Manure Issues: Identifying nutrient overload, odor research report[1]

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Identifying Nutrient Overload

Over-applying manure nutrients to land is considered to be a major cause of nitrates, converted from manure ammonia sources while in the soil, leaching to groundwater and contributes to surface runoff of N and P that contaminate surface waters. If land application rates are limited to agronomic application rates, manure nutrients are recycled by plants into forages, other feeds, or fiber products. Manure is well recognized for its fertilizer value but we don't often calculate that value. Too often in the past it has been assumed that recovery costs were greater than value and manure nutrients were not fully utilized. However, environmental concerns mandate manure utilization regardless of costs. The plan for utilization needs to use manure resource value to pay for its implementation to the fullest extent possible.

Several faculty from the University of Florida and one from the University of Georgia are developing and Extension Circular that will provide worksheets for use by dairymen to help them develop manure nutrient management plans. The worksheets, which will be distributed soon, are designed for use as a computer spreadsheet to invite easy recalculation to look at alternative nutrient management plans. Background information can be found in University of Florida Cooperative Extension Circular 1016. Manure nutrient management plans will become even more important when the new Animal Husbandry Rule that is being developed by the Florida Department of Environmental Regulation takes effect. However, it will be helpful for planning purposes for you to assess the approximate nutrient balance status for your farm before discussions with regulatory officials. Objectives of your manure nutrient plan (or budget) include:

1. To show you and, perhaps, your urban neighbors what happens to manure and manure nutrients on your farm. It helps to document that you are not polluting or to identify needed improvements.

2. To predict crop production (acreage and yields) needed to recycle manure nutrients and limit losses to waters and atmosphere to environmentally acceptable amounts.

3. To identify dollar value of manure nutrients recovered that help pay for costs to manage manure in an environmentally acceptable manner.

4. To determine if or how many manure nutrients must be exported off-farm.

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[1] This paper is abstracted from Van Horn et al., 1997a, *Managing Dairy Manure Accountably: Worksheets for Nutrient Budgeting* and Van Horn et al., 1997b, *Effect of Anaerobic Digestion and Commercial Additives on Odors from Liquid Dairy Manure.*

How many nutrients are excreted by dairy cows? We have developed a procedure to approximate budgets fairly easily. The procedure makes estimates of manure N, P, and K excretion and asks you to estimate manure nutrients that you recover for use as fertilizer (or use some suggested average values). Additionally, you must estimate yields of crops and nutrients removed from fields and determine fertilizer application rates in order to determine acres of crop production needed to utilize either manure N, P, or K accountably. If acreage available is less than needs, an estimate can be made of how much manure must be transported off-farm for recycling as fertilizer nutrients on other farms.

An accurate way to estimate daily N, P, and K excretions is to calculate N, P, and K in the feed the cows consume and subtract the amount in milk. For example, protein contains about 16% N so if a cow consumes 50 lb dry matter (DM) per day which is 18% protein, she consumes 50 x .18 x .16 lb N (1.44 lb N). Milk usually contains about 3.2% protein, so if average production is 60 lb milk/day, N output in milk is about 60 x .032 x .16 lb N (.31 lb N in milk). Thus, estimated excretion is 1.44 minus .31 lb N/day (1.13 lb N/day). Milk contains an average of .10% P and .15% K. Use diet percents of P and K multiplied times DM intake to estimate P and K intake and subtract milk output (average milk yield per day times milk P and K contents). Expected ranges in average N, P, and K excretions/day by milking cows are:

For N:	.60 to 1.15 lb/day
For P:	.12 to .24 lb/day
For K:	.24 to .60 lb/day

If you wish to obtain excretion estimates for dry cows, make calculations with zero milk yield and determine their DMI and diet composition. Recall that dry cows eat only about half the DM of high producing lactating cows. Nutrient output can be considered to be almost the same as nutrient intake because the amount of N, P, or K stored in body weight gain and fetal tissues is a very small percentage of total intake.

What percent of time do cows spend in the manure management system being evaluated? This is a very important number for use when cows split their time between pastures or pasture lots and areas from which manure is collected and managed, for example holding pens, milking parlor area, and feed barns. Available data suggest that manure flow through the digestive tract is relatively steady throughout the day. Therefore, we estimate that cows distribute their manure equal to the percent of time they spend in an area.

How much of the excreted nutrients do you recover for fertilizer? A key measure needed to help evaluate your manure management is the amount of N and P recovered in the manure you recycle. Also, you need nutrient quantities to fertilize crops correctly and to determine the dollar value you realize when you fertilize your crops with manure. Weighing enough loads of manure hauled to the fields to estimate amount and analyzing enough samples to predict N, P, and K composition are necessary. Nutrient recoveries are obtained by multiplying concentrations by load weights and number. If an irrigation system is used to distribute wastewater from a lagoon or holding pond, wastewater analyses are needed to go with the volume of wastewater distributed. Volume meters on irrigation pumps are important; if not available, gallons pumped must be estimated by hours pumped and estimated gallons/min from pump specifications.

