Managing Dairy Manure Resources to Avoid Environmental Pollution[1]

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Manure nutrients and decaying organic matter are natural components of the environment that ultimately contribute to the production of more plant and animal tissue. Thus, although they may be called wastes, they are in fact resources to be recycled in the natural ecosystem. When these resources are in short supply, they are valued and reused as true resources. However, when they are in excess and result in detrimental environmental effects, they are truly wastes. In such circumstances, society chooses to pay for their management even if costs exceed the direct value of the resources recovered.

Currently, there are major concerns with nutrient losses to ground and surface waters from the manure of large dairy herds, which can seriously affect water quality. Emissions of odorous compounds are regulated in all US states through nuisance legislation and, in several states, through odor measurements taken at the property line. Additional regulations sometimes include standards for volatile emissions of ammonia (e.g., in The Netherlands), and studies of methane emissions may lead to regulatory oversight in the future.

All states are starting to monitor farms where large numbers of food producing animals are maintained on small acreage to avoid nutrient leakage to the environment. Similar concerns exist with overapplication of commercial fertilizer which might lead to leakage of nutrients to surface or ground water.

NUTRIENT BUDGETS

Nutrients in manure are recyclable. Applications of manure nutrients to plants that benefit from nutrient fertilization is the most used method to recycle. To avoid excessive applications of environmentally sensitive nutrients at inappropriate points, it is helpful to budget nutrient flow through the total dairy farm system. To do this, quantitative estimates of nutrients in manure and on nutrient flow through all segments of system are needed. Critical questions are:

1. How much of individual nutrients are excreted?
2. How does manure management system affect where nutrients flow?
3. What is potential nutrient uptake by plants?
4. How do you develop a manure nutrient budget?

How Much of Individual Nutrients Are Excreted?

Nutrient excretion standards most often used in the design of manure management systems have been those of the American Society of Agricultural Engineers (ASAE, 1990). These standards are based on body weight of cows; however, they do not account for large variation among dairies in feeding levels and consequently excretion levels. Variation is caused by differing voluntary feed intake, supplement levels, and amounts of nutrients harvested in milk which can be accounted for in conjunction with the feeding management of the herd. For example, University of Florida experiments (Morse et al., 1992; Tomlinson, 1992) showed that P and N excretion by dairy cows vary dramatically with level of P or N intake and were predictable with equations based on daily P or N intake, DMI, and milk yield. Excretion also was estimated accurately based on dietary intake of a nutrient minus amount secreted into milk. Excretion estimates are shown in table 1 based on the following milk composi

[1]This paper is based upon other publications of the author, most notably Van Horn, et al., 1991, Circular 1016 of the Florida Cooperative Extension, University of Florida, Gainesville and Van Horn et al., J. Dairy Sci. 77:2008.1994.

Table 1. Daily and yearly excretion estimates of various fractions and nutrients by 1400 lb Holstein cows.

	From ASAE (1990)	Daily milk and DMI for: 30 days	70 days	205 days	60 days	Total for year
Milk, lb/cow = = = >		100	70	50	Dry	18150
DMI, lb/cow = = = >		55.8	46.3	39.2	25.2	14462
		Excretion for cow described in column above[1]				
Fraction or nutrient	Lb/day	Lb/day	Lb/day	Lb/day	Lb/day	Lb/yr/cow
Raw manure (feces + urine)	120.4	195.0	160.0	125.0	80.0	47475
Feces (wet)		125.0	100.0	75.0	45.0	28825
Urine	36.4	70	60	50	35	18650
Total solids (.33 DMI+urine DM)	16.8	21.5	18.0	15.2	9.9	5612
Water in manure	103.6	173.5	142.0	109.8	70.1	41863
Volatile solids	14.0	18.0	15.0	12.7	8.2	4676
BOD, 5-day	2.24	2.87	2.40	2.02	1.32	748
COD, lb	15.4	19.8	16.5	13.9	9.1	5144
Total N, lb (NRC, low)	.63	.899	.727	.601	.364	223
Total N, lb (NRC, high)	.63	1.030	.846	.698	.439	260
Urea+ammonia N (NRC, low)		.408	.308	.249	.125	92
Urea+ammonia N (NRC, high)		.500	.391	.319	.178	118
Ammonia N	.11					
P lb (diet .40% P)	.132	.123	.115	.107	.101	40
P lb (diet .45% P)	.132	.151	.138	.126	.103	47
P lb (diet .60% P)	.132	.235	.208	.185	.151	69
Ortho P	.085					
K lb (diet .8% K)	.406	.296	.265	.239	.201	88
K lb (diet 1.2% K)	.406	.519	.450	.396	.302	146
Ca lb (diet .65% Ca)	.224	.242	.217	.195	.164	72
Ca lb (diet .90% Ca)	.224	.382	.333	.293	.227	108
Mg lb (diet .20% Mg)	.099	.102	.086	.073	.050	27
Mg lb (diet .35% Mg)	.099	.185	.155	.132	.088	49
Na lb (diet .35% Na)	.073	.145	.127	.112	.088	42
Cl lb (diet .55% Cl)	.182	.197	.178	.161	.138	60
Sulfur	.071					
Iron	.017					
	g/day					
Manganese	1.2					
Boron	.45					
Molybdenum	.05					
Zinc	1.14					
Copper	.28					
Cadmium	.002					
Nickel	.18					

[1] Adapted from Van Horn et al. (1991). Crude protein percent of total diet dry matter for cows producing 100, 70, 50 lb milk/day and dry cows for "NRC, low" diets were 16.0, 14.8, 13.8, and 11.0%; respective CP% for "NRC, high" diets were 17.5, 16.4, 15.3, and 12.0% of total diet dry matter.

tion typical of Holsteins, which was used along with pounds of milk to determine recovery of fed nutrients in milk:

Protein	3.30% (N .512%)
Phosphorus (P)	.10%
Calcium (Ca)	.12%
Potassium (K)	.15%
Magnesium (Mg)	.01%
Sodium (Na)	.05%
Chlorine (Cl)	.11%

Phosphorus excretion estimates in table 1 illustrate dietary P of .40%, .45%, or .60% of total diet DM causes changes in estimated annual excretion of actual P from 40 to 46 to 69 lb per cow per year. Thus, dairy producers have considerable control of mineral excretion through control of mineral contents in diets they feed. Feeding adequate P is important for animal health and performance, but .40% of total diet DM or slightly more is very near estimated requirements for lactating cows (NRC, 1989). Although these data do not lead to lowering recommended feeding levels for P below NRC standard feeding recommendations, the data point out the need to keep excretions as low as possible and still maintain optimum animal performance.

