FACTORS AFFECTING MANURE QUANTITY, QUALITY, AND USE

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INTRODUCTION

Over-application of nutrients to land leads to losses of fertilizer nutrients and is a threat to the environmental standards we want, especially with respect to water quality. Manure management and application has been specifically targeted by regulatory agencies in recent years to try to assure that losses are low and to avoid environmental consequences off-site. Previous papers, including one given at this conference in 1995, described principles of nutrient budgeting that are important to fully utilize fertilizer value of manure and avoid overapplication and resulting pollution of ground and surface waters (Van Horn et al. 1995, 1996, 1997, 1998). A nutrient management plan, or budget includes:

1) number of animals,
2) estimated nutrient excretion in manure,
3) manure nutrients recovered and applied for fertilizer, and
4) contingency plan to export nutrients off-farm if there is an excess of critical manure nutrients relative to on-farm crop production needs.

This paper focuses on factors that influence the manure nutrient excretion and composition of recovered manure to be used for fertilizer, two key components in a total farm nutrient budget.

MANURE QUANTITY AND QUALITY

Input-Output Relationships

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. Digestibility is considered to be the percentage of the dry matter (DM) or particular nutrient in the diet that the animal could absorb from its digestive tract and have available to use for maintaining life and producing offspring, body weight gain, milk, eggs, wool, etc. By definition, apparent digestibility is considered to be the difference between amounts fed and amounts recovered in feces. Previous nutrition research has given us good estimates of apparent digestibilities of ingredients that can be combined to estimate total ration digestibilities.

Knowing digestibility and, hence, indigestibility of the ration DM and organic matter (**OM**) permits us to estimate the amounts of DM and OM excreted, components that determine manure volume. Digested carbon-containing compounds are the energy components of the diet that are either oxidized, and the carbon exhaled as carbon dioxide, or they are used for the synthesis of animal products. There are minor emissions of methane from anaerobic digestion within the animal's digestive tract, primarily eructated (belched) from ruminants (5 to 6% of intake carbon, references cited by Van Horn et al., 1994), but some minor amounts are emitted as well from lower digestive tracts by flatulence. Relatively little carbon is excreted through the urine. Urine contributes significantly to wet manure weight or volume, perhaps 30 to 50%, but contributes much less to dry volume, perhaps 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., 1992b; 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

Table 1: Estimates of N, P, and K excretions based on ration and products produced

Herd or Flock information	Units	Numbers below expand from daily averages to years			Numbers below based on life cycle grow-out		
		Dairy cows	Beef steer	Hens	Broilers	Turkeys	Hogs
Animals/day or animals/grow-out	No.	1	1	1000	1	1	1
Average DMI/day =	lb	48.0	21.0	194.0	8.40	51.88	711.00
Average diet CP % (DM basis) =	%	17.0	12.0	16.4	21.0	16.5	16.5
Average diet N % = CP % x .16 =	%	2.72	1.92	2.624	3.36	2.64	2.64
Average diet P % (DM basis) =	%	0.50	0.40	0.65	0.65	0.65	0.55
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 net body weight gain/day	lb	0.20	3.10	1.85	4.80	23.80	254.00
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	2.93	1.75	2.18	2.80
Daily or grow-out balances:							
Nitrogen:							
Input: lb DMI x N/DMI =	lb	1.306	0.403	5.091	0.282	1.370	18.770
Export: lb milk or eggs x N% =	lb	0.298		1.747			
lb gain x N/gain =	lb	0.002	0.050	0.041	0.125	0.500	5.893
Difference (manure estimate) =	lb	1.006	0.354	3.303	0.157	0.870	12.878
Yearly manure N =	lb	367	129	1205	0.157	0.870	12.878
Phosphorus:							
Input: lb DMI x P/DMI =	lb	0.240	0.084	1.261	0.055	0.337	3.911
Export: lb milk x P/milk =	lb	0.060		0.221			
lb gain x P/gain =	lb	0.001	0.022	0.011	0.029	0.143	1.829
Difference (manure estimate) =	lb	0.179	0.062	1.029	0.026	0.194	2.082
Yearly manure P =	lb	65	23	376	0.026	0.194	2.082
Potassium (K):							
Input: lb DMI x diet K%/100	lb	0.576	0.168	1.164	0.050	0.311	4.693
Export: lb milk or eggs x K%/100	lb	0.090		0.126			
lb gain x K%/100	lb	0.0004	0.0062	0.0037	0.0096	0.0476	0.508
Difference (manure estimate) = input - expo	lb	0.486	0.162	1.034	0.041	0.264	4.185
Yearly manure K =	lb	177	59	378	0.041	0.264	4.185