With relatively hard data in hand on nutrient excretion and nutrient recovery for fertilizer use, calculating the difference provides a good estimate of nutrient losses in the manure management system. If you don't have measures of how much manure N, P, and K are recovered for fertilizer use, estimates will have to be made for preliminary planning. For dairy cows, about half of the original N excretion is urea (from urine) or other easily degraded N compounds in feces that yield ammonia. Recoveries of P and K should be high, 90% or more for P and close to that for K because P and K are not lost to the air. Losses of P should be explored if they were large, e.g., greater than 30%. If anaerobic lagoons are utilized, the sludge at the bottom of the lagoon may be a place where P is accumulating. That P will need to be budgeted and managed sometime later when sludge is emptied from your lagoon. Large holding ponds also are a reservoir for P. Some suggested estimates to use if you have not measured what you are recovering and applying are:

With quick application and incorporation, for example, irrigation of flushed manure within 5 days after excretion to crops grown under sprayfield, N recovery 65%

Application of wastewaters from anaerobic lagoon with a 21-day or longer holding time, N recovery . . . . .20 to 30%

An average recovery for N 40%

For P, estimate recovery of 90% or more unless you use an anaerobic lagoon and discount for what likely remains in the sludge in bottom of the lagoon. That could be as much as 50% in lagoons with 21-day or more average retention time.

For K, estimate recovery of 80 to 90%.

Budgeting use of recovered manure nutrients. After estimating total manure nutrient excretion and accounting for losses in the manure management system, the next step is to utilize the remaining nutrients on your farm or find a place to export them.

If sufficient acreage and crop production potential exists, it is likely that the optimum use of the fertilizer value in the manures will be to develop budgets based on P and, thus, manure N will be supplemented with additional N from commercial fertilizer. Optimum crops probably will be high-energy crops that are conducive to high per animal milk production rather than maximum DM yields. If acreage is short and soil storage of excess P is permitted, multiple-cropping with forages and maximum application of N will be required. Irrigation is almost essential for consistent maximum production and nutrient utilization per acre in most regions. If land or water resources make irrigation unsuitable, lower fertility, less intensive systems should be used. If excess nutrients exist after cropping system needs are met, they will have to be exported off-farm.

A key question is, what fertilizer application rates are needed to achieve the N and P harvests in those crops? Obviously, it will greater than that harvested unless your soils have high fertility stores of N and P. Table 1 shows expected nutrient removals for certain crops and yields. In Table 1 example fertilizer application rates, N removals were multiplied by 1.3 which allows 20% more than crop removals for denitrification and volatilization and 10% for losses to ground and surface waters. For P and K, crop removals were multiplied by 1.1 which allows for 10% more than crop removal for losses to surface waters.

Table 1. Estimating N, P and K application rates to use or compare with other agronomic rate recommendations.

Crop	Wet tons per acre	DM%	DM tons per acre	Composition, % of DM				Crop removals, lb/acre			A calculated application rate[1]				
				CP%	N%	P%	K%	N	P	K	N	P	K	P_2O_5[2]	K_2O[2]
Corn silage	22.0	30	6.6	10.0	1.60	.30	1.2	211	37	158	270	40	174	90	210
Rye or wheat haylage	7.0	40	2.8	20.0	3.20	.36	1.0	179	20	56	230	22	62	50	70
Perennial peanut haylage	15.0	40	6.0	16.0	2.56	.30	1.9	307	36	228	400	40	251	90	300
Perennial peanut hay after no-til corn for silage	2.3	86	2.0	16.0	2.56	.30	1.9	102	12	76	130	13	84	30	100
Bermudagrass hay	7.0	86	6.0	14.0	2.24	.30	1.5	269	36	180	350	40	198	90	240
Bermudagrass hay after no-till corn for silage	2.3	86	2.0	14.0	2.24	.30	1.5	90	12	60	120	13	66	30	80
Stargrass hay	8.0	86	6.9	12.0	1.92	.30	1.5	265	41	207	340	45	228	100	270
Forage sorghum silage (after corn)	20.0	28	5.6	9.0	1.44	.30	1.2	161	34	134	210	37	147	80	180
Bermudagrass pasture	20.0	20	4.0	16.0	2.56	.30	2.0	205	24	160	270	26	176	70	210
Rye pasture	13.3	15	2.0	22.0	3.52	.30	1.5	141	12	60	180	13	66	30	80
Multiple-crop totals:															
Corn silage – bermudagrass hay - rye silage	28.3		11.4					480	69	274	620	75	302	170	360
Corn silage – perennial peanut hay	24.3		8.6					313	49	234	400	53	258	120	310
Corn silage-forage sorghum - rye silage	49.0		15.0					551	91	348	710	99	464	240	550
Corn silage – bermudagrass hay	24.3		8.6					301	49	218	390	53	240	120	290