Table 1 shows excretion estimates for N from two different diet formulation procedures used by NRC. One is for cows consuming diets formulated to supply crude protein **(CP)** standards (NRC, high); the other (NRC, low) minimizes dietary N by providing minimal nonprotein N and ruminally degradable intake protein **(DIP)** for optimum rumen microbial fermentation and provides remaining animal requirements with ruminally undegraded intake protein **(UIP)**. Numeric estimates of yearly N excreted by high producing 1400 lb cows were 260 lb per cow per year when fed according to the NRC CP standards and 223 lb N per year when diet protein was formulated for minimum needs of UIP and DIP. As with P, these data suggest that some diet control over N excretion is possible.

Although, yearly excretion estimates in table 1 are based on diets designed to support higher milk production than many dairy producers currently are achieving, most dairies with lower milk production choose to feed as much protein as was used in this example (e.g. up to 17.5% CP of total diet DM for high producing groups). Excretion estimates for cows eating enough to produce more than 20,000 lb of milk per year were used because most herds feed diets to support that level of production even if they still are not achieving that production. Individual farms, however, should develop their management plan based on excretion estimates for their cows: e.g., if their herd averages 50 lb milk per day for all milking cows, use excretion estimates for cows producing 50 lbs milk (table 1) and multiply by average number of days in milk per year, e.g. 305, plus average excretion for dry cows times average days dry, e.g. 60.

How Does Manure Management System Affect Nutrient Flow?

After excretion, manure may be stored wet, stored after being allowed to dry, flushed with water to lagoon or holding pond, spread fresh on land, or spread in some form at a later time. The longer time in storage, the greater potential for N losses to air as ammonia. The greater the dilution with water, the greater potential for nutrient losses to surface and ground waters unless included as part of an irrigation program to distribute water and nutrients to growing crops. Few manure systems on farms actually collect all feces and urine at one location for application to one particular unit of land. Separations or losses occur in many ways.

1. Flushed manure from milking parlor and feed barn may go through sand trap and be pumped over a separator screen before irrigation of land with effluent.
2. Manure is dropped in different areas such as pasture, milking parlor, cooling barns, and primary feeding area and some of these separations may not be collectible for land-spreading.
3. Some gaseous loss of ammonia occurs (volatilization) which returns a variable but often controllable portion of N to the air.

Other possibilities include surface runoff and loss to groundwater. Management practices must control all of these components so that surface runoff and losses of nutrients to groundwater are minimized and do not cause violations of state water quality standards.

Choice of a manure management system depends on existing facilities. For example, if existing buildings were designed for flushing, a dry handling system would not be possible without major structural modifications. If a new dairy is being planned, then other factors can be considered. In both cases, changes in system must be compatible with other management practices on the dairy and manure nutrients must be spread in a way to recover nutrients in harvested crops or stockpiled in a way which will not pose environmental risks before being spread.

Stationary screen separators often are used with flush systems and take out 20 to 30% of organic matter from flushed dairy manure. With very dilute flushed dairy manure, about 20% removal of organic solids is probably the best estimate. The constant rinsing of solids as they are washed across the screen assures that almost all soluble nutrients stay with the water portion. Most minerals and N are in soluble form (>80%).

Table 2. Composition of screened manure solids.

Nutrient[1]	% of DM
Ash	13.3 - 13.4
Nitrogen	1.2 - 1.6
P	.10 - .20
NDF	77.7 - 83.5
ADF	50.5 - 52.7
ADL	12.9 - 15.1
Cellulose (ADF-ADL)	35.4
Hemicellulose (NDF-ADF)	32.0

[1]Moisture content usually about 75% (DM, 25%).

Expected composition of dairy manure fiber recovered from a screen and squeezed with a screw press is about 72.0% moisture (28% dry matter) with a nutrient content as in table 2 (data on a 100% DM basis). Feeding value of this product will not support acceptable daily gains in growing animals. However, manure solids could be fed as an appreciable percentage of diets for cattle which need only to maintain themselves and sustain a slow rate of gain, e.g., dry cows.

Screened manure solids have been used extensively for bedding in free stalls. However, management to prepare properly is critical. An accepted practice seems to be to compost solids so that internal temperatures within the pile become high enough to kill coliform bacteria. Research has shown that even though bacteria decline to low or undetectable numbers during composting, bacteria often return in bedding material in free stalls unless the solids are dry and kept dry. Even when researchers found higher bacterial counts in composted dairy waste solids bedding than on rubber mats, there was no difference in bacterial counts on teats or in milk of cows using the two types of bedding. They concluded that with adequate composting, dairy waste solids were a suitable bedding in free stalls. Many dairy producers with excellent mastitis control programs are using dry, screened manure solids for bedding in free stalls.

An alternative to removing solids from flushed manure with screening is to design holding ponds for gravity separation (settling basins). More solids can be removed with well designed sedimentation basins (40 to 60%) than with stationary screens. The key is detention time of water carrying solids. However, sedimented solids have much higher moisture content and are not as useful as screened solids if bedding for free stalls or composting is desired. Thus, land spreading is the most likely method of disposal.

What is Potential Nutrient Uptake by Plants?

