ECONOMICS AND ENVIRONMENTAL EFFECTS OF MANURE HANDLING SYSTEMS FOR NORTHEASTERN DAIRY FARMS

Ralph E. Heimlich

ABSTRACT

Economic and environmental analyses of manure handling systems have implications for programs to regulate agricultural nonpoint sources of water pollution and programs to subsidize manure handling practices. Previous economic analyses in the literature are discussed. Manure systems are evaluated in a consistent framework to determine construction and operating costs. The effect of soil type on nutrient conservation is examined for two hypothetical farms. Dissolved phosphorous runoff is estimated for the farms varying storage capacity and soil type. Costs of phosphorus reduction by handling system, housing type and soil type are examined. Conclusions for cost-sharing policy are drawn.

INTRODUCTION

Dairy manure handling systems have been given increased attention in recent years for at least two reasons. The Federal Water Pollution Control Act Amendments of 1972 (PL-92-500) and later legislation known as the Clean Water Act of 1977 (PL-95-217) both contain requirements for control of nonpoint sources of water pollution from agriculture, including animal wastes (Holmes, 1979). In addition, since 1978 rapid price increases for fertilizers led to a switch in emphasis from manure as a disposal problem to manure as a resource in crop production. Since the pressures for better handling of dairy wastes come from both off-farm concerns for the environment and on-farm economics, any evaluation of alternative systems must consider both aspects.

These pressures are the focus of the Vermont Agricultural Runoff Study being conducted by USDA in cooperation with the Vermont Agency for Environmental Conservation. Interest in dairy manure handling practices is part of a larger concern for agricultural nonpoint sources contributing to the eutrophication of Lake Champlain. Cost sharing of manure systems is proceeding under several public programs. Both agricultural and environmental interests want to determine best management practices and their costs.

This paper analyzes dairy manure handling systems applicable to Vermont and the Northeast generally. First, recent literature on manure handling systems is examined with strengths and weaknesses noted. Second, economics of alternative systems are discussed. An evaluation of potential water quality impacts of different spreading systems is discussed. Finally, some conclusions for public subsidy of manure storages for water quality purposes are drawn.

Ralph E. Heimlich is Economist, Economic Research Service, U. S. Department of Agriculture, Ithaca, New York.

LITERATURE REVIEW

Economic analysis of manure handling systems in recent literature concentrates on two areas: analysis of manure handling systems as farm investments and comparison of alternative systems. Fixed and variable costs are compared with benefits, in terms of nutrients conserved and labor saved, somtimes examining differences of scale.

Casler and LaDue (1972) analyzed a liquid manure system, comparing it with a conventional solid system using daily spreading. They found that labor savings and increased nutrient conservation did not offset the increased cost of the liquid system. An estimate of effective nutrients conserved, net of runoff, volatilization, and leaching was made. Based on limited field study literature, an argument was made that environmental benefits attributable to manure handling systems were slight or nonexistent. A brief analysis of scale economies and other types of systems was included.

Jacobs and Casler (1972) estimated construction and operating costs for five stanchion barn and thirteen free-stall barn manure systems. An index of environmental effects was subjectively evaluated measuring characteristics such as odor, appearance, flies, and risk to water quality. Manure nutrient conservation was not valued directly but was included in the environmental index. Comparison of environmental impacts and costs suggested that almost all systems cost more than daily spreading systems, but did not necessarily reduce environmental impacts. Daily systems for both housing types brought more "environmental quality," as measured by the index, than more complex systems.

A handbook for economic analysis of manure systems prepared by Christensen, et al., (1981) included a discussion of concepts and methods. Six case studies, representative of regions and farm types, followed. The Lake States dairy case study compared two types of pit storages for solid manure to daily spreading. Both storage systems had negative returns based on benefits from nutrients retained. Both also required more fuel, peak time labor and capital than the daily system. Nutrient losses from field application were considered.

Cason and McAuslan (1974) examined thirteen manure handling systems for English herds at several small herd sizes. This analysis contains an excellent discussion of the factors affecting choice of manure handling systems. No estimates of the value of nutrients retained were included. Several of the factors, such as labor utilization, soils, and crop mix, were mentioned but not incorporated in the quantitative analysis.

Lessley and Via (1976) examined six kinds of systems for 50, 100, and 200 cow herds. They found economies of scale per cow for all systems. An analysis of nutrient value was based on Casler and LaDue (1972). Net annual costs for all systems were lowest for daily spread systems. Labor savings for liquid systems were sufficient to offset higher annual costs.

Detailed analysis of animal waste handling systems for all types of livestock was done by White and Forster (1978). Twenty-seven systems were analyzed, twenty-two of which are applicable to the Northeast. Nutrient losses in storage and application were estimated, and 50 percent and 100 percent of estimated nutrients retained were valued. Economies of scale were analyzed for herd sizes varying between 50 and 500 cows, depending on system type. All systems showed negative net returns at all herd sizes, although economies of scale were present. A numerical index was used to rate water and air quality impacts of each system.

A comprehensive analysis of system costs for 34 manure management systems was done for New York State by Safley (1977a). Manure samples from many systems were collected and analyzed for nutrient content and estimates of field losses made. In Saffley, Haith and Price (1979), a daily spread, solid system was found to be the least cost system, compared to two liquid storage systems. A linear programming format was used to select the optimum system, given resource constraints specific to a particular farm operation.