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).

Nutrition-based models predict the amounts of nutrients in fresh manure excretions more accurately than collections from animal pens because of the dynamic state of manure after excretion. For example, usually 40 to 50% of the excreted N will be in urea or uric acid in the urine component for ruminants (Tomlinson et al., 1996) and up to 75% for swine (ASAE, 1994; Carter et al., 1996). Urease enzyme, that is of bacterial origin and is nearly ubiquitous in the environment, converts urea and uric acid N to ammonia that can be lost to the atmosphere. Also, anaerobic digestion that begins in the large intestine of animals before feces are voided, continues after excretion if environmental conditions permit. Or a shift to oxidative fermentation may take place, e.g. composting and degradation on soil surfaces. Either way, volume reduction takes place as carbon compounds are emitted to the atmosphere, primarily carbon dioxide from aerobic degradation and methane, carbon dioxide, and odorous volatiles from anaerobic degradation. Additionally, variation in composition of manure collected occurs because physical separations may take place in animal pens and within the manure management system.

Table 1 presents a nutrition-based approach to estimating manure N, P, and K excretions based on ration content less amounts estimated to be in milk, eggs, or animal gain. 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 same principles can be used to estimate content of many other dietary elements but discussion here will focus on N, P, and K, the major fertilizer nutrients other than Ca, with N and P the major nutrients of environmental concern. 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 2 continues from Table 1 with calculations of DM in feces as a function of ration DM digestibility and DM in urine estimated as 5% of dry matter intake (**DMI**; Van Horn et al., 1994; Tomlinson et al., 1996). Composition of excreted manure was calculated by dividing amounts of N, P, and K excreted (from Table 1) by the predicted amounts of DM excreted. Additionally, manure composition was estimated by assuming that 60% of the N was lost through volatilization (see later subsection on Ammonia Volatilization), that 20% of original DM 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 2 illustrate that there is little difference expected on a DM 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. The estimate of DM percentage of freshly excreted manure from different species is given in Table 2 only to make an estimate of wet weight amounts.

Predicted N concentrations (DM basis) in residual manure (Table 2) were lowest for dairy cattle compared with manure from other species consuming more-digestible, higher-concentrate rations that were estimated to contain similar N concentrations. Estimated P concentration was lowest for dairy cows and highest for laying hens.

Some error is certain but the excretion and total manure N, P, and K collections estimated from animals in confinement operations gives an approximation of fertilizer resources in manures that potentially can spare purchases of commercial inorganic fertilizers. Annual inventory and slaughter data from USDA National Agricultural Statistics Service (USDA-FAS, 1997) were used to extrapolate individual animal estimates from Tables 1 and 2 to generate total volumes shown in Table 2 and Figure 1.