[1]Calculated application rates (rounded to nearest 10 lb for N, P_2O_5, and K_2O) are developed from crop removals plus losses to expected groundwater and surface runoff that are within environmental standards, plus expected change in soil storage which is assumed to be 0 in this table, plus, for N, expected losses to denitrification and volatilization of ammonia. For N, removals were multiplied by 1.3 which allows 20% more than crop removals for denitrification and volatilization and 10% for losses to ground and surface waters. For P and K, crop removals were multiplied by 1.1 which allows for 10% more than crop removal for losses to surface waters.

[2]Application rates rounded to nearest 10 lb. for P_2O_5 are actual P rates divided by .436 unit P/unit P_2O_5; K_2O application rates are K rates divided by .83 unit K/unit K_2O.

An alternative to calculating your own nutrient application rates is to use accepted agronomic recommendations for commercial fertilizer applications in your area. If those are greater than determined in Table 1, use those. There should not be risk in applying manure nutrients up to those levels (certainly no more risk than with commercial fertilizers). Most non-ammonia manure N is stable organic N from the feces which requires extra time to decompose and become available and may not be available for the first crop grown after application. The degradation rates are somewhat climate and region dependent and, therefore, the extra amount should be determined based on appropriate factors determined for your situation by agronomists experienced in manure utilization. While the N in dry feces scraped from an unpaved dry lot may be only 40% available during the first month or two after application (depending upon climate and soil type, as noted), N in lagoon or holding pond effluent is often 90+% inorganic (depending upon the amount of sludge pumped) and essentially as available as commercial sources. However, this N may also be somewhat less effective than expected for one or two seasons as the addition of water and organic matter may stimulate denitrification and other soil microbial changes that require time to equilibrate.

Many dairy farmers apply manure at established per acre rates year after year and the amount of carryover averages out so that it is less important for budget calculations. Also, this likely will be the case if you are starting a manure budgeting plan on land that has had routine manure applications in the past. However, for the first year of manure application, especially when manure is solid or semi-solid, it is important to discount the availability of the organic N and assume, for example, that about 30% of that will not be available during the first year. Thus, some extra N from commercial fertilizer during the first year may be needed.

Analyzing Example N, P, and K Accounting Budgets

Estimated N, P, and K budgets for two example 100-cow dairies are used here for discussion purposes. **Example 1** was based on 100 cows producing an average of 60 lb milk/day all year in a confined system permitting 100% of the manure to be accounted for within one system. Dry matter intake was estimated to be 48 lb/d per cow which contained 17% crude protein, .50% P, and 1.20% K. **Example 2** is a partial grazing dairy (cows in pastures 60% of time) where 40% of the manure is collected in holding, milking, and feeding areas. Average year-round milk yield was 50 lb/day. Dry matter intake was estimated to be 42 lb/d which was 17% crude protein, .41% P, and 1.2% K. With these assumptions, daily excretions per cow would be:

Table 2. Calculating recovered manure nutrients for fertilizer use.

Category	Example 1			Example 2		
	N	P	K	N	P	K
Lb daily excretion/cow	1.01	.18	.49	.89	.12	.43
Lb yearly excretion/100 cows	36,865	6,570	17,885	32.485	4,380	15,695
% manure collected	100	100	100	40	40	40
Yearly lb to manage	36,865	6,570	17,885	12,994	1,752	6,278
Estimated % recovered for fertilizer	44	92	82	30	50	80
Lb manure fertilizer nutrients	16,220	6,044	14,666	3,898	876	5022

Note that the estimated % recoveries for fertilizer for Example 1 are perhaps typical of a dairy with short-time holding of flushed manure from some areas before irrigating wastewater on a sprayfield and some solid manure scraped from some areas and stored for spreading every two or three weeks. Example 2 recoveries are representative of what might be expected with an anaerobic lagoon designed for 21-day or more average holding time, 30% for N, 50% for P, and 80% for K. Remember with this system, the P in the lagoon will have to be managed at a later time when the lagoon is cleaned out.

