applying manure based on P limits will demand purchase of supplemental N to meet crop needs. Therefore, another step was to presume management practices might be available to reduce N volatilization from manure to 65% and bring the N:P ratio closer to 8.2:1, the ratio for this cropping program that applies 480 lb N and 75.9 lb P/acre. With this scenario, 46.1 acres of triple-crop production are needed for the P budget and 33.9 acres for the N budget. Needed acreages are much closer together than was the case with the first scenario. Perhaps even more importantly, the 28.8 lb of DM produced/milking cow/day is an amount that can be used on-farm if we assume that some harvested forage is needed for dry cows and heifers.

An even greater P crisis may occur if cases arise where P applications are not permitted up to amounts removed in harvested forage. This could happen when soil levels of available P reach amounts that regulatory agencies consider to be maximum for specific soil types. If forced to limit manure applications to even less than crop removals, almost all livestock farms will be forced to export manure or manure products containing most of the manure P. Poultry farms and beef cattle feedlots already export manure or manure products but exporting manure products will be a new enterprise for dairies and most swine farms.

**Summary**

Amounts of manure nutrients, e.g., N, P, and K, originally excreted are predicted accurately with a nutritionally based input-output model, where input equals the amount in feed consumed and output equals amount in products produced, e.g., milk, eggs, meat, or offspring. Amount of manure dry matter is a function of ration digestibility, i.e., the amount of dry matter not digested is the expected amount of fecal dry matter; additional dry matter in urine is small.

The percentage composition and the amounts of nutrients in manure **recovered** in manure are much more difficult to predict because manure composition is a moving target after excretion. Anaerobic digestion initiated in the large intestines of animals continues after excretion or a shift occurs to aerobic decomposition reducing volume as carbon dioxide and methane are emitted. Non-volatile nutrients such as P and K are concentrated in the remaining dry matter. From 40 to 75% of excreted N is in the urine as urea or uric acid (birds) and can be quickly volatilized as ammonia. Some losses are unavoidable, probably at least 35% of excreted N in best case scenarios and 60%, or more, in most situations. Manure becomes increasingly P-rich with N:actual P ratios usually below 3:1 whereas ratios based on plant needs are much wider. Thus, acreages of crop production needed to recycle manure P are much greater than acreages needed for manure N. In the future, priority will be on reducing dietary P and consequent excretion of P and on retaining a higher percentage of excreted N. Additionally, technology may need to be used that will separate nutrients and prepare manure products for sale and transport off-farm.

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