NEW YORK'S FOOD AND LIFE SCIENCES BULLETIN NO. 20, OCTOBER 1972

SOCIAL SCIENCES
AGRICULTURAL ECONOMICS NUMBER 1

CORNELL UNIVERSITY AGRICULTURAL EXPERIMENT STATION, NEW YORK STATE COLLEGE OF AGRICULTURE AND LIFE SCIENCES, A STATUTORY COLLEGE OF THE STATE UNIVERSITY, CORNELL UNIVERSITY, ITHACA, NEW YORK

Environmental, economic, and physical considerations in liquid handling of dairy cattle manure

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INTRODUCTION

Manure, which in the past was highly valued for its ability to increase crop yields, is now frequently considered a waste product. Declining fertilizer nutrient prices, combined with increasing costs of labor and equipment for handling manure, put livestock producers in a position where the cost of manure handling frequently exceeds the value of the nutrients in the manure. Many producers would be pleased to have the manure "just go away". The apparent low dollar value of manure results in handling systems that focus on disposal with little regard for retention of fertilizer value. Such systems lead to a situation in which some of the nutrients from manure are lost.

If the lost nutrients enter stream or ground water they may lower the water quality in several ways. Nitrate (NO_3) levels above the U.S. Public Health Service drinking water standard of 45 mg/liter may be injurious to health, particularly to that of infants. High levels of nitrogen and, more importantly, phosphorus in stream and lake water lead to excessive growth of aquatic plants, particularly algae, which lowers the usefulness of these waters for recreational purposes.[1]

Nutrient losses may occur either from animal production sites or from the fields upon which manure is spread. In addition to the nutrient problem, if manure from animal production sites is discharged directly into streams, the dissolved oxygen level of the stream is lowered as a result of the BOD (biochemical oxygen demand) of the manure. Low-dissolved oxygen levels may cause fish kills. In 1969, 20 percent of the fish kills in the United States were caused by agricultural waste (7). Some of these were a direct result of manure from feedlots.

In addition to the decline in the value of the nutrients in manure and the increasing concern over water pollution, the manure disposal problem has been aggravated by an increase in the number of animals in each livestock production unit. This has been most dramatic in cattle feeding where feedlots of several thousand head are common, particularly in the Southwest. Larger numbers of cattle in confinement in one location tend to increase the cost of land disposal of manure and increase the chances of runoff of large quantities of manure directly into streams. The increase in sizes of dairy herds in the Lake States and Northeast has been less dramatic than that of cattle feedlots in the Southwest, but dairy herd sizes have rapidly increased in these areas and year-round confinement feeding is increasing. In addition, the high annual

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[1] Other nutrients may be limiting factors in algal growth, but phosphorus and nitrogen are currently believed to be the limiting nutrients in many lakes and streams (31).

precipitation rates increase water movement and thus water pollution potential for any given size of facility.

Associated with the increase in average size of dairy herd has been a change from stanchion barns to free stall systems on many dairy farms. This change is usually accompanied by a change to year-round confinement. Although free stall barns have been found to require less milking, feeding and bedding labor than stanchion barns, they do not increase the efficiency or solve the problems in manure handling. In a 1965 study of free stall systems, manure handling was considered the most important problem or disadvantage (19).

The manure in free stall barns contains very little or no bedding and all of the urine is retained and mixed with the feces. This creates a material which has a sloppy consistency and is difficult to handle. It is especially difficult and time-consuming to move such manure up an incline or around a corner.

Most currently developed manure handling equipment is not suited to this type of manure. Gutter cleaners often have a low capacity for sloppy manure and usually cause a bottleneck if placed on an incline. Conventional beater spreaders do not contain sloppy manure well and adding endgates only partially solves the problem.

Another problem with manure handling in free stall barns is that manure has to be hauled every day. This problem was not created by free stall systems but is one that free stalls have failed to solve. To former pen stable operators who have become accustomed to infrequent hauling it is considered a backward step.

Associated with the problem of everyday hauling is the problem of finding a place to spread the manure during certain times of the year. Although this has always been a problem, it is accentuated by larger herd sizes. During late spring and much of the summer there is often no place where manure should be spread. It should not be spread on growing crops during much of the growing season or pasture land that is being used and can be spread on hay land only for a few days after each cutting is removed. This leaves only unused land areas and sparsely wooded areas. Also, during the early spring there are times when all of the land area on some farms is too wet for spreading manure.

Liquid systems to handle the manure from dairy cattle have been proposed both as economically efficient methods of handling and to alleviate some of the environmental problems associated with the manure. With enough storage capacity to eliminate spreading on frozen ground, a liquid system would tend to reduce runoff of manure during the winter and spring, thereby reducing loss of nutrients and organic matter, which should be of benefit to both farmers and the rest of society.