The next step is to decide on the cropping system or to compare several alternatives. For example, let's compare acreage needed for N, P, or K budgeting with either corn silage or bermudagrass hay as single crops per year with a triple-cropping system of corn for silage on bermudagrass sod followed by hay harvests and rye planted as a winter forage crop. Fertilizer application rates per acre for these scenarios from Table 1 are 270 lb N, 40 lb P, and 174 lb K for corn silage; 350 lb N 40 lb P, and 198 lb K for bermudagrass; and 630 lb N, 75 lb P, and 302 lb K for the triple-cropping system. Acreage needed for various scenarios can be determined by dividing the amounts of N, P, or K available for fertilizer by the annual application rate for the system. For example, we have 16,220 lb N available for Example 1 which would supply enough N for 60 acres of corn silage (16,220 divided by 270 lb N applied per acre). Other acreages are shown in the following table:

Table 3. Acreages needed with different cropping systems based on N, P, or K budgets.

Category	Example 1			Example 2		
	N	P	K	N	P	K
Acreage needed:						
Corn silage	60	150	83	14	22	29
Bermudagrass hay	46	150	73	11	22	25
Corn silage, bermudagrass hay, rye haylage	26	80	48	6	12	17

Although only examples, several points can be made. Note in Example 1, approximately three times as many acres were needed for manure application when manure applications were based on P as compared with N-based applications; acreages based on K fell in between.

In Example 2, where appreciable P was removed from the waste stream and stored in lagoon sludge, K was expected to remain soluble and flow with lagoon effluent. This is the only type of system where K budgets might require more acreage than P budgets. However, K almost always will be over-applied when manure is applied based on N. Repeated over-application of K leads to high-K forages because most forages will luxury-consume K. Dairymen wish to avoid high-K forages for their dry cows.

With an N budget with triple-cropping, 26 acres of cropland were needed producing 22 tons/acre of wet-weight corn silage, 2.3 tons of bermudagrass hay, and 7.0 tons of rye haylage (yields from Table 1). Applying manure based on a P budget would have required 80 acres.

In Example 2, P budgets were much closer to N budgets. There are two major reasons for this, 1) dietary P was reduced to .41% versus .50% in Example 1; 2) the long storage time of wastewater in an anaerobic lagoon led to the estimate that 50% of the entering P remained in sludge in the lagoon. Additionally, DMI was lower in the grazing example. Keep in mind that Example 2 budgets are for the manure collected in the holding, milking, and feeding areas only and not for the 60% dropped in the pastures.

If sufficient land is available to apply manure based on a P budget, more fertilizer value will be utilized. For Example 1, about 30% more value was recovered if manure applied to crop-producing acreage utilizing all of the P than if applied based on a N budget ($12,700 versus $9,900 per 100 cows based on equivalent commercial fertilizer values, calculations not shown).

However, can you make good use of the feed produced if you farm all the acres needed to utilize the P? With the estimated tonnages of DM harvested, 6.6 tons/acre for corn silage, 2.0 for bermudagrass after corn silage, and 2.8 tons/acre for winter rye before corn), we estimate 296 tons of DM from the 26 acres utilized with an N budget which will supply 16.2 lb DM/cow daily on a year-round basis. With a P budget, 936 tons of DM from the 80 acres required translates to 50.0 lb DM/cow daily. The DM amount with the P budget is about twice as much forage DM as most dairymen feed their lactating cows. Therefore, you would have an excess, probably even more than could be used for heifers and dry cows. Also, many dairies do not have the .80 acre/cow of land required for crop production with this system (more if triple-cropping rye after corn silage and bermudagrass is not possible).

The acreage required for the N budget would allow most dairymen to utilize the manure and forage produced. However, the 296 tons DM produced annually with this system, which supplies only 16.2 lb DMI/day, may not be enough. Thus, additional forage production or purchasing of forage may be needed.

Note in Table 1 that triple-cropping with conventional tillage to produce corn, sorghum, and winter rye consumed the most N, P, and K. However, sod-based triple cropping was chosen for the example because sod cover and roots should reduce runoff and leakage of N to groundwater.

What can you do if you are forced to follow a P budget? The first and easiest step is to reduce P in the diet to NRC requirements. If diets formulated to supply required P average out at .41% of DMI, like in Example 2, recalculating Worksheet 1 predicts a daily P excretion of .136 lb/cow versus .18, which leads to excretion estimates of 4964 lb (versus 6570 lb) and an application of 4468 lb of P/yr if we recover 90% of P for fertilizer use. This change in diet, which would not be expected to affect performance, would change acreage needed with the triple-cropping system to 59.6 acres which would supply 690 tons of DM (37.8 lb DM/day to milking cows year-round). This is still 2.3 times the acreage needed for N budgeting but the forage production required is more nearly in line with needs if some of it is fed to heifers and dry cows.