Table 2: Estimating manure quantities, nutrient concentrations, and annual fertilizer resources available from confinement animal feeding

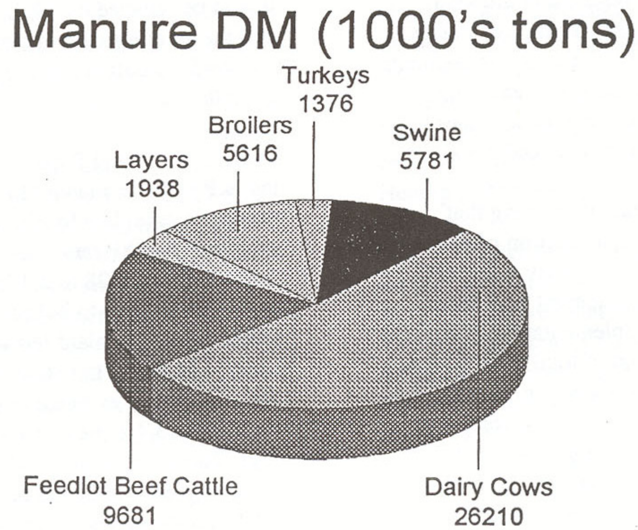
	Units	Numbers below expand from daily averages to years			Numbers below based on life cycle grow-out		
		Dairy cows	Beef steer	Hens	Broilers	Turkeys	Hogs
Animals/day or animals/grow-out	No.	1	1	1	1	1	1
Dry matter (DM):							
Input: lb DMI (from line 7)	lb	48.0	21.0	194.0	8.4	51.9	711.0
Output (feces): = lb DMI - (digestibility x DM	lb	16.8	4.2	34.9	1.4	8.8	120.9
Output (urine):	lb	2.4	1.1	9.7	0.4	2.6	35.6
Total DM output = feces + urine DM =	lb	19.2	5.3	44.6	1.8	11.4	156.4
Manure DM output, % of input =	%	40.0	25.0	23.0	22.0	22.0	22.0
Manure DM/yr or grow-out period =	lb	7008	1916	16286	1.85	11.41	156.42
Estimated DM% of fresh manure	%	14	16	20	20	20	16
Yearly manure (wet) @ estimated DM % =	lb	50057	11977	81432	9.2	57	978
% of manure collected (% of time in collectib	%	100	100	100	100	100	100
Cubic feet of wet manure stored/day	cu ft	2	1	4	0	0	0
N lb excreted yearly or per animal grow-out	lb	367	129	1205	0.157	0.870	12.878
P lb excreted yearly or per animal grow-out	lb	65	23	376	0.026	0.194	2.082
K lb excreted yearly or per animal grow-out	lb	177	59	378	0.041	0.264	4.185
Excreted N recovered (40% of excreted)	lb	147	52	482	0.063	0.348	5.151
Manure N% of DM (excreted)	%	5.24	6.74	7.40	8.52	7.62	8.23
Manure P% of DM (excreted)	%	0.93	1.19	2.31	1.40	1.70	1.33
Manure K% of DM (excreted)	%	2.53	3.08	2.32	2.21	2.31	2.68
N% of DM if 40% of N recovered, 20% DM r	%	2.62	3.37	3.70	4.26	3.81	4.12
P% of DM if 20% DM reduction	%	1.16	1.48	2.88	1.75	2.13	1.66
K% of DM if 20% DM reduction	%	3.16	3.85	2.90	2.76	2.89	3.34
N:P ratio predicted in recovered manure	ratio	2.25	2.27	1.28	2.44	1.79	2.47
USDA inventory (yearly) or numbers slaughtered/yr:							
Cows, steers, or hens/d or animals slaughte	millions	9.35	12.63	297.48	7,598.00	301.38	92.39
U.S yearly manure lb (extrapolated from above):							
DM recovered if 20% DM reduction	1000s of tons	26210	9681	1938	5616	1376	5781
N recovered (40% of excretion)	1000s of tons	686.4	326.0	71.7	239.2	52.4	238.0
P recovered	1000s of tons	304.8	143.6	55.9	98.0	29.3	96.2
K recovered	1000s of tons	828.6	372.9	56.2	155.0	39.7	193.3
Yearly DMI of USDA number of animals	1000s of tons	81,906	48,404	10,532	31,912	7,818	32,845
Estimated corn consumption (DM) by USDA	1000s of tons	24,572	29,043	7,899	23,934	5,863	26,276

The data suggest that dairy cows contribute about 42% of the national manure N and P collected **from animals in confinement** which needs to be managed accountably, feedlot beef cattle about 20%, poultry (broilers, hens, and turkeys) 22 to 25%, and hogs 13 to 15%. Note that the spreadsheet approach represented in Tables 1 and 2 could be used on a state or county basis simply by changing livestock inventory numbers and could be further improved with ration and performance adjustments that best fit the region.