Walter, Robillard, Gilmour and Hexem (1978) used Safley's program to estimate costs of manure systems by herd size and storage period. They developed a field ranking and spreading schedule based on agronomic and environmental considerations. This ranking was applied to two case study farms.

Review of this literature highlights two important considerations that have been ignored or slighted in previous analyses. First, definitions of the system vary between analyses with no two studies using similar terminology or definitions. System costs are estimated on an ad hoc basis, usually based on sampled data, and may not be consistent from system to system within a study, let alone consistent across studies. Only the Safley analysis provided for a consistent, reproducible accounting system which was comprehensive, consistent and capable of updating over time and over regional variations.

Second, analysis of nutrient retention ignored variations in soil and crop mix. The amount of nitrogen retained by a system depends heavily on gaseous losses after application due to volatilization to the atmosphere and denitrification. Therefore, the economics of manure systems could be quite different on heavier soils that promote high denitrification than for lighter soils in which denitrification is less rapid. The value of nutrients conserved depends on the nutrient requirements of crops grown. Nutrients conserved over and above nutrient requirements have no economic value. This fact is mentioned in White and Forster (1978) and Christensen, et al., (1981) but was not explicitly incorporated in their analyses. The field ranking used by Walter, et al., (1978) considers crop nutrient requirements to determine application rate but does not value manurial nutrients.

In light of the considerations above, four aspects of manure handling economics on dairy farms typical of Vermont will be discussed. First, a comparative analysis of construction and operating costs of alternative systems will be presented. Next, effects of soil type and crop mix on the value of nutrients retained will be analyzed for hypothetical farms. Third, estimates of the impact on water quality of alternative spreading schedules for the two hypothetical farms are calculated. This analysis takes into account changes in spreading schedule dependent on manure storage and changes in application method, which are also dependent on manure storage. Finally, implications of the analysis for cost sharing policy are discussed.