Calculating value of recovered N, P, and K. Animal nutritionists and most dairymen use and think in terms of actual N, P, and K. Agronomists and the fertilizer industry use actual N, but refer to P in terms of P_2O_5 and K in terms of K_2O. The P_2O_5 actually contains 43.6% P (.436) and K_2O is 83% K (.83). Thus, 10-10-10 fertilizer units are equivalent to 10- 4.36 - 8.3 units of actual N, P, and K.

Conversions are needed to work from actual P and K excretion calculations to fertilizer recommendations or values based on P_2O_5 and K_2O. Note that the application rates used in Worksheet 3 were based on actual P and K from Table 1. Conversions often are needed for pricing as well. For example (as used in Worksheet 3, Lines 114 to 118), quotes obtained from a fertilizer dealer on a N-only fertilizer, e.g., ammonium nitrate, leading to $.36/unit N; a phosphate, leading to $.32/unit P_2O_5, and a K source leading to $.15/unit K_2O calculates to values of actual N, P, and K of $.36, $.73, and $.18. Divide P_2O_5 values by .436 and K_2O values by .83 for the conversion.

How could these worksheets be used for a pasture budget? If in Example 2, in the worksheets we were interested in some analysis of the pasture budget, we could recalculate the worksheets with a change in the percent time in the manure collection area (Line 40, Worksheet 1) to 60%, the amount of time the cows were on the pastures. Additionally, let's assume our pasture system is described by the bermudagrass and rye pasture data in Table 1. This would be managed as bermudagrass overseeded with rye in the fall, thus, double-cropping. The total calculated application rates per acre for these two crops (from Table 1) is 450 lb N, 39 lb P, and 242 lb K. For this example, it was assumed that 40% of N, 90% of P, and 80% of K dropped on those pastures was recovered as fertilizer. Putting those application rates and recovery percentages into Worksheet 3 in place of one of the 6 systems illustrated gives 17.4 acres (N basis), 61.8 acres (P basis) or 31.1 acres (K basis) of pasture needed.

Obviously 17.4 acres based on N is not enough acres to feed 100 cows. How many acres do you need? If we assumed that we had pasture to graze 90% of the year and that cows ate 15 lb DM from pasture per day, that computes to 4900 lb DM/cow yearly. Table 1 assumptions for those pastures were for 6 tons DM grazed/acre (12,000 lb). Dividing 12,000 lb/acre by 4900 lb per cow gives 2.45 cows per acre as an average stocking rate or 100 cows divided by 2.45 cows/acre equals 40.8 acres. If you choose your acres to have in pasture based on estimated DM consumption, you can estimate relative N, P, and K availability from the ratios of calculated acreages to acreage needed. For example for N, 17.4/40.8 = 43%, which is an estimate that manure would supply only 43% of the total N fertilizer needed for 40.8 acres. The ratio for P of 61.8/40.8 = 1.49 indicates that manure would be supplying about 1.5 times as much P as recommended. Thus, soil P storage amounts would be expected to increase. The K ratio, 31.1/40.8 is about .76 which indicates little K application should be needed.

This pasture example helps support some general conclusions about pasture budgets. First, if pastures are truly grazed and not simply used as a sodded dry lot, additional N from commercial fertilizer generally will be needed beyond that supplied by manure N. Second, additional P from commercial fertilizer will not be needed unless soil P storage previous to current grazing year was below soil fertility recommendations based on soil tests. Third, soil tests are recommended to help decide if K fertilization is needed.

How many, if any, nutrients should be exported off-farm? This may be one of the most important things that you need to find out. This calculation can be approximated from the worksheets. For example, if you don't have the acreage needed for your selected crop production system, the ratio of acreage you have to that needed is the fraction of the total manure nutrients that you can utilize. The remaining fraction may have to be exported if you can't intensify crop production to utilize more nutrients on the acres that you have.

Summary

- Nutrient excretions by lactating dairy cows, especially N and P, are easily estimated accurately when DMI, nutrient composition of the diet, and milk yields are known.

- Dairymen must quantify manure nutrients recovered from the waste management system to accurately develop a whole-farm nutrient budget. That means weighing loads of manure, measuring gallons of wastewaters used in irrigation, and having samples analyzed for nutrient composition.

- Losses of more than 50% of the excreted N are common. If an average recovery must be used for preliminary calculations, we suggest that 40% be used, i.e., 60% lost. Losses of P should be less than 10% and losses of K should be less than 20%.

- Manure nutrient applications for fertilizer are usually of less risk to the environment than equal nutrient applications of commercial fertilizer because enough of the recovered manure N is in organic form to lessen risk of leaching.

- Most dairy manure budgets find enough P to fertilize two to three times as many acres of crop production based on P as can be fertilized appropriately with manure N.

- Pasture budgets will almost always show need for supplemental N from commercial fertilizer N with no supplemental P needed from commercial fertilizer.