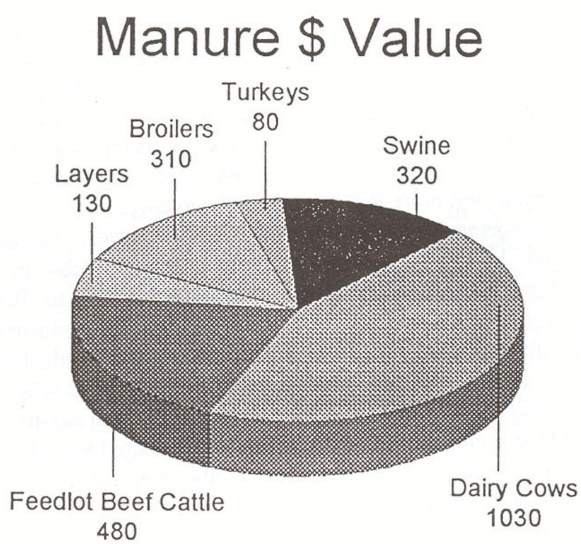
Cross checks that help to verify that the total manure excretion estimates may be relatively good were derived from data in: 1) Feedstuffs (1997) that reported that 182.1 million metric tons of feed-grain and by-product concentrates (including protein concentrates) were fed to dairy, beef, hogs, and poultry in 1995 and 2) Cattle Feeders Annual (1997) that projected 5.20 billion bushels of corn to be fed to livestock in 1996-97. Grain, by-product, and protein concentrates make up about 47% of the DM consumed by dairy cattle (about 50% of DM is forage), 87% DM eaten by feedlot beef cattle (10% forage), and 93 to 97% of the DM consumption of other species. Mineral supplements, estimated to be 3 to 7% of ration DM, were excluded. With those numbers, total tons of DM consumed in Table 1 convert to 146 million metric tons and 162 million metric tons of 90% DM concentrate, 89% of the Feedstuffs (1997) estimate. Estimating that corn composes 30% of DM eaten by dairy cattle and 60, 75, 75, 75, and 75% for feedlot beef, broilers, hens, turkeys and hogs, respectively, accounts for 4.6 billion bushels of corn consumption, 88% of the 5.20 billion bushels of corn estimated to be fed to livestock in 1996-97 (Cattle Feeders Annual, 1997). These numbers are referenced only to indicate that the feed amounts accounted for in Tables 1 and 2 represent 88 to 89% of the estimated livestock feed-grain and concentrate consumption by animals in the U.S. The animal groups not represented in Table 1 that were fed small amounts of supplemental concentrates would be expected to consume most of the remainder of the concentrates, e.g., about 44.6 million beef cows, 39.5 million beef calves, and 4.0 million dairy heifers >500 lb of body weight. These cattle were fed primarily forage, usually from grazing. Manure from grazing operations is recycled effectively on pasture without collection, handling, or processing being necessary. Concentrate consumption by horses, minor numbers in broiler breeder flocks, sow maintenance feeding needs not reflected in growth requirements of sows slaughtered, etc. would account for the remainder.