It is generally accepted that manure nutrients can be applied slightly above the level of nutrients removed by crops harvested. When animal numbers are high in relation to land available, the system needs to utilize maximum application rates of environmentally sensitive nutrients such as N and P for given soil types and different cropping systems in order to avoid transporting manure nutrients off the farm.

A long-term research project at Tifton, Georgia was designed to identify maximum application rate of flushed dairy manure nutrients when a triple cropping system was used. Flushed dairy manure nutrients were applied through center pivot irrigation. Cropping system included Tifton 44 bermudagrass sod in which corn was sod-planted for silage in spring and abruzzi rye was sod-planted in fall. Harvests included rye for grazing from about Dec 1 until Feb 15, rye for silage about Mar 20 (corn planted day following), corn for silage in mid-July, low-quality bermudagrass hay about 10 days later, and high quality bermudagrass hay or grazing until rye was planted again about Nov 1.

In the Georgia experiment, large-particle manure solids were separated from liquid with an inclined stainless steel separating screen (1.0 x 6.0 mm hole size) to facilitate irrigation of effluent.

Liquid portion was applied to cropping area at four rates. Actual DM and N yields of the three crops in their rotation in response to different rates of liquid manure application are shown in table 3. Harvests of all crops yielded 11.69 tons or more of DM per acre (23,380 lb).

Due to luxury consumption of N in plants with higher N applications, particularly in rye, total N harvested in three crops continued to increase after DM yields plateaued. The N application rate reported (340, 440, 660, 880 lb N/acre) is the amount of N pumped to irrigation sprinklers. Losses of N through volatilization during irrigation (e.g. 20%), surface runoff, and acceptable losses to groundwater potentially make application of 660 lb N/acre in environmental balance with a total harvest of 525 lb N. These data do not show what happened to excess N with 880 lb N application. From personal communication with Dr. Johnson, preliminary data showed nitrate level in drainage water underneath center pivot area was similar to levels under many corn fields fertilized with commercial fertilizer but was slightly above environmental standard of 10 ppm nitrate N. Due to close proximity of plots, they could not differentiate between application rates but presumably most of excess came from 880 lb N/acre applications.

The Georgia data in table 3 show that it is possible for N removal in crops to be greater than that applied, e.g., 377 lb N harvested with 340 lb N applied. For this to happen, N must have originated from soil reserves of N carried over from previous years, from N in rainfall (often estimated at about 15 lb N/year), or from N fixation from air (not likely without legumes in system). For N budgets developed later in this publication, N in rainfall was estimated to be offset by gaseous loss of N from soil and, thus, neither were included in calculations. However, with a deficit of N in soil, gaseous losses from soil might be reduced appreciably permitting gain from rainfall to make a positive contribution. This gain might not be enough to make up the difference in plots with 340 lb N application rate. However, it could explain much of the difference in 452 lb N harvest with 440 lb N application.

Although Johnson et al. (1991) did not report P application rates, P recoveries and recoveries of several other minerals were estimated from feed composition tables (NRC, 1989). These data and data for several other example crops and systems are in table 4. The P recoveries were 55 to 60 lb per acre which are of particular interest since more acres would be required to accommodate manure P than manure N. Although tempting to compare data in this table directly with estimated excretion rates to estimate acreage needed for manure disposal, factors such as volatilization of N, surface and groundwater runoff, export of some manure fractions off farm, etc. must be considered in budgeting.

The Georgia cropping system has tremendous potential for the Southern US because the majority of harvest is corn silage, a high-energy forage that most dairy producers use for high producing cows and the sod base is bermudagrass which grows well in a warm season. Alfalfa, perennial peanut, and giant elephantgrass systems are more hypothetical and need further testing.

One advantage of flushed manure systems along with irrigation, is that additional water can be applied with fertilizer nutrients so that full response to added nutrients is possible.

How Do You Develop a Manure Nutrient Budget?

After designing essential components of manure management system and estimating total manure nutrient excretion, next step is to account for what happens to nutrients. If needed, one can develop alternatives to avoid nutrient leakage to environment. If land with appropriate cropping is available to utilize all nutrients, it is important to apply manure soon after it is produced to recover maximum N. Amounts of N which plants recover are much greater than when manure is stored anaerobically before application due to gaseous losses of N to air. If storage conditions become aerobic, there is substantial additional reduction in amounts of N available to plants.

Amount of N volatilized is influenced by level of N in manure (particularly part originating in urine) and by method of application. Nitrogen in urine originally is excreted in the form of urea. Urease enzyme of bacterial origin is present almost everywhere so N in urea is converted readily to ammonia which is lost to the air as free ammonia unless conditions of storage are acidic. In table 1, nearly half of manure N from cows was estimated in urea or ammonia form (mostly from urine). Fecal N from cattle is more stable.

Leaching losses also may occur. Application of manures outside the growing season or in amounts which exceed crop needs may result in nitrate leaching losses of 25% or more of applied N. High utilization of N by crops can be achieved with lowered environmental risks when manures are applied at a time crops can absorb mineral-N and at rates which do not exceed crop needs.

Several example systems to illustrate how nutrients might flow through different manure management systems and acreage needed to utilize manure are illustrated in tables 5 and 6. Manure excretion data for Systems 1, 2, and 3 are for 100 cows producing 50 lb milk per day on a year-around basis. System 4 is for 100 dry cows. Yearly totals were obtained by multiplying daily data by 365. The systems are:

1. Milking cows producing 50 lb milk per day and fed diets based on NRC Low standards for protein and .40% P are confined in concrete lots, all manure flushed into holding pond for frequent irrigation of cultivated crops taking up 400 lb N and 50 lb P per acre. Solids screened to facilitate irrigation and spread on land.

2. Milking cows are producing, fed, confined, and managed as in System #1 except all manure is flushed into anaerobic lagoon with effluent from second stage of lagoon system used for frequent irrigation of same cultivated crops.