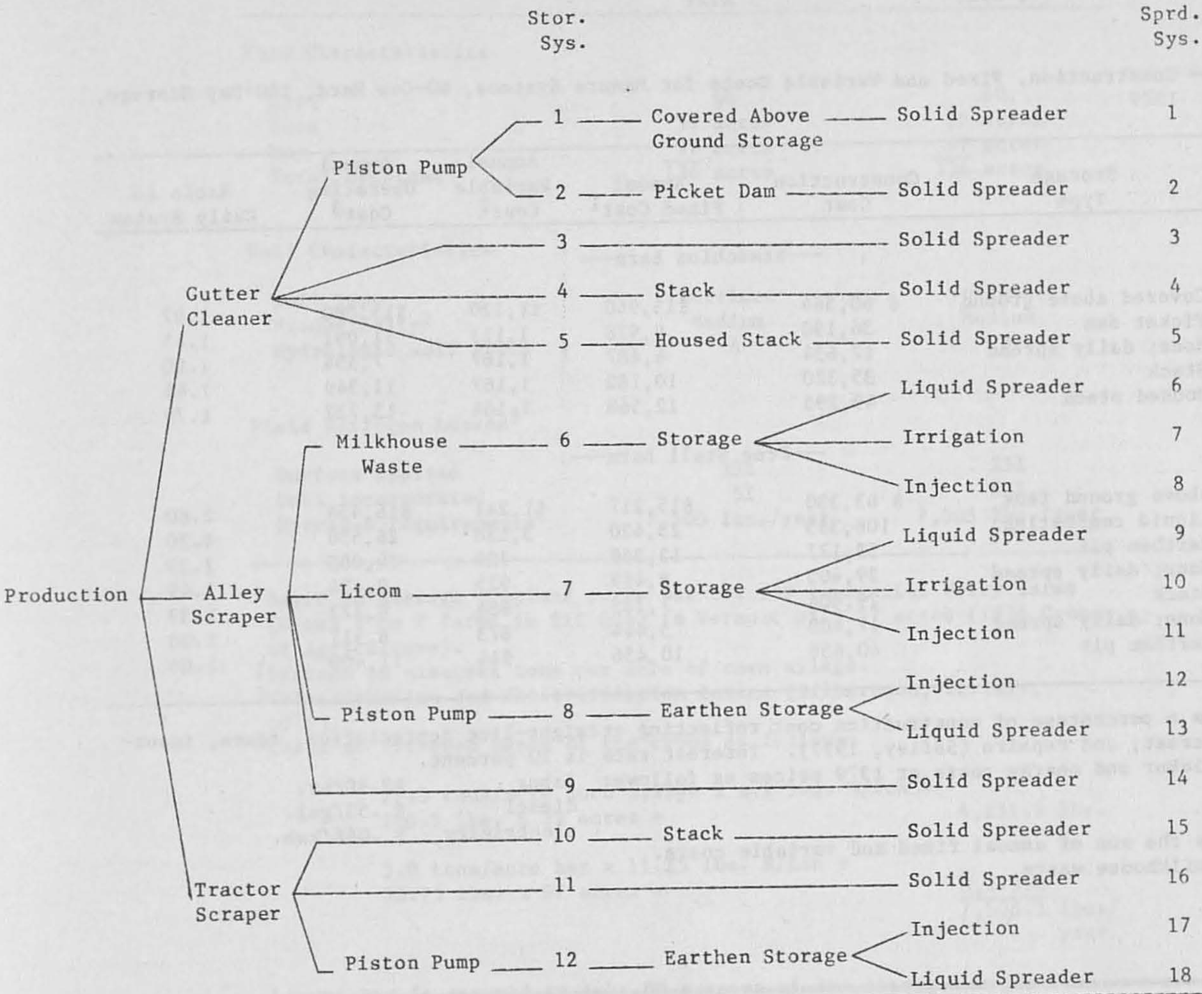
ECONOMIC EVALUATION

L. M. Safley, Jr., developed an interactive computer program to estimate manure system costs on a comprehensive basis from user-supplied information about herd size, storage period, machinery preference, and local prices for labor, fertilizer, and fuel. Details of this program are contained in Safley (1977a and b) and Safley, Haith and Price (1979). Using economic engineering methods, the program estimates cost, energy, and manure nutrient retention for each of 34 systems. For the Vermont Ag Runoff Study, this program was run with inputs typical of Vermont conditions estimated by agricultural engineers of the Soil Conservation Service, USDA. Systems using anaerobic lagoons and oxidation ditches were eliminated from consideration due to the short season during which digestion can effetively occur in Vermont. The remaining 12 systems are displayed in a decision tree representation in Figure 1. In this network, manure handling is broken into five components: collection, transfer, storage, unloading storage, and application. Some elements in Figure 1 accomplish more than one component (e.g., the gutter cleaner of system 4 collects manure and transfers it to the stack) while some are excluded (e.g., storage in daily spread systems 3, 9, and 11). Systems up to the application component are denoted storage systems and numbered 1 through 12. When variations in application method are included, 18 management systems are distinguished. Construction and machinery cost factors in the computer program were updated to 1979 price levels using price indices (ENR, 1979; ESCS, 1979). Runs were made for 20, 40, 60, 90, 115 and 225-cow herds at 90, 180, and 360-day storage periods, but results are presented here for 60 cows with daily spreading and 180 days of storage.

Manure System Costs

Initial construction costs of typical manure handling systems are shown in Table 1. Construction costs shown here include all five components of manure systems: collection, transfer, storage, unloading storage, and application on the field. Costs are based on new machinery prices and contract construction rates and are, therefore, quite high. The utility of this approach is not in the absolute dollar costs shown but in relative comparisons between systems on a consis-

FIGURE 1. NETWORK OF MANURE HANDLING SYSTEMS



tent cost basis.

When compared to daily spreading systems, all storage systems have higher initial construction costs. Annual fixed costs (i.e., debt service) increase less than proportionally because storage structures are amortized over a useful life of 20 years, whereas components of a daily system have useful lives of 10 years or less. About $20,000 of the cost of systems 6-9 is due to the alley scraper collection system. The 56 percent higher cost of daily system 9 over daily system 11 is also due to the alley scraper system. System 6 includes milkhouse waste which must be handled separately in the other systems.

All of the liquid systems in Table 1 use liquid spreaders. Application by liquid spreaders equipped with injectors adds $1,950 to construction costs and $274 to annual fixed costs. Injection can reduce nitrogen losses from volatilization, but requires at least 15 more horsepower to overcome increased drag and may not work well or consistantly on heavy lakebed clays or under frozen soil conditions. Application by irrigation adds $8,572 and $645 to construction and fixed costs, respectively. Irrigation may be a useful source of supplemental crop moisture during drought, but has obvious limitations for application to distant fields.

Initial cost may be a limiting factor in manure system investment decisions for some farmers. A more relevant decision variable for most farmers is annual operating cost, also shown in Table 1. For manure systems, annual operating cost consists of the sum of fixed costs and variable costs, of which fixed costs are the largest proportion.

Variable cost is lowest, at this herd size and storage period (60 cows, 180 days), for the earthen pit of system 8, which has the lowest labor requirement of all systems. Since fixed costs are so large, however, the two daily systems have the lowest annual operating costs, followed by the stack system (number 10). The liquid composting system has the highest variable costs because of extremely high electricity costs associated with motor driven aerators in both tanks.

Table 1 — Construction, Fixed and Variable Costs for Manure Systems, 60-Cow Herd, 180-Day Storage, 1979

System Number	Storage Type	Construction Cost	Annual Fixed Cost[1]	Annual Variable Cost[2]	Annual Operating Cost[3]	Ratio to Daily System
	---Stanchion Barn---					
1	Covered above ground	$ 60,564	$13,960	$1,120	$15,080	1.97
2	Picket dam	36,190	9,978	1,113	11,091	1.45
3	None; daily spread	17,634	6,487	1,167	7,654	1.00
4	Stack	35,320	10,182	1,167	11,349	1.48
5	Housed stack	49,295	12,568	1,164	13,732	1.79
	---Free Stall Barn---					
6[4]	Above ground tank	$ 63,330	$15,217	$1,241	$16,458	2.60
7	Liquid composting	106,355	23,420	3,138	26,558	4.20
8	Earthen pit	53,177	13,359	729	14,088	2.23
9	None; daily spread	29,405	8,499	925	9,424	1.49
10	Stack	29,404	7,789	984	8,773	1.39
11	None; daily spread	17,409	5,444	873	6,317	1.00
12	Earthen pit	40,656	10,456	944	11,400	1.80

[1]Defined as a percentage of construction cost reflecting straight-line depreciation, taxes, insurance, interest, and repairs (Safley, 1977). Interest rate is 10 percent.
[2]Includes labor and energy costs at 1979 prices as follows: labor $2.90/hr.; diesel $ .53/gal.; electricity $ .046/kwh.