Although predicted amounts of manure production by food animals in Table 2 cannot be compared directly with the Harkin report, **An Overview of Animal Waste Pollution in America**, it is of interest. This report (Harkin, 1997) estimated total animal manure production as 1.37 billion tons annually, which included 1.23 billion tons from cattle, 116 million tons from hogs, 14 million tons from chickens and 5 million tons from turkeys. Amounts of freshly excreted wet manure from confinement cattle from Table 2 (total of dairy and beef yearly wet manure multiplied by USDA inventory numbers) were 310 million tons, from chickens (laying hens and broilers) 47 million tons, turkeys 8.6 million tons, and hogs 45 million tons. The Harkin report apparently underestimated poultry manure amounts and greatly overestimated swine manure amounts. Cattle amounts are not as easily compared because Table 2 includes only confinement cattle. An average daily excretion of 57 lb wet manure daily by the 44.6 million beef cows, 39.5 million beef calves and 4.0 million dairy heifers added to the 310 million tons from confinement cattle would equalize the estimates. Fifty-seven lb wet manure/day probably is reasonable and, thus, the cattle estimate in the Harkin report appears reasonable. However, 75% of the cattle manure likely is not of much concern with respect to pollution, because it is from non-confinement cattle that distribute their manure over acreage that needs those nutrients to regrow grass the cattle ate.

The estimated total recoveries of manure N and P in 1996 for confined food animals represented in Table 2 (sum of all species) were 1,613,700 tons of N (assuming that 40% of excreted N is recoverable) and 727,800 tons of P. These amounts, along with K, represent significant resource value as fertilizer and certainly need to be considered and credited against the expense of collecting and managing manure accountably. One method of estimating much of the resource value of manure is to assign a value to the *utilized* N, P, and K, the most valued fertilizer nutrients. For example, based on assumed values of \$.30/lb N, \$.60/lb actual P, and \$.15/lb K, the equivalent fertilizer value for the



Total Manure DM = 50,602 X 1000 tons



Total Manure \$ Value = \$2,340 X 10^6

Figure 1. Estimated amounts of manure dry matter (DM) and fertilizer value of manures from confined food animals in the U.S. Amounts in daily or life cycle manure, predicted from nutritionally based input-output models less expected losses of N, were extrapolated to yearly amounts for national inventory numbers of animals and manure value was calculated from amounts of N (\$0.30/lb), actual P (\$0.60/lb), and actual K (\$0.15/lb).

amounts of N, P, and K represented in the total manure production estimates in Table 2 calculate to be $2.340 billion (Figure 1). Other manure elements and the OM in manure add additional value for fertilizer and soil conditioning but those values are more difficult to quantify than N, P, and K values.

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 example, supplementation of limiting amino acids permits reduction of total dietary protein and, hence, reduces excretion of N (e.g., Carter et al., 1996). 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.

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% changed 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.

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 DM was 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 2 (range 1.28 to 2.47) illustrate that manures are P-rich relative to N because N:P ratios recommended in plant fertilizers usually are much wider, e.g., 9:1 N to actual P. Note that calculated ratios in freshly excreted manure (not shown in table) range from 3.4:1 (hens) to 6.1:1 for broilers and 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., 1997) suggests that dietary P content might be able to be reduced to .35% of dietary DM without detriment to the animal. This is below the currently accepted dietary requirement (NRC, 1989). Changing the P content of ration DM for the average dairy cow in Table 1 to .35% of dietary DM 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% (see later subsection on Ammonia Volatilization), then the N% of DM in the manure collected would increase to 4.26% and the N:P ratio would increase to 6.13:1, much closer to ratios needed by plants. Acreages of plant production needed for N and P recycling would be much more nearly equal.

Variation in Excretion Estimates and Composition of Recovered Manures

Variation in nutrient intake by animals is the single most important contributor to variation in nutrient excretions (Tomlinson et al., 1996; Morse et al., 1992b). Utilization of an input-output model like used in Tables 1 and 2 adjusts for the variation in intake and the amounts of nutrients that are converted to the products produced. As an example, excretions by a dry cow and an early lactation cow producing 100 lb of milk per day varied from 9.9 lb to 21.6 lb of DM/d (DM equals total solids, TS), from .36 to 1.03 lb N/d, and from .101 to .208 lb P/d (Van Horn et al., 1994). These differences were expected and predictable based on ration parameters and performance. Although widely used excretion estimates such as ASAE (1994) fall within the cited ranges, the estimates tend to be for average performance, are not farm specific, and do not provide a method to show producers consequences of overfeeding given nutrients. Similarly with poultry, Patterson and Lorenz (1996) utilized an input-output method to predict excretions because they found, in their extensive 2-yr field study on eight commercial Leghorn layer flocks, that today's hens produce **less** manure than older literature values imply.