3. Milking cows producing and fed as in Systems 1 and 2 are maintained in dirt lots where 75% of manure is dropped; manure is scraped and hauled every 3 mo; 25% of manure from milking parlor, holding areas, etc. is flushed and managed as in System #1. Surface runoff water from dirt lots is put into holding pond with flushed water.

4. Dry cows fed to meet NRC Low protein standards and .40% P are maintained on pasture. It was assumed cows harvest 5.0 ton of DM/acre/yr of nonirrigated bermudagrass which recovers 200 lb N (12.5% CP of forage) and 25 lb P. Additional feed was supplemented to provide amounts for dry cows shown in table 1.

Table 3. Yields of forage dry matter and recycled N from crops fertilized with flushed manure through center pivot.[1]

Estimated annual application of N Lbs/acre	Crop, tons of DM or lb N/acre							
	T-44 bermuda		Abruzzi rye		Corn silage[2]		Total Tons	Total Lb
	DM	N	DM	N	DM	N	DM	N
340	1.82	95	1.90	125	7.97	157	11.69	377
440	2.30	122	2.26	154	7.54	176	12.10	452
660	2.06	112	2.78	222	7.70	190	12.54	525
880	2.03	115	2.48	219	8.00	209	12.51	543

[1]Data from Johnson et al. (1991). Fibrous solids of flushed manure were moved before irrigation with stationary manure solids separating screen.
[2]Mean bushels of grain/acre in silage were 175, 163, 161, and 169.

Table 4. Comparison of annual estimated uptakes of nutrients by different cropping systems with excretion rates by dairy cows.

Crop	Estimated lb harvested/acre: DM	N	P	K	Ca	Mg	Na	S
DM and N data from Johnson et al., 1991; others estimated:								
#1 (340 N/acre)	23390	377	55	284	61	43	12	33
#2 (440 N/acre)	24200	452	57	302	63	44	13	34
#3 (660 N/acre)	25080	525	60	317	66	45	14	35
Estimated recoveries:								
Corn silage	16000	208	35	154	37	31	5	24
Sorghum silage	16000	154	42	163	46	43	5	23
Alfalfa	14000	448	41	358	216	34	21	43
Perennial peanut	10000	240	22	153	125	31	11	27
Bermudagrass	18000	346	40	306	58	29	24	22
Perennial peanut/rye	14000	329	30	197	131	35	22	30
Bermudagrass/rye	20000	403	43	306	57	29	23	22
Bahiagrass pasture	10000	200	25	145	46	27	10	10
Giant elephantgrass	40000	499	100					
Bermudagrass harvested,[1]								
0 N/acre	2160	30						
100 lb N/acre	7920	132						
300 lb N/acre	14220	323						
600 lb N/acre	17460	442						
900 lb N/acre	18900	554						
Amount excreted/cow/yr								
Lower estimate		223	40	88	72	27	42	26
Higher estimate		267	46	146	108	49		

[1]From data cited by Staples, C.R. 1989. Proc. West Florida Dairy Prod. Seminar. FL Coop. Ext. Serv., Dairy Sci. Dept., Univ. Fl., Gainesville, 32611.

Anaerobic lagoons (#2) which detain flush water for a much longer time than temporary holding ponds have been used extensively. Losses of N from lagoon systems where effluent is applied through overhead irrigation were assumed to be similar to dirt lot system (#3). A more uncertain part is how much of P and other minerals accumulate in sludge at bottom of lagoon. In this example, it was estimated that 50% of P and 10% of N are complexed in sludge which needs to be periodically removed. Although lagoons reduce acreage needed for day-to-day P budgets, the P must be eventually distributed on acres needing P applications, e.g. every 3 to 10 yr depending on size of lagoon. Finding suitable acreage on which to spread these nutrients may present a problem unless the sludge is spread on farm land other than that used for regular manure spreading. Quantitative data are needed to show how much P and other minerals are retained in lagoons so that acreage requirements for regular manure disposal can be adjusted accordingly. However, it is well documented that sludge accumulates and therefore it needs to be included in nutrient budgets for dairies with anaerobic lagoons.

In the four example manure management systems, these assumptions were made:

1. Manure is applied year after year to the same land at same rates so carryover of nutrients from previous applications, if any, can be assumed to be equal each year.
2. Assumed losses of N through volatilization were:
   a. 2% of N dropped on concrete before daily flushing or scraping,
   b. 10% of N from flushed manure being held only a short time before irrigation,
   c. 50% of N dropped in dirt lots for clean-up and spreading every 3 mo,
   d. 40% of runoff from dirt lots which was estimated as 10% of N dropped on dirt,
   e. 20% in the field after land-spreading N from irrigation or land spreading, and
   f. 50% of total N dropped in pasture.
3. Runoff from flushed or scraped concrete lots was captured in a holding pond for frequent irrigation and that from dirt lots was captured in a separate holding pond which also was added to the irrigation but after longer time in storage.
4. Surface runoff losses from crop fields of N and P were assumed to be 5% of nutrients applied.
5. To account for normal and acceptable losses to groundwater, it was estimated that 20 lb N/acre and 2 lb P/acre/year pass with water moving through soil into groundwater. This amount was added to estimated uptake of N or P by crops harvested. Estimated uptake of N was 400 lb/acre for cropping systems and 200 for pasture; for P estimated uptake was 50 lb/acre for cropping systems and 25 for pasture. Although groundwater standards have not been set for P, it was assumed that 1.0 ppm P would be acceptable and that this level would be obtained from 2 lb P/acre/yr.

Table 5 shows a N budget generated from a computer spreadsheet for the four 100-cow groups managed according to scenarios described previously and fed minimal dietary levels of N (NRC low, table 1). Note, N produced yearly by cow groups flowed somewhat differently through the four hypothetical management systems. Predicted manure disposal acreage needed per 100 cows varied from 17 to 36 acres. Similarly using a P budget in table 6, manure disposal acreage needed varied from 71 to 129 acres. It is important to note that 38 of the 73 acres estimated with 100% use of an anaerobic lagoon system were future acres needed when sludge will be removed from the lagoon. Acres for sludge application, however, might very well be acres on another farm to which sludge could be hauled or sold to other farmers for fertilizer.