[3]Defined as the sum of annual fixed and variable costs.
[4]Includes milkhouse waste.

Manure Nutrient Value

One of the primary benefits of a manure handling system is increased conservation of manurial nutrients, mostly nitrogen, which can be substituted for commercial fertilizers. As mentioned previously, many studies value all of the nutrients conserved by the handling system up to the point manure is applied to the field. This may overstate system benefits for two reasons. Much of the nitrogen is lost from manure after application so that benefits should be based on effective nutrients available to the crop. Field losses of nitrogen are affected by method of application and by soil type (NDPC, 1978; Gilbertson, et al., 1979). Roughly half of the N content of fresh manure is unstable ammonia N. Surface application allows this unstable portion to volatilize to the atmosphere. Soil incorporation of manure reduces volatilization losses, but exposes this unstable fraction of the N to denitrification. Denitrification occurs more readily in wet, oxygen-limited soils. Second, manurial nutrients have no economic value unless they supply nutrients needed by the crop. For example, the nitrogen content of manure applied to alfalfa has little economic value since little N fertilizer is required for crop growth.

This reasoning implies that the benefits of a manure system cannot be adequately considered in isolation from the soil resources and crop pattern of the farm. To integrate these aspects, hypothetical farms are analyzed to estimate the value of nutrients for each system. The use of hypothetical farms allows a precise comparison not possible with actual farms since herd size and crop acreage are specified. The farms assumed here are based on 1974 Census of Agriculture statistics for Vermont dairy farms (SIC 024). Soils and soil characteristics are typical of cropland in Vermont. Values for manure production, nutrient content and losses are taken from published literature.

Both farms are assumed to have 60 milk cows, supported on 136 acres of cropland planted 28 percent to corn and 72 percent to hay in a typical year, as shown in Table 2. To illustrate the importance of soil type on the economics of manure management, two soils were chosen with roughly equal productivity but different soil textures. Farm 1 is assumed to have Merrimac soil, which is relatively coarse and drains well.

Table 2 -- Characteristics of Hypothetical Farms

	Farm 1	Farm 2
Farm Characteristics		
Cows	60	60
Corn	39 acres	39 acres
Hay	97 acres	97 acres
Total cropland[1]	136 acres	136 acres
Soil Characteristics		
Soil type	Merrimac	Vergennes
Productivity[2]	Medium	Medium
Hydrologic soil group	A	D
Field Nitrogen Losses[3]		
Surface applied	33%	33%
Soil incorporated	5%	67%
Nitrogen requirements[4]	7,505 lbs./year	7,505 lbs./year

[1]Based on average cropland acres per cow for commercial dairy farms (Class I to V farms in SIC 024) in Vermont of 2.27 acres (1974 Census of Agriculture).
[2]Sixteen to nineteen tons per acre of corn silage.
[3]Volatilization and denitrification losses (Gilbertson, et. al., 1979).
[4]Based on nitrogen needs of the crops as follows:

17.5 tons/acre corn silage x 6.2 lbs. N/ton = 108.5 lbs. x 39 acres =	4,231.5 lbs.
3.0 tons/acre hay x 11.25 lbs. N/ton = 33.75 lbs. x 97 acres =	3,273.8
	7,505.3 lbs./year

Legume hay is assumed to take 80 percent of its nitrogen needs from the atmosphere.

(Midwest Plan Service, 1975.)

Losses of nitrogen from manure due to volatilization are decreased by soil incorporation on this soil while denitrification losses are small. Farm 2 is assumed to have Vergennes soil, which is a fine-textured lakebed clay and drains poorly. Soil incorporation of manure on this soil increases nitrogen losses to denitrification, which is larger than volatilization loss from surface application.

Based on animal numbers and annual manure production, 60 mature cows will produce 1,258.8 tons of fresh manure per year, containing 12,437 pounds of total nitrogen (ASEA D384, 1977).[1] Nitrogen retention during storage ranges between 54 percent and 84 percent, as measured in field experiments conducted by Safley (1972). For this illustration, the manure spreading pattern is assumed to have been repeated over a sufficient number of years so that mineralization of nitrogen from manure applied in previous years provides available N equal to the total N in manure applied in the current year (Mathers and Goss, 1976). Under a daily spreading system, only manure spread within, at most, seven days of either spring or fall plow down is incorporated in the soil before all of the ammonia N volatilizes. Therefore, field nitrogen losses are 33 percent for 98 percent of the annual manure production (.98 = (365 - 7)/365) and 5 percent for the remaining 2 percent of annual manure production which can be incorporated into the soil. Field losses under daily spreading are, thus, equal to the weighted average of surface applied and incorporated losses for the soils on each farm, as shown in Table 3. For 180-day storage systems, the recommended spreading schedule is to empty manure stored over fall and winter just

[1] Calculated as 60 cows (1,400 lbs. live weight) times 20.98 tons/cow/year = 1,258.8 times 9.88 lbs./ton total Kjeldahl nitrogen.