- Practical goals to realize the most value from dairy manure usually include 1) reducing dietary P to NRC requirements to reduce diet cost and manure P excretion, 2) applying manure based on P budgets, and 3) applying manure to growing crops as soon as possible after excretion to minimize N volatilization losses.

Odor Research Report

Odors from livestock operations are the basis of a great number of complaints by neighbors. Odors from animal manure during transport, storage, treatment, and disposal have become an acute public relations problem for animal agriculture. The odorous compounds are present at such low levels (ppm or ppb) that they are not toxic at concentrations found downwind of livestock production facilities but the smell often bothers people. This "nuisance" of odor is the basis by which odors are regulated (Sweeten and Miner, 1993). If a producer is forced to try to reduce an odor nuisance, the options are to either find a means of diluting odor prior to it leaving the property, prevent production of the odor, or prevent release of odorous compounds. On dairy farms in Florida, the most severe odor problems have been associated with center pivot irrigation of dairy manure flushwaters after short-term (1- to 7-day) holding.

Odor is made up of many individual odorants (specific chemical compounds) interacting with one another. The odorants are produced during anaerobic digestion, which begins in the animal's large intestine and continues in feces droppings, manure piles, and storage facilities. Anaerobic lagoons continue this type of fermentation to reduce solid organic waste volume by converting it, as completely as possible, to carbon dioxide and methane. If the fermentation can be carried to completion and the odorous compounds confined, the carbon in these intermediary odorous compounds will be metabolized to CO_2 and methane but additionally there will be some release of ammonia and hydrogen sulfide (H_2S). The H_2S is very odorous but, as will be confirmed with experiments reported later, it is rapidly oxidized to nonodorous gases when released to oxygenated air and is not a serious odor threat off-site and ammonia is not odorous at concentrations found around lagoons. Thus, well-managed anaerobic lagoons seldom are the cause of an odor problem. However, anaerobic digestion produces more odorous intermediate compounds initially than are present in fresh manure. Thus, partially digested manure may be more odorous than either fresh manure or well-digested manure from lagoons (see later results).

Anaerobic digestion systems in which biogas fuel is generated usually do an excellent job of processing odorous compounds. In some cases, such systems now are being installed with odor control as one of the primary objectives (Wilkie et al., 1995); energy recovery via methane fuel is important to help defray the cost of installation but economics of energy conversion have not encouraged installation of anaerobic digesters for energy recovery alone. Anaerobic digestion of swine manure for methane gas production reduced the odor emission rate from land-applied digested slurry by 91% as compared to untreated pit-stored slurry (Pain et. al., 1990).

Numerous commercial products are available to producers, which are advertized to aid in odor control. These products vary widely in origin and mode of action and variable success has been reported for their effectiveness (Williams, 1995). Some of these differences may be explained by the inability to provide a true control in an on-site investigation due to changing atmospheric conditions. Additionally, a standard procedure to evaluate all products is needed. Measures are being taken to address this issue between a number of universities and other groups (Williams, 1995).

Biochemicals used to control odors have included masking agents, (disguising on odor with another, more acceptable odor) and oxidizing agents, e.g., ozone, potassium permanganate, and chlorine-containing compounds. Other methods include digestive deodorants and feed additives. Digestive deodorants are the most prevalent and necessitate that the added bacteria become the predominant strain. Some of the products currently marketed have been shown to be helpful in controlling odor and some have not. In cases where they may have been effective, costs were high, e.g., $6 to $23 per hog per year. More research is needed in the area of additives to control odors in order to prove efficacy and to evaluate cost effectiveness.

Experimental Methods

Laboratory-scale anaerobic digesters, or artificial lagoons, were fed with dairy manure diluted to simulate flushing of housing with or without a solids separating screen. Factors studied to identify their effects on odor intensity and concentration of selected odorants were:

1. Holding time of flushwater in the digesters. The holding time was varied from 1.5 to 20 days. The control samples were undigested flushwater.

2. Screening of fibrous solids from flushwater which often is done to facilitate irrigation.

3. Addition of commercial additives or digesters.

Benchtop digesters with an operating volume of 4 liters were used to simulate full-scale conventional anaerobic digesters or well-managed lagoons. All digesters were maintained at room temperature (24^{o} C). Two dilutions were prepared; the first was whole manure diluted to a solids content of 2% and the second was this 2% wastewater poured over a no. 10 sieve (2 mm mesh diameter) to simulate a solids separator, yielding a 1.3% total solids flushwater. Retention times of 20, 15, 10, and 6 days were tested in standard digesters and 2.3 and 1.5 days in fixed-film digesters. A fixed-film digester has surfaceds in it to which bacteria cling and not wash out when liquid materials flow by. For example, forage particles form a floating mat in the rumen of a cow and provide a fixed-film for bacteria in the rumen, an example anaerobic digester.