If the same cows had been fed to meet NRC crude protein standards and a more typical level of P (.45% of diet DM), acreage requirements would vary from 19 to 41 acres for N budgets and 84 to 133 acres for P budgets. Direct acreage comparisons are in table 7.

Regardless of manure management system, more acres are needed to dispose of manure with plant uptake of P as application criterion than with plant uptake of N. Level of feeding (level of production) also has a significant effect. Remember, manure management system differed between groups 1, 2, and 3 and feeding level and system were different for the dry cow group, group 4.

Many more scenarios are possible than those illustrated here. Because of large variations from dairy to dairy in systems used and in feeding and production levels, it is essential that each farm be permitted to develop its own budget for nutrient flow. Tables are presented only to help individuals make estimates which are appropriate for an individual farm.

Principles of nutrient budgets can best be summarized by visualizing the total nutrient cycle necessary to achieve environmental balance. Figure 1 illustrates a system balanced for N which is constructed from data presented in previous

Table 5. Manure worksheet for nitrogen: needed acreage for 100-cow groups.

Category	Diet N (NRC,low); System: 1	2	3	4	Worksheet for your dairy
	MY=50	MY=50	MY=50	Dry	
Number of cows per group	100	100	100	100	
% to be flushed to holding pond	100	0	25	0	
% to be flushed to anaerobic lagoon	0	100	0	0	
% to be scraped from concrete daily	0	0	0	0	
% scraped from dirt lot quarterly	0	0	75	0	
% dropped in pasture	0	0	0	100	
Lbs daily N excretion/cow	0.601	0.601	0.601	0.364	
Lbs yearly N excretion/group	21937	21937	21937	13286	
	Lbs	Lbs	Lbs	Lbs	
Volatilized N on flush floors (2%)	439	439	110	0	
N flushed for weekly irrigation	21498	0	5374	0	
N removed by solids separator screen	1306	0	326	0	
N to holding pond--irrigation weekly	20192	0	5048	0	
Volatilized N from holding pond (10%)	2019	0	505	0	
N irrigated from short-term holding	18173	0	4543	0	
N flushed to anaerobic lagoon	0	21498	0	0	
N retained in sludge (10% of N)	0	2150	0	0	
Volatilized N from lagoon (60%)	0	12899	0	0	
N irrigated from lagoon--2nd stage	0	6449	0	0	
N runoff from dirt lot (10% of original)	0	0	1645	0	
Volatilized N from dirt lot holding (40%)	0	0	658	0	
N irrigated from dirt lot holding	0	0	987	0	
Total N applied through irrigation	18173	6449	5530	0	
Volatilized N during irrigation (20%)	3635	1290	1106	0	
Volatilized N on scraped floors (2%)	0	0	0	0	
Volatilized N, pastures (50% of original)	0	0	0	6643	
Volatilized N, dirt lot (50% of original)	0	0	8226	0	
Yearly lb N hauled daily from concrete	0	0	0	0	
Yearly lb N hauled quarterly from dirt	0	0	6581	0	
Volatilized N, land-spread from concrete	0	0	0	0	
Volatilized N, land-spread from dirt lots	0	0	1316	0	
Surface runoff (5% of crop applications)	909	322	606	332	
Irrigated N available to plants	13630	5837	4148	0	
Screened solids, N available to plants	1306	0	326	0	
From concrete, N available to plants	0	0	0	0	
From dirt lots, N available to plants	0	0	4936	0	
Pasture N available to plants	0	0	0	6311	
Summary: Total N in lagoon sludge	0	2150	0	0	
Summary: Total N volatilized	6093	14627	11921	6643	
Summary: Surface runoff	909	322	606	332	
Summary: Applied N available to crops	14935	4837	9410	6311	
Total N managed (= yearly excretion)	21937	21937	21937	13286	
Acres needed/100 cows for manure for:	acres	acres	acres	acres	
Irrigation if N/acre = 400 + 20	32.5	11.5	9.9	0	
Scrapings from concrete, N/acre=400+20	0	0	0	0	
Scrapings from dirt lot, N/acre=400+20	0	0	11.8	0	
Screened solids, N/acre = 400 + 20	3.1	0	0.8	0	
Pasture if N/acre = 200 + 20	0	0	0	28.7	
Future: Lagoon sludge, N/acre=400+20	0	5.1	0	0	
Total acres needed, N basis	35.6	16.6	22.4	28.7	

[1]Acres calculated by dividing nutrients available to plants by estimated uptake of 400 lbs N/yr for cultivated crops (pasture=200) + 20 lbs/acre groundwater passage.

Table 6. Manure worksheet for phosphorus: needed acreage for 100-cow groups.