Total amount of wet manure is more difficult to predict than amounts of TS and nutrients excreted because water content may vary somewhat independently of amounts excreted, e.g., amounts of nutrients excreted are more confidently predicted than total amount of wet manure produced or percentage of a nutrient in the manure (Tomlinson et al., 1996). However, under similar conditions, water content of manure (feces plus urine) for a given species usually is fairly consistent. For dairy and beef cattle, water content usually is reported as 85 to 88% (ASAE, 1994; MWPS-18, 1993; Powers et al., 1997; Tomlinson et al., 1996; Safley et al., 1986). The ASAE (1994) estimated that swine manure from a 61 kg animal contained 13% solids. Poultry produce manure with higher percentage TS than cattle and hogs (ASAE 1994) with estimated TS for layers, broilers, and turkeys at 25, 20, and 19%. Flachowsky and Hennig (1990) found excreta from laying hens ranged from 12.0 to 26.5% TS with an average of 20.0%.

Tables 1 and 2 suggest that there is less variation in freshly excreted manure composition than usually reported in collected manures. For example, Flachowsky and Hennig (1990) showed data on N composition of beef cattle excreta where even the upper range (2.7% N, DM basis) was lower than the Table 2 estimates for beef steers. Their lower N concentrations may have been from cattle consuming more forage, resulting in dilution of excreted N with more indigestible residue in feces. The higher crude fiber content of beef cattle excreta compared with dairy cow excreta (Flachowsky and Hennig (1990) also supports this conclusion.

Other literature also confirms a large variability in manure nutrient content. Tomlinson et al. (1996) showed that diets containing 12%, 15%, or 18% crude protein (CP) on a DM basis yielded urine and fecal N excretions that combined to produce manures containing 3.2%, 4.2%, and 5.3% N of total manure DM. Morse et al. (1994) observed a mean P content of 0.67% but manure P concentrations of DM were .42, .53, and .81% when diet DM contained .31, .42, or .54% P (calculated manure compositions from P excretion data in Morse et al., 1992b and average manure DM excretion reported in Morse et al., 1994).

Patterson and Lorenz (1996) found that layer manure composition on an *as collected* basis averaged 1.85% N (range 1.08 to 3.76%), 1.19% actual P (range .64 to 2.35%) and 1.30% actual K (range .79 to 3.01%) with DM percentages of manures averaging 40.7% (range 24.6 to 67.9%). They also used an input-output model to estimate original manure excretion. Data from this study were used to help validate the outputs for hens in Tables 1 and 2.

In spite of variation, data from Tables 1 and 2 and other data cited show that poultry manures usually are higher in N concentration than ruminant manures and layer manure is higher in ash content than all other manures. Inclusion of bedding material into the collected manure reduces the nutritive value of the manure primarily by reducing N concentration and increasing fiber content.

Manures and litters from all species are good sources of Ca. The Ca content usually is higher than P and much higher with caged layer manure. The Ca content of manure usually is high enough to provide all of the Ca needed by crops fertilized heavily with manures and may contain enough Ca and Mg to gradually increase soil pH over time when manures are applied heavily year-after-year.

These 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.

Ammonia Volatilization

Even with a *tightly* managed system, there is considerable N loss through ammonia volatilization. The amount volatilized is influenced by level of N in the manure (particularly the urea component originating in the urine) and by the method of storage and application.