Table 3 -- Nutrient Conservation for Manure Systems, 60-Cow Herd, 180-Day Storage, Hypothetical Farms, 1979

System Number	Storage Type	(1) Nitrogen Retention in Storage	(2) Nitrogen Rentention on the Field[1] Farm 1	(3) Farm 2	(4) Effective Nitrogen to Field Farm 1	(5) Farm 2	(6) Net Nitrogen Substitution Farm 1	(7) Farm 2	(8) Net Value of Manure Nutrients[2] Farm 1	(9) Farm 2
		Stanchion Barn	Percent		Pounds		Pounds		Dollars	
1	Covered above ground	80%	81%	50%	8,059	4,975	7,505	4,975	5,060.20	4,250.53
2	Picket dam	70%	81%	50%	7,052	4,353	7,052	4,353	4,915.16	4,051.54
3	None; daily spread	63%	68%	72%	5,328	5,641	5,328	5,641	4,320.36	4,420.65
4	Stack	64%	81%	50%	6,447	3,980	6,447	3,980	3,558.94	2,769.34
5	Housed stack	70%	81%	50%	7,052	4,353	7,052	4,353	4,915.16	4,051.54
		Free Stall Barn								
6	Above ground tank	66%	81%	50%	6,649	4,104	6,649	4,104	4,833.01	4,018.74
7	Liquid composting	84%	81%	50%	8,462	5,223	7,505	5,223	5,107.00	4,376.92
8	Earthen pit	80%	81%	50%	8,059	4,975	7,505	4,975	5,107.00	4,297.33
9	None; daily spread	78%	68%	72%	6,597	6,985	6,597	6,985	4,726.44	4,850.47
10	Stack	54%	81%	50%	5,440	3,694	5,440	3,694	3,236.58	2,677.81
11	None; daily spread	58%	68%	72%	4,905	5,194	4,905	5,194	4,185.00	4,277.37
12	Earthen pit	80%	81%	50%	8,059	4,975	7,505	4,975	5,107.00	4,297.33

[1]Assumes only 2 percent of manure can be incorporated into the soil under daily spreading and 50 percent under storage systems (100 percent of manure that is applied to corn).

[2]Includes 85 lbs. P_2O_5 and 166 lbs. K_2O per cow, less losses described in Livestock Waste Facilities Handbook (Midwest Plan Service, 1975). Fertilizer prices assumed are N = \$.32/lb., P_2O_5 = \$.30/lb., K_2O = \$.15/lb.

prior to spring plowing and manure stored over spring and summer just prior to fall plowing. This assumes that half the manure is spread on corn and plowed down in spring and half is surface applied on hayland in the fall.

Net nitrogen substitution (columns 6 and 7, Table 3) equals total nitrogen contained in fresh manure less storage losses and field losses. If this amount is larger than the annual nitrogen requirements of the crops, then the excess nitrogen has no economic value. One- third of the systems conserve more nitrogen than is required on Farm 1. However, all systems fail to conserve necessary nitrogen when higher field losses incurred on the wetter soils of Farm 2 are taken into account. The three daily spread systems conserve more nutrients on Farm 2 than they do on Farm 1 because relatively little of the manure is incorporporated and subject to high denitrification losses.

The value of plant nutrients conserved with each system is shown in columns 8 and 9 of Table 3. This includes values for P2O5 and K2O, whose losses are dependent on storage system but are not dependent on soil type.

Labor Costs

Another reason often advanced for installing a manure handling system is labor savings. Manure handling systems reduce labor requirements by increasing the degree of mechanization, by reducing machinery setup and cleanup time, and by reducing partial spreader loads. Higher maintenance and repairs on more complex systems may offset some of these labor savings. Table 4 shows labor requirements for different handling systems. No significant labor savings are achieved at this herd size with solid systems in the stanchion barn configuration. Handling systems for free-stall barns require less labor than for stanchion systems since free-stall systems substitute machinery for hand labor in cleaning stalls. The earthen pit (system 8) requires a third less labor than the daily spread system and less than half the labor required in the stanchion systems. Savings occur in collection with alley scraper and in spreading with the large liquid spreader.

In addition to total labor requirements, an advantage of storage systems is said to be additional flexibility in scheduling manure handling. This flexibility allows operators to avoid spreading when conditions are uncomfortable (early on January mornings), environmentally undesirable (thaw, heavy rain), or impossible (wet fields, growing corn). Utilization of labor at planting and harvest time, however, is critical to the profitability of the dairy enterprise since small delays in planting and harvesting can reduce yields and quality of feed. The marginal value of an additional hour at these periods may be high enough, in light of the availability and quality of hired labor, to justify manure storage which releases labor from daily spreading chores.