Category	P (.40% of diet); System: 1	2	3	4	Worksheet for your dairy
	MY=50	MY=50	MY=50	Dry	
Number of cows per group	100	100	100	100	
% to be flushed to holding pond	100	0	25	0	
% to be flushed to anaerobic lagoon	0	100	0	0	
% to be scraped from concrete daily	0	0	0	0	
% scraped from dirt lot quarterly	0	0	75	0	
% dropped in pasture	0	0	0	100	
Lbs daily P excretion/cow	0.107	0.107	0.107	0.101	
Lbs yearly P excretion/group	3901	3901	3901	3675	
	Lb	Lb	Lb	Lb	
P flushed for weekly irrigation	3901	0	975	0	
P removed by solids separator screen	326	0	82	0	
P to holding pond--irrigation weekly	3575	0	894	0	
P irrigated from short-term holding	3575	0	894	0	
P flushed to anaerobic lagoon	0	3901	0	0	
P retained in sludge (50% of P)	0	1951	0	0	
P irrigated from lagoon--2nd stage	0	1951	0	0	
P runoff from dirt lot (20% of original)	0	0	585	0	
P irrigated from dirt lot holding	0	0	987	0	
Total P applied through irrigation	3575	1951	1479	0	
Yearly lb P hauled daily from concrete	0	0	0	0	
Yearly lb P hauled quarterly from dirt	0	0	2341	0	
Surface runoff (5% of crop applications)	179	98	191	184	
Irrigated P available to plants	3396	1853	1405	0	
Screened solids, P available to plants	326	0	82	0	
From concrete, P available to plants	0	0	0	0	
From dirt lots, P available to plants	0	0	2224	0	
Pasture P available to plants	0	0	0	3491	
Summary: Total P in lagoon sludge	0	1951	0	0	
Summary: Surface runoff	179	98	191	184	
Summary: Applied P available to crops	3722	1853	3710	3491	
Total P managed (= yearly excretion)	3901	3901	3901	3675	
Acres needed/100 cows for manure for:	acres	acres	acres	acres	
Irrigation if P/acre = 50 + 2	65.3	35.6	27.0	0	
Scrapings from concrete, P/acre = 50	0	0	0	0	
Scrapings from dirt lot, P/acre = 50 +	0	0	42.8	0	
Screened solids, P/acre = 50 + 2	6.3	0	1.6	0	
Pasture if P/acre = 25 + 2	0	0	0	129.3	
Future: Lagoon sludge, P/acre = 50 +	0	37.5	0	0	
Total acres needed, P basis	71.6	73.1	71.4	129.3	

[1]Acres calculated by dividing nutrients available to plants by estimated uptake of 50 lbs P/yr for

Table. 7. Acres needed per 100 cows with N or P criteria.

100-cow group	N based		P based	
	NRC low	NRC high	.40% P	.45% P
Milking cows:				
100% rapid irrigation	36	41	72	85
100% anaerobic lagoon[1]	17	19	73	87
25% flushed, 75% dirt lots	22	26	71	84
Dry cows on pasture	29	35	129	133
[1]Includes these acres for sludge N and P (average acres/yr)	5	6	38	44

tables. For this system, average dairy cows producing 50 lb milk/day/yr were chosen with manure flushed to a holding pond for frequent irrigation (System 1, table 5). Irrigated N was utilized in the triple crop system of corn silage, bermudagrass hay, and rye silage (table 3) with 452 lb N recovered in harvested crops. To achieve balance, manure from 3.5 cows was flushed and effluent from solids separating screen was irrigated with sprinkler irrigation heads on one acre of land. Cows consumed feed containing 1105 lb N, produced milk (7420 gallons) containing 327 lb N and 3 newborn calves with 10 lb N. The 3.5 cows excreted manure containing 768 lb N of which 15 lb N volatilized before flushing, 53 lb N were recovered in screened manure solids, 70 lb N volatilized during holding, 126 lb N volatilized during irrigation, 31 lb N were lost to surface runoff, and 20 lb N passed through to groundwater. Net recovery of 452 lb N in harvested feed was recycled to dairy cows in feed harvested from the acre to which flushed manure effluent was applied. Purchased concentrates and supplements (53% of estimated DM cows were estimated to consume) imported 653 lb N to farm. In this system, it is assumed the 53 lb N in screened manure solids (separated to facilitate irrigation) were exported from the farm after composting. Note, in this system it is estimated that 15 lb N available to the crop acre in annual rainfall is directly offset by an equal amount of gaseous N loss from soil. Data from the Georgia experiment and some other sources are suggesting that gaseous N losses from soil (denitrification) probably are greater than this in many soil conditions, perhaps as much as 80 to 100 lb N per acre annually.

RESOURCE POTENTIAL

Information in table 1 easily can be extrapolated to any herd size by multiplying number of cows by appropriate factor, e.g., a herd with 100 cows would be estimated to excrete 100 times as much as the yearly excretion estimates in table 1 (table 8).

Table 8. Annual manure production and nutrient value for 100 cows (1400 lb cows).

Manure constituent	Lb/year/ 100 cows	Initial value[1]
Raw manure (feces+urine)	4,747,500	
Total solids	561,200	
Volatile solids	467,600	
BOD, 5-day, lb	74,800	
COD, lb	514,400	
Total N, lb (NRC, low)	22,300	$6,690
P (diet dry matter .45% P)	4,600	2,760
K (diet dry matter .80% K)	8,800	1,320
TOTAL VALUE of N, P, and K		$10,770

[1]Based on assumed values of $.30/lb N, $.60/lb P, and $.15/lb K.