Five commercial products aimed at controlling odor were added to effluent from the digesters and to digester feedstock (simulated flushwaters). Additives used were chosen to represent the variety of products available for use by producers. Products #1 and #3 were plant extracts in which the proposed mechanism for controlling odor was by binding of ammonia. Product #2 was a commercial chemical with oxidation being a suspected mode of action. Product #4 was an organic compound with a strong, but, not unpleasant odor. This product may have worked as a masking agent or counteractant. Because the mode of actions and chemical compositions of the commercial products were vague, two chemical oxidants, hydrogen peroxide (H_2O_2) and potassium permanganate ($KMnO_4$) were tested. Commercial products were added at the manufacturer's recommended dosage to 100 ml of effluent or feedstock. Samples were placed in black-painted Erlenmeyer flasks and stoppered for 3 days. The control feedstock (0-days HRT) was stored for 1 and 2 days as well, to determine if length of reaction time affected odor. Product #5 also was stored for 1, 2, or 3 days with product being added each day to evaluate potential benefit from multiple applications. Additive effects were not influenced by these differences in use, therefore results reported herein are all associated with 3-day holding at room temperature after additive was mixed with digester effluents and manure wastewaters

One commercial additive, which was a yeast-based fermentation product that the manufacturer felt would increase milk production, was fed to 36 cows in a switch-back design to see if milk production changed within cows. Odor measures were made as well on fresh feces, urine, and combined feces plus urine.

Odor sample chemical analyses included NH_3-N, total phenol, individual and total VFA. Odor intensity was determined by a human panel. A forced-choice panel method was utilized using 250 ml Erlenmeyer flasks, which had been painted black so panelists could not see the product they were evaluating. Eight to ten stations were available for each panelist to test on a given day. At each station were three flasks one of which contained a sample and the other two, water. Each panelist was asked to stop at all stations and at each station identify which flask contained the sample. Based on the flask chosen, the panelist was then asked to rate and record the detected odor on intensity and unpleasantness using a 1-10 scale. For example, a score of 1 assigned to both scales indicated a 'very weak' and 'highly acceptable' odor whereas a score of 10 for the intensity and unpleasantness categories corresponded to a 'very strong' and 'highly offensive' odor. In the case that a flask containing water was chosen as the source of odor, a score of zero for both scales was assigned to the proper flask.

Results and Discussion

Anaerobic digestion. The 20-day digesters produced an average .20 liters of methane per gram of organic matter (OM) and the rate of methane production (liters/g OM) was directly related to holding time falling off to .03 liters/g OM in the 6-day digesters (Table 4). Data shown in Table 4 are the average of the digesters fed the 2.0% and 1.3% total solids flushwaters. Screening out hard-to-digest fibrous solids improved methane recovered by .04 liters/g OM fed (data not shown). Data for change in COD are not shown but were similar to OM.

Table 4. Effluent characteristics and gas production of anaerobic digesters fed dairy manure wastewater and operated under varying retention times.[1]							
Digester (ave. of 1.3 and 2.0% feedstocks)	Effluent concentration:			Biogas (Liters/day)	OM % removed	Liters CH_4 /g OM fed	CH_4, % of biogas
	TS %	OM %	H_2S (ppm)				
Conventional stirred tank digester							
20 d HRT[2]	.96	.66	582	.72	43	.20	67
15 d HRT	1.08	.79	784	.84	32	.18	66
10 d HRT	1.28	.94	696	.80	24	.10	67
6 d HRT	1.44	1.08	>2000	.56	11	.03	50
Feedstock	1.62	1.23	5	---		---	---
Fixed-film digesters							
Ave. of 1.5- and 2.3-d	1.16	.82	>2000	2.32	23	.10	70

The 1.5- and 2.3-day fixed-film digesters produced an average of .10 liters/g OM, the same as the 10-day standard digesters (Table 4). The 20-day digesters removed 43% of the organic matter while the 6-day digesters removed only 11%. The 1.5- and 2.3-day fixed-film digesters average 23% removal, almost the same as the 10-day conventional digesters.

Odor intensity and offensiveness were highly correlated. Therefore, only odor intensity data are discussed herein. Odor intensities, as perceived by the human panel, were reduced by both conventional and fixed-film digesters, and fixed-film digesters were 6.40, 4.31 (average of 20-, 15-, and 6-day digesters), and 5.59, respectively. Odor intensity decreased linearly with increasing time in conventional digesters (from 6 days to 20 days) and the 20-day digesters had an average mean odor intensity score of less than half the feedstock mean score (3.0 versus 6.40). The average of the fixed-film digester odor intensity scores was nearer to that of 6-day digesters than 10-day digesters.