Despite the real impact labor requirements are likely to exert on the decision to invest in manure handling systems, they are difficult to quantify. The distribution of the marginal value of labor across time is not measurable and would vary across operators. Also, the value of a manure storage system depends on the skill with

Table 4 -- Labor Requirements and Cost for Manure Systems, 60-Cow Herd, 180-Day Storage, 1979

System Number	Storage Type	Labor Hours	Labor Cost[1]	Ratio to Daily System
	---Stanchion Barn---			
1	Covered above ground	349	$1,012.11	.96
2	Picket dam	347	1,006.30	.96
3	None; daily spread	362	1,049.80	1.00
4	Stack	356	1,032.40	.98
5	Housed stack	355	1,029.50	.98
	---Free Stall Barn---			
6[2]	Above ground tank	290	841.00	1.20
7	Liquid composting	229	664.10	.95
8	Earthen pit	165	478.50	.68
9	None; daily spread	249	722.10	1.03
10	Stack	266	771.40	1.10
11	None; daily spread	242	701.80	1.00
12	Earthen pit	249	722.10	1.03

[1]At labor cost per hour of $2.90.
[2]Includes milkhouse waste.

which it is used. A poorly managed storage system may have greater negative impact on the timing of crop operations than a well managed daily spreading system. For these reasons, only total annual labor costs for each system will be considered here.

Net Costs Of Manure Systems

The net annual cost of a manure handling system equals the annual operating cost, including labor costs, less the value of nutrients conserved. These results, taken from Tables 1 and 3, are shown in Table 5 for both hypothetical farms. In accordance with other studies cited above, none of the systems pays for itself in terms of nutrients conserved. The least costly systems are daily spreading systems 3 and 11, for both farms. Relative rankings between systems are unchanged by subtracting nutrient values.

The additional cost of manure storage is the net annual operating cost for storage systems less the cost of the least expensive daily spreading system. This additional cost varies from \$2,842 to \$19,319 for Farm 1 and \$3,806 to \$20,141 for Farm 2. For Farm 1, the least additional costs are \$2,842 (system 4, picket dam) for stanchion barn and \$3,404 (system 10, stack) for free stall barn. The same systems apply to Farm 2, but the additional costs are \$3,806 and \$4,055 for stanchion and free stall barns, respectively.

ENVIRONMENTAL EVALUATION

The impact of animal waste handling on surface water quality is primarily due to loadings of phosphorus, usually the limiting nutrient for algae blooms which impair water uses directly and contribute to reduced dissolved oxygen content in surface waters. Nitrogen contributed to water percolating below the root zone and entering groundwater can also be a significant problem. It must be noted that loading of phosphorus and nitrogen to receiving waters is only a potential problem. The extent to which this potential is realized depends on conditions in the receiving waters, such as flow, temperature, depth, and sunlight, and the magnitude of other point and nonpoint sources.

Loadings of nutrients from manure vary with a host of conditions, including rainfall, runoff, temperature, soil condition, slope and distance to receiving waters (Klausner, et al., 1976). Factors subject to management that influence nutrient loadings from manure include application rate, season spread, and method of application (incorporated into soil or surface applied). Estimates of dissolved nutrients in runoff from manure applied under various conditions were derived from empirical results published in the literature by Gilbertson, et al. (1979). When combined with runoff estimates reflecting these crop conditions, per acre loadings of dissolved nutrient runoff can be estimated, as in Table 6. These estimates are used to evaluate nutrient losses under alternative manure handling systems on the hypothetical farms in Table 7. All manure applied to hay is assumed surface applied, although an opportunity for incorporation of manure on hay occurs when the stand is established.

Potential dissolved phosphorus losses from manure handling are two to six times as great on Farm 2 because runoff from soils in hydrologic soil group (HSG) D is greater than from HSG A, and the corresponding loading rates in Table 6

Table 5 — Net Annual Costs for Manure Systems, 60-Cow Herd, 180-Day Storage, 1979

System Number	Storage Type	Annual Operating Cost[1]	Value of Manure Nutrients[2] Farm 1	Farm 2	Net Annual Operating Cost[3] Farm 1	Farm 2
	---Stanchion Barn---					
1	Covered above ground	\$15,080	\$5,060	\$4,251	\$10,020	\$10,829
2	Picket dam	11,091	4,915	4,052	6,176	7,039
3	None; daily spread	7,654	4,320	4,421	3,334	3,233
4	Stack	11,349	3,559	2,769	7,790	8,580
5	Housed stack	13,732	4,915	4,052	8,817	9,680
	---Free Stall Barn---					
6[4]	Above ground tank	\$16,458	\$4,833	\$4,019	\$11,625	\$12,439
7	Liquid composting	26,558	5,107	4,377	21,451	22,181
8	Earthen pit	14,088	5,107	4,297	8,981	9,791
9	None; daily spread	9,424	4,726	4,850	4,698	4,574
10	Stack	8,773	3,237	2,678	5,536	6,095
11	None; daily spread	6,317	4,185	4,277	2,132	2,040
12	Earthen pit	11,400	5,107	4,297	6,293	7,103

[1]Includes fixed costs, labor costs, and energy costs. See Table 1.
[2]Net value after application to field. See Table 3.
[3]Annual operating cost less value of manure nutrients.
[4]Includes milkhouse waste.