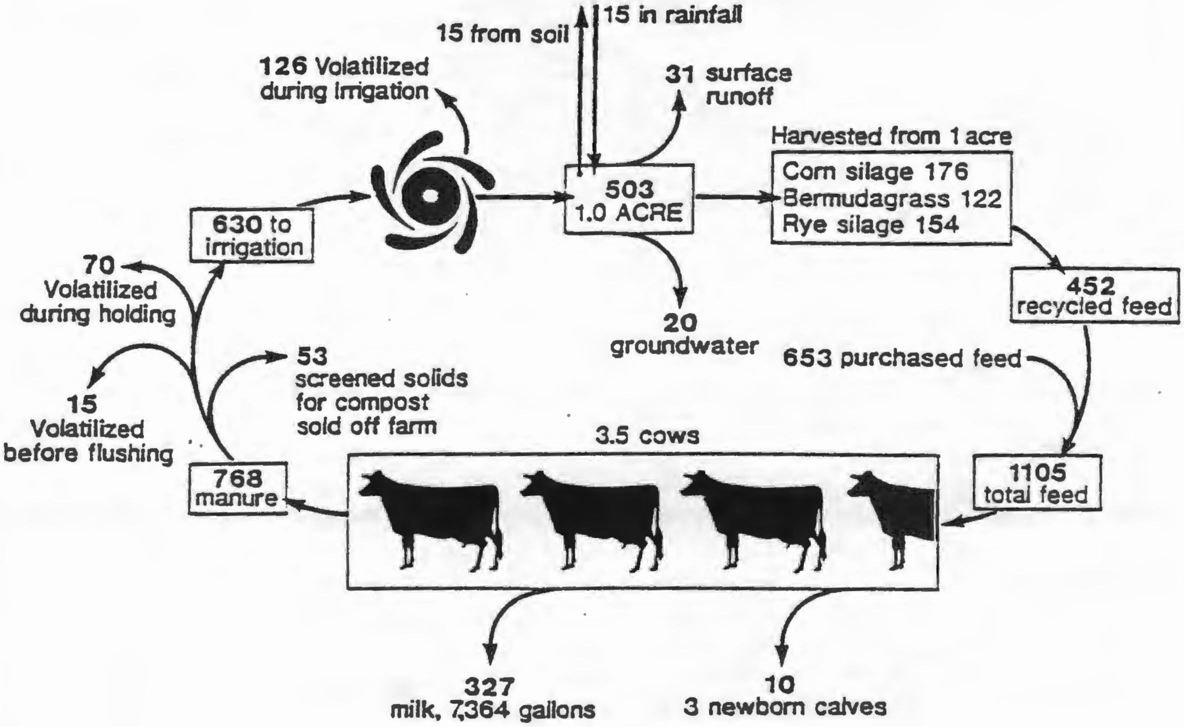

Figure 1. Example of dairy manure system where N is environmentally balanced. Numbers represent lb N. Crop N is from Table 3; excretion and losses are calculated as in Table 5, System 1.

Although value of N, P, and K fertilizer nutrients in manure usually is not as great as total costs of the waste management system, their value helps minimize net cost of waste handling. However, this will happen only if nutrients in dairy manure displace purchased inorganic fertilizer nutrients. Also, these values do not take into account losses from the system that decrease the amount actually applied to crops. For example, data from table 8 imply that fresh dairy manure contains:

N 9.4 lb actual N/ton wet manure
P 1.9 lb actual P/ton wet manure (equivalent to 4.4 lb P_2O_5)
K 3.7 lb actual K/ton wet manure (equivalent to 4.5 lb K_2O)
Total solids 12.8%

Even if this were the composition when excreted, composition when scraped and loaded usually is different due to changes in moisture content and volatilization of N. It is important to take samples of manure or wastewater applied to cropland and have these analyzed at a commercial laboratory. Analyses should include total Kjeldahl N and not just nitrate N since nitrate form of N does not occur in manures. Nitrification does not occur until after the manure is incorporated into soil. Major forms of N in dairy manure are organic N; urea N, the major source, is converted easily to ammonia and lost to air as gaseous ammonia.

Fertilizer Value. One method of estimating the resource value of manure is to assign a fertilizer value to the yearly production of N, P, and K, the most valued fertilizer nutrients. For example, based on assumed values of \$.66/kg N, \$1.32/kg P, and \$.33/lb K, the range in value for N, P, and K in manure illustrated in table 1 would be \$107 to \$146/yr per cow. In practice, realized values probably are only about half these amounts because of N volatilization and less than optimal use of other nutrients. The organic matter in manure has some value in fertilizer, but this value is difficult to quantify. Manure organic matter aids water retention and organically bound nutrients do not leach easily.

Energy Value. Manure, in relatively dry form, may be burnt directly as fuel. The use of manure as fuel is an ancient practice still utilized in many developing countries. The first large-scale resource recovery project in the world to burn cattle manure as fuel is in the Imperial Valley of southern California (Western Power Group and National Energy Associates, El Centro, CA). Approximately 80,000 tons of feedlot manure from beef cattle are stored on site at all times. In addition to supplying inhouse electrical needs, the plant generates about 15 megawatts of power, sufficient to meet the electrical needs of 20,000 homes.

The energy value of manure is a potential resource which, however, is usually discarded. Figure 2 shows how a typical cow producing 50 lb (22.7 kg) milk/day partitions megacalories of gross energy during digestion and metabolism. Of the nutrients consumed that yield dietary energy, approximately 5% is belched from the rumen as methane, 20% is secreted into milk at overall average production level, 40% is lost as heat (maintenance energy plus heat of fermentation), and 35% is excreted in manure of which approximately 93% is in feces. Although not shown except indirectly in table 1, higher production per cow results in more feed intake, more milk production, and more manure per cow. However, the percentage of feed nutrients recovered in milk increases and the percentage in manure decreases with increased milk production.

An important question to be answered is whether the potential energy in manure is economically recoverable. Anaerobic digestion of manure to produce biogas, which can be captured and used as a fuel, is the most feasible method to recover the energy value from manure on individual farms. With estimated biogas production of .35 liter of biogas/gram of volatile solids (VS, organic matter) input, about 2005 liter/day (2.005 m^3) could be produced from 5.73 kg VS/day obtained from an average cow (table 1). If this is converted to electricity with an efficiency of 1.0 kilowatt hr (**kWh**)/.934 m^3 of biogas, 2.005/.934 = 2.15 kWh/day per cow would be generated; estimated value would be $47/yr (at $.06/kWh) to $78/yr per cow (at $.10/kWh). Relative returns may be even greater if the biogas can be utilized as a substitute for other fuels used to produce heat.

Feed and Bedding Values. The ranking of animal wastes for ruminant feed in descending order of nutritive value was excreta of young poultry, deep litter of young poultry, hog feces, excreta of laying hens, hog and layer manure solids, and excrement of cattle (Fontenot, 1991). Fibrous solids, separated from dairy manure by screening, are more amenable to use as feed than is manure. However, digestibility is low, and solids of this type have not been of much value as a source of digestible nutrients because the digestible energy value is too low to support production above maintenance. Screened solids may, however, have potential as a diluent for use with dry cows or heifers fed corn silage or other high energy feedstuffs that promote overfattening if offered free choice and unamended. Use of fibrous solids for bedding (e.g., in free stalls) is feasible; many dairy farm utilize them in this way.