Pre-screening of the feedstock did not affect odor intensity.

Effluent phenol concentrations were reduced by conventional and fixed-film digesters. Concentrations of total phenols were more highly correlated with odor intensity measures by the human panel than any other chemical measure (Table 5). Ammonia concentrations were affected to some extent by anaerobic digestion but effects were small and not linear. Ammonia was not correlated well with odor intensity.

Hydraulic retention time affected acetic acid and total VFA concentration in the conventional digesters. Other volatile fatty acids measured (propionic, butyric, isobutyric, valeric, and isovaleric) were affected but their concentrations were small and, thus, they were excluded from the data selected for Table 5 except as their total, along with acetic, in total VFA. All VFA demonstrated a curvilinear (quadratic) decrease in concentration with increased retention time.

The high acetic acid concentrations in 6-day conventional digesters is indicative, along with low organic matter removal and methane production (Table 4), and small reduction in odor intensity, of their poor performance.

Additive evaluation. The effect of additives on odor intensity and chemical analytes is shown in Table 5 (lower section). Additives did not perform differently for different digester effluents or feedstocks. Therefore, additive effects are averaged across all effluents and feedstocks.

Table 5. Odor intensity scores (scale of 1 to 10 from least to most offensive) and selected odorant concentrations[1] of effluent from anaerobic digesters fed dairy manure wastewater and digester effluents and feedstock treated with manure additives.

Digester	Odor intensity	NH_3-N (mg N/liter)	Phenols (mg/liter)	Acetic acid (mM/liter)	Total VFA (mM/liter)
Conventional stirred tank digester					
20 d HRT	3.06	1607	21.2	---	---
15 d HRT	3.66	1704	23.6	---	---
10 d HRT	4.25	1747	27.6	3.8	4.8
6 d HRT	5.66	1691	38.1	10.5	13.6
Feedstock	6.40	1540	50.6	12.2	14.3
Fixed-film digesters					
Ave. 1.5- and 2.3-day	5.56	1754	33.7	9.1	12.3
Commercial or chemical additive					
Control	4.29	1543	27.4	.5	1.3
1	4.28	1183	26.3	0	.3
2	3.79	1508	26.7	.4	.9
3	6.10	1505	39.9	3.06	4.6
4	5.08	1547	29.6	.2	.7
5	4.21	1392	25.1	---	---
$KMnO_4$	3.73	1222	13.4	1.7	3.1
H_2O_2	4.21	1218	34.6	2.6	3.8

Addition of commercial products and chemicals to digester effluents did not affect odor intensity beneficially (Table 5). One product, product 3, was found to increase odor intensity. Some additives altered the concentration of ammonia; for example, overall ammonia concentrations were reduced significantly compared to the controls (1368 mg/L versus 1543 mg/L) but the average was influenced primarily by additive #1, $KmnO_4$, and H_2O_2. Total phenol and VFA concentrations were unaffected, on average, by commercial product or chemical additions. However, there were differences between individual additives and the control. For example, additive #3 increased acetic acid and total VFA concentrations.

Feeding the yeast-based commercial additive to dairy cows had no detectable effect on milk production, milk composition, manure odor intensity, or odorant concentrations. However, within this study, it was found that the odor intensity scores of manure (feces and urine mixed) were significantly higher than either the feces or urine scores. For example, odor intensity scores of mixed manure averaged 4.41 while scores of urine and feces were 2.57 and 2.27 respectively. This demonstrates the additive nature of some odorants when combined and, perhaps, shows that urine contributes readily available nitrogen, which helps anaerobic microbes, proceed faster with degradation of organic matter and, thus, produce more odorants. Note, also, that the odor intensity score for the fresh manure mixtures are considerable less than the average score 6.40 for the feedstock (Table 5). The difference in these manures primarily is storage, the feedstock manures were held for three days during collection before mixing and freezing for storage. During this storage time some anaerobic fermentation would have taken place to produce more odorants.

Summary

Anaerobic digestion like that occurring in anaerobic lagoons was shown to greatly reduce several measures of malodor. Loading rates also were a factor with digesters operated at 20-day average retention times giving off less odor than digesters with shorter retention times. Fixed-film digesters were used to increase surface area within the digesters on which bacteria attach to reduce washout of the bacteria. Organic matter reduction and methane production in fixed-film digesters operated at 1.5- and 2.3-day average retention times were similar to that in 10-day retention conventional digesters; odor reduction with fixed-film digesters was more similar to 6-day conventional digesters. Testing of several commercial additives indicated potential to affect ammonia and a few individual odorants such as acetic acid but, under the conditions of this experiment, overall odor intensities of effluents from digesters were not reduced with additives.

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