Table 6 -- Dissolved Phosphorus Loadings[1]

Hydrologic Soil Group and Season Applied	Crop and Application Method		
	Corn		
	Manure Incorporated	Not Incorporated	Hay Not Incorporated
	---Pounds of Dissolved Phosphorus Per Acre[2]---		
HSG = D			
Spring	.02	.19	.25
Summer	N/A	N/A	.20
Fall	.03	.11	.14
Winter	N/A	1.50	3.95
HSG = A			
Spring	.01	.10	.10
Summer	N/A	N/A	.07
Fall	.01	.06	.06
Winter	N/A	.27	.51

[1]All manure applied at agonomic rates.
[2]Calculated as:

$$W_x = 0.226\ (0.95\ R_r C_r + 0.80\ R_s C_s)$$

where: W_x = loading rate in pounds per acre;
R_r, R_s = runoff from rainfall and snowmelt (inches);
C_r, C_s = phosphorus concentration in runoff (PPM);
0.226 = conversion factor from lbs./acre-inch to lbs.; and
0.95,0.80 = runoff retardance from surface applied manure (not used for incorporated values).

Source: Gilbertson, et. al. (1979).

are higher. Reduction in dissolved P loading with 90-day storage is small since all manure must still be spread in the season that it is generated. However, short-term storage may be useful to avoid spreading manure during severe rainfall events or thaws, thus avoiding large direct runoff losses (Steenhuis, 1977). Dissolved P losses can be reduced to between one-tenth and one-quarter of the amount under daily spreading if sufficient storage is available. These reductions result from incorporating all manure applied to corn and spreading on hay in the fall when runoff is lowest. When corn is tilled in spring, no benefit results from 360-day storage. This would not hold if corn were fall plowed, as all of the manure would need to be spread in fall.

DISCUSSION AND IMPLICATIONS

From an environmental perspective, any manure system that provides 180 days of storage will enable a spreading schedule that reduces phosphorus loss. However, the additional cost of storage varies significantly by system, by housing type, and by soil resources. The amount of phosphorus reduction from manure storage varies by soil resources, as well. These additional costs for storage are displayed in total and per pound of phosphorus reduction in Table 8.

Public subsidies for manure systems are about $1,000 less for all systems on the lighter soils of Farm 1 than on the heavier soils of Farm 2. This is due to higher private benefits for nutrient conservation on Farm 1 since fewer nutrients are lost with soil incorporation than without. However, public subsidies are more cost effective if spent on Farm 2 since each pound of phosphorus reduction costs far less. This is because phosphorus losses without storage are much higher on Farm 1 than on Farm 2. Even though needed subsidies on Farm 1 are lower, they buy smaller phosphorus reductions than on Farm 2.

Implications for cost sharing are several. First, cost sharing for manure systems should not exceed the cost for the cheapest system that will provide 180 days of storage (systems 2 and 10). Second, needed subsidies will be higher for farms

Table 7 -- Dissolved Phosphorus Losses by Spreading Schedule, 60-Cow Herd, Hypothetical Farms

	Farm 1	Farm 2
	Average Annual Dissolved Phosphorus, Pounds	
Daily Spread[1]		
Corn	5.23	22.20
Hay	17.74	110.10
Total	22.97	132.30
90-Day Storage[2]		
Corn	4.38	20.98
Hay	17.74	110.10
Total	22.12	131.08
180-Day Storage[3]		
Corn	.39	.78
Hay	5.82	13.58
Total	6.21	14.36
360-Day Storage[3]		
Corn	.39	.78
Hay	5.82	13.58
Total	6.21	14.36

[1]Assumes 25 percent of manure spread each season, 2 percent of manure on corn incorporated in spring, all other manure surface applied.
[2]Assumes 25 percent of manure spread each season, 33 percent of manure on corn incorporated in spring, all other manure surface applied.
[3]Assumes 50 percent of manure applied to corn in spring and 50 percent applied to hay in fall, 100 percent of manure on corn incorporated in spring, all other manure surface applied.

Table 8 — Additional Cost of Manure Storage

System Number	Storage Type	Additional Cost of Manure Storage: Total[1] Farm 1	Total[1] Farm 2	Per Pound of P[2] Farm 1	Per Pound of P[2] Farm 2
---Stanchion Barn---					
1	Covered above ground	$ 6,686	$ 7,596	$ 399	$ 60
2	Picket dam	2,842	3,806	170	32
3	None; daily spread	N/A	N/A	N/A	N/A
4	Stack	4,456	5,347	266	45
5	Housed stack	5,483	6,447	327	55
---Free Stall Barn---					
6[3]	Above ground tank	$ 9,493	$10,399	$ 566	$ 88
7	Liquid composting	19,319	20,141	1,153	171
8	Earthen pit	6,849	7,751	409	66
9	None; daily spread	N/A	N/A	N/A	N/A
10	Stack	3,404	4,055	203	34
11	None; daily spread	N/A	N/A	N/A	N/A
12	Earthen pit	4,161	5,063	248	43

[1]Net annual operating cost for storage less net annual operating cost for daily spread system.
[2]Additional cost divided by difference in phosphorus loss with 180 days storage and with daily spreading.
[3]Includes milkhouse waste.
N/A = Not applicable.

with free stall housing than for farms with stanchion systems because daily spreading is more efficient in free stall barns so the difference in cost is larger. Third, needed subsidies for farms in areas of light, well-drained soils are lower than for farms in areas of heavy, poorly drained soils. Phosphorus reductions in light soil areas should be smaller, however.