Purpose

The purpose of this bulletin is to provide information about the environmental, economic, and physical implications of liquid handling of dairy cattle manure. This information should be useful to extension agents and others who will be giving advice about manure handling to dairy farmers as well as to the farmers who must decide whether to invest capital in a liquid manure system. The economic evaluation is within the framework of a free stall dairy system but much of the economic analysis is applicable to stanchion dairy systems.

Approval Is Required

All liquid manure systems constructed on Northeast dairy farms must be approved by the agencies supervising the sanitary requirements on the farm. Dairymen should not build any part of a liquid system until plans are approved by the proper agencies.

Dairymen planning free stall systems and considering liquid manure will find the Northeast Dairy Practices Committee publication, *1972 Guidelines for Handling Manure as a Liquid,* NDPC 2, of value. This bulletin was prepared by sanitarians and college and industry personnel as a guide for planning free stall and liquid manure systems.

ENVIRONMENTAL POLLUTION

The recent increase in awareness and concern about the degradation of the quality of the environment has led to scrutiny of many possible sources of pollution, including livestock manure. Manure produces odors that are unpleasant to many people. It may add nutrients and organic matter to streams when not properly handled. Manure may also contribute nutrients, particularly nitrogen, to ground water, which may result in high nitrate levels in wells. Research data from which to determine the effect of liquid manure handling on these environmental considerations is limited. The intent of this bulletin is not to provide a comprehensive treatment of the effects of manure on environmental quality. Rather, it will analyze the effect on the environment of liquid compared with conventional handling of manure insofar as available data will allow.

Odors

A liquid manure system will eliminate the odors produced by daily spreading, but will replace these with extremely offensive odors when the stored manure is pumped and spread. The odor from fresh manure is not overly offensive to most people. Anaerobic bacteria, which produce offensive odors, build up during storage, and these odors are released when the manure is spread. Some farmers located near urban centers may find that these odors will be so great a problem at cleaning time that a liquid manure system cannot be used on their farms.

Bacterial odors build up gradually. Thus, more frequent cleaning, if it is assumed that most of the manure is removed at each cleaning, should reduce the odor level in the manure when it is spread. More frequent cleaning will also reduce the amount of manure that is spread at any one time. These 2 factors indicate that frequent cleaning should reduce the odor problem. However, one of the main reasons for installing a liquid system is to reduce the frequency of spreading.

Spreading the manure during or just before a rain is recommended by some (37) to reduce the strength and (or) duration of the odor. The major problem with this is that it often conflicts with efforts to schedule spreading to avoid periods of peak crop labor requirements or bad weather and may contribute to increased runoff. Forecasting rain with sufficient accuracy to allow spreading before a rain is also difficult.

Some work is being done with chemicals and perfumes in an effort to find a way to reduce, eliminate, or mask these odors. So far, these experiments have not produced encouraging results.

Runoff and Nutrient Loss

In a 3-year study begun in the winter of 1967, on 10 to 12 percent slopes at Lancaster, Wisconsin, reported by Minshall, et al. (25), runoff[2] and nutrient loss were measured from plots with no manure, fresh manure applied in winter, and fermented and liquid manure applied in the spring. Each summer, corn was grown on all the plots.

While N and P runoff from winter-manured plots was much greater than from any of the other plots, the spring-manured plots had less nutrient runoff than the non-manured plots (table 1). It might be concluded that spring-spread manure reduces nutrient losses and that winter spreading should be avoided. This conclusion is tempered somewhat by a rather unusual occurrence in the winter of 1967. Two hours after the manure was spread on frozen ground with no snow cover, 0.75 inch of rain in 1 hour resulted in almost 100 percent runoff. During the winter of 1966-67, 72 percent of the N and 42 percent of the P losses from the winter-manured plots occurred during this one rainfall.

Table 1. *Annual nutrient losses from manured and non-manured corn plots, 1967–69, Lancaster, Wisconsin*

Nutrient	Manure treatment			
	None	*Fresh winter*	*Fermented spring*	*Liquid spring*
		lbs. per acre		
1966–67				
Total N	4.94	24.00	4.75	4.53
Total P	1.09	5.15	0.86	1.05
1967–68				
Total N	3.22	2.72	2.99	2.57
Total P	1.33	0.92	0.67	0.85
1968–69				
Total N	3.52	7.17	3.02	2.51
Total P	1.09	1.79	0.61	0.68
Average				
Total N	3.89	11.30	3.59	3.20
Total P	1.17	2.62	0.72	0.86

Source: Minshall, Witzel, and Nichols (25).