OTHER ENVIRONMENTAL CONCERNS

Livestock manures often are considered to be significant polluters of the surface or groundwaters. For this reason, regulatory oversight by the US Environmental Protection Agency and cooperating state agencies has become a significant force to ensure that dairies manage their manure so that surface and groundwater qualities are not compromised. Recycling manure's fertilizer nutrients through agricultural crops is an effective way of keeping excessive amounts of those nutrients out of these waters (see later section). Odors and other emissions from dairy manure management systems are further causes of environmental concern.

Odor Control

Volatile odorous compounds emitted from manure during transport, storage, treatment, and disposal have become an acute public relations problem for animal agriculture. Odorous compounds usually are present at such low levels (parts per million or parts per billion) that they are not toxic at the concentrations found in or near livestock production facilities. Thus, the problem depends largely on subjective factors, how much the smell bothers people or the "nuisance value" of the odor.

Volatile fatty acids, phenols, and sulfides are thought to be the major odor-causing compounds. However, typical chemical analyses measure concentrations of only a small number of constituents that contribute to the odor people identify by smell. One device for the estimation of odor intensity that can be used on-site is the scentometer, which is based upon an evaluator acclimating his or her sense of smell to odor-free air and progressively introducing higher proportions of odorous air, mixed with odor-free air, until an odor is first detected coming through the device (termed the threshold concentration).

Manure odors are caused principally by intermediate metabolites of anaerobic decomposition. If odorous compounds can be confined until the fermentation is far along, many of the intermediary odorous compounds will be metabolized to less odorous compounds or will exist in lesser concentrations. Anaerobic digestion systems in which biogas fuel is generated do an excellent job of processing odorous compounds. In some cases, such systems are being installed with odor control as the primary objective and energy recovery is a by-product which helps defray the cost.

Ammonia Emissions

Two primary forms of N exist in manure, ammonia and organic N. The major source of ammonia is urea from urine, or uric acid in the case of birds, which can be easily converted to ammonia (NH_3), a gas. Urea plus ammonia N from urine usually accounts for 41 to 49% of total N excreted in manure (table 1). In aqueous solution, NH_3 reacts with acid (H^+) to form an ion (NH_4^+), which is not gaseous. However, most animal manures, lagoons, and feedlot surfaces have a pH >7.0, making H^+ scarce and, thus, permitting rapid loss of ammonia to the atmosphere. As a consequence, N losses from animal manures can easily reach 50 to 75%, most as NH_3 before NH_3 is converted to nitrate (NO_3^-) through nitrification.

An important question to be answered is whether it is important to minimize low level emissions of ammonia to the atmosphere, and, if not, should livestock producers be encouraged to use manure management procedures to volatilize more ammonia? In Europe, atmospheric ammonia concentrations have become a public concern through their perceived contribution to acid rain and the destruction of forests. Consequently, European livestock and poultry operations are being required to utilize practices to minimize ammonia losses to the atmosphere.

Elliott et al. (1990), prepared an excellent review on atmospheric disposal of ammonia for use in manure-management policy development for the Chesapeake Bay area. Most volatilized ammonia is dissolved in water vapor in the lower atmosphere and washed back to earth by rainfall. During this process, ammonia neutralizes the acidity of the rainwater. In industrial regions with somewhat acid rainfall, e.g., Pennsylvania, neutralization is one potential benefit of ammonia release. If techniques were used to promote ammonia volatilization, a portion would be redeposited from the atmosphere to nonagricultural, N-poor areas such as forests. The resulting increase in soil fertility would be a potential benefit. However, soil pH would begin to drop over time, just as continued application of ammonia-containing fertilizers acidifies agricultural soils.

Current data do not prompt concern about negative effects on the environment caused by diffuse ammonia emissions from animal manures in North America. However, local concern about animal, human, and plant health is warranted when ammonia concentrations are high.

Methane Emissions

Methane emissions from animal production systems do not present an odor-control problem because methane is odorless. The concern with methane relates to its contribution to global warming. The earth is blanketed by a layer of gases that is relatively open to penetration by incoming short-wave solar energy. The percentage of this energy that is radiated from the earth back to space as long-wave radiation is determined by the concentration in the atmosphere of several of these gases. The principal long-wave, energy-absorbing gases are carbon dioxide, methane, chlorofluorocarbons, and nitrous oxide. These gases are called greenhouse gases because they absorb the long-wave radiation, just as glass absorbs radiation in a greenhouse, rather than allowing the heat to be radiated away from the earth. The steady enrichment of the atmosphere with greenhouse gases creates a warming effect, referred to as global warming. The actual contribution of greenhouse gasses to global warming is not precisely known because the extent to which their emissions affect global warming is still a topic of much debate. Data on methane in this section are from Johnson et al. (1992).

Carbon dioxide is the most abundant greenhouse gas and is expected to cause about 50% of the global warming occurring in the next half century. Methane is generally held to be the second most important and is expected to contribute 18% of future warming. Indeed, molecule for molecule, methane traps 25 times as much of the sun's heat in the atmosphere as carbon dioxide. Thus, methane is estimated to contribute 18% of future warming from <1% of the total greenhouse gas emissions.

The origin of methane produced by animals is microbial action in the gastrointestinal tract, which occurs to varying degrees in all animals. Major fermentative digestion, allowing utilization of fibrous dietary components, occurs in ruminants. This, coupled with large body sizes, dry matter intakes, and animal numbers, results in 95% of animal methane emissions arising from ruminants, about 80% from the Bovidae family.

The methane produced by animals and animal manures worldwide constitutes 16.4% of estimated annual methane emissions, which translates roughly to 2.9% of the estimated contribution of all greenhouse gases to global warming (i.e., 16.4% of 18%, the projected contribution of all methane).

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