CONCLUSIONS

Pressures for better handling of dairy wastes originate in on-farm economics and off-farm environmental impacts. From the dairy operator's perspective, investment in manure systems cannot be justified by either nutrient conservation or labor savings. The extent of on-farm benefits from nutrient conservation depends on soil type and crop grown.

Significant reductions in dissolved phosphorus loading potential are likely when sufficient waste storage is available to adjust spreading schedules to account for seasonal runoff and plowing operations. Public cost-share subsidies should be geared to net costs to the farmer. These net costs vary by system, housing type, and soil resources.

REFERENCES

ASAE. "Manure Production and Characteristics." ASAE Standard D384, 1977 Agricultural Engineering Year Book, St. Joseph, MO.

Casler, George L., and Eddy L. LaDue. "Environmental, Economic, and Physical Considerations in Liquid Handling of Dairy Cattle Manure." New York's Food and Life Science Bulletin No. 20, Cornell University Agr. Exp. Station, Cornell University, Ithaca, NY, October 1972.

Cason, R. G., and J. T. McAuslan. "Systems and Costs of Handling Manure from Dairy Cows." Farm Management Review, Vol. 2, June 1973.

Christensen, L. A., J. R. Trierweiler, T. J. Ulrich, and M. W. Erickson. "Managing Animal Wastes: Guidelines for Decisionmaking." ERS 671, Economic Research Service, USDA, Washington, DC, November 1981.

Economics, Cooperatives and Statistics Service, USDA. Agricultural Prices, 1978 Annual Summary, Washington, DC, June 1979.

Engineering News Review. 20 City Construction Cost Index, 1979.

Gilbertson, C. B., F. A. Norstadt, A. C. Mathers, R. F. Holt, A. P. Barnett, T. M. McCalla, C. A. Onstad and R. A. Young. "Animal Waste Utilization on Cropland and Pastureland: A Manual for Evaluating Agronomic and Environmental Effects." USDA Science and Education Administration/U.S.E.P.A., Office of Research and Development, USDA URR No. 6, October 1979.

Holmes, Beatrice H. "Institutional Bases for Control of Nonpoint Source Pollution." U.S. Environmental Protection Agency, Office of Water and Waste Management, WH-554, Washington, DC, November 1979.

Jacobs, J. J. and G. L. Casler. "Economic and Environmental Considerations in Dairy Manure Management Systems." Department of Agricultural Economics, Bulletin No. 72-18, Cornell University, Ithaca, NY, 1972.

Klausner, S. D., P. J. Zwerman and D. R. Coote. "Design Parameters for the Land Application of Dairy Manure." U.S.E.P.A., Office of Research and Development, EPA-600/2-76-187, October 1976.

Lessley, B. V., and J. E. Via. "Economic Analysis of Alternative Manure Handling Systems by Size of Dairy Herd." Journal of Northeastern Agricultural Economics Council, 5 (1): 113-124, April 1976.

Mathers, A. C. and D. W. Goss. "Estimating Waste Applications to Supply Nitrogen Requirements." Agronomy Abstracts: 150.

Midwest Plan Service. Livestock Waste Facilities Handbook. MWPS 18, Iowa State University, Ames, Iowa, July 1975.

Northeast Dairy Practices Council. "Dairy Manure Management: Land Application." NDPC 27.2, Cooperative Extension Service, Burlington, VT, revised June 1978.

Safley, L. M., Jr. "System Selection and Optimization Models for Dairy Manure Handling Systems." Unpublished Ph.D. Thesis, Cornell University, Ithaca, NY, 1977.

Safley, L. M., Jr. "User's Manual for Systems Analysis of Dairy Manure Management Systems Computer Program." AWM77-01, Department of Agr. Engineering, Cornell University, Ithaca, NY, 1977.

Safley, L. M., D. A. Haith and D. R. Price. "Decision Tools for Dairy Manure Handling Systems' Selection." Transactions of the American Society of Agricultural Engineers, 22 (1): 144-151, Jan.-Feb., 1979.

Steenhuis, T. S. "Modeling Nitrogen and Other Nutrient Losses from Winter Spread Manure." Unpublished thesis, Department of Agr. Engineering, University of Wisconsin, Madison, WI, 1979.

Walter, M. F., P. D. Robillard, R. Gilmour, and R. W. Hexem. "BMP Development for Manure in New York State." ASAE Technical Paper No. 78-2033. Presented at 1978 summer meeting of American Society of Agricultural Engineers, Utah State University, Logan, UT, June 27-30, 1978.

White, R. K. and D. L. Forster. "A Manual On: Evaluation and Economic Analysis of Livestock Waste Systems." U.S.E.P.A., Office of Research and Development, ADA, OK EPA-600/2-78/102, May 1978.