The University of Florida Dairy Research Farm (Van Horn et al., 1998) utilized a manure management system in which:

1) manure was flushed from feeding areas, freestall lanes, and milking parlor,
2) sand traps were used to settle out sand which was reused for bedding,
3) a stationary screen removed fibrous solids,
4) sediment basins removed additional solids,
5) effluent from sediment basins flowed to a small (.2-ha) lagoon,
6) effluent from the small lagoon was pumped to a 2-ha holding pond,
7) holding pond wastewater was pumped to two 30-acre sprayfields about once every 2 weeks.

Estimated recoveries of N and P over a 4-year period were:

- 28% of estimated N excretions from the 275 to 380 cows managed in the system was in wastewater irrigated on the sprayfields;
- 12% of excreted N was in the solids recovered from the screen and sediment which were land-spread;
- 61% of estimated P excretion was in wastewater irrigated on sprayfields; and
- 15% of excreted P was in solids recovered from the screen and sediment.

Most of the nonrecovered N (60% of excreted N) was volatilized, but a small amount would be expected to be in the sludge, which accumulated in the lagoon and holding pond. Data from excretion and ratios of N concentrations in sprayfield wastewater to N concentrations in concurrent samples taken from effluent from the lagoon suggested that 28% of the excreted N (in addition to the 12% in solids recovered) was lost before effluent left the lagoon (by volatilization or sedimented in bacterial cells in sludge in lagoon) and 32% was lost in the holding pond (volatilization plus sludge in holding pond). Most of the excreted P (76%) was recovered. The 24% unaccounted for is not an unusual amount to expect to be in the lagoon and holding pond sludges, e.g., Hill et al. (1990) showed 47% reduction of P in wastewaters flowing through three-pond lagoon systems.

In a 2500-cow dairy that separated solids and held effluent for only 3 to 5 days before distributing on sprayfields, N recoveries applied to the sprayfield were 66% of estimated N excretion managed through that system (51% through distributed wastewater and 15% in separated solids). The P recoveries were 99% of the estimated P excretion managed through that system with 86% recovered in irrigated wastewater and 13% in separated solids (Van Horn et al., 1998).

In an extensive 2-yr field study on eight commercial Leghorn layer flocks, Patterson and Lorenz (1996) concluded that approximately 40% of feed N was lost to the atmosphere (i.e., >60% of estimated N excretion). Losses also were correlated with manure storage time; the longer manure was stored the lower the concentration of N. Concentrations of P, K, and DM increased with storage time.

Recoveries of 40% of excreted N in the first dairy example above and in layer flocks evaluated by Patterson and Lorenz (1996) are the basis for suggesting that 40% N recoveries for use as fertilizer are more likely than the 50% or more that often is cited. The 66% estimated recovery in the 2500-cow example probably is a best-case scenario. Recoveries often are much less than 40%. Hill et al. (1990) found that N reductions in three-pond lagoon systems averaged 69%. With any of these scenarios, additional losses occur after application to fields as fertilizer. Estimates of losses associated with many individual practices were summarized by MWPS-18 (1993).

NUTRITIONAL STRATEGIES HELP BALANCE TOTAL FARM BUDGETS

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.

Nutritionists that balance rations for amino acids help to produce animal foods with less dietary protein and less N excretion to manage. 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) indicated that the herd averaged 10,953 kg/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 11,818 kg/cow in 1995. Additionally, manure analyses suggested that N excretion had been reduced by about one-third.

The primary challenge for livestock producers, however, will be to meet P budgets 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 little more than crop removals, most farms will not produce enough crops to utilize all the manure unless P excretions can be reduced dramatically. 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. To balance P budgets, dietary P must be reduced to the fullest extent possible and new technology developed that will separate nutrients and prepare manure products for sale and transport off-farm.

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 DM is a function of ration digestibility, i.e., the amount of DM not digested is the expected amount of fecal DM; additional DM in urine is small. The percentage composition and the amounts of nutrients **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 DM. 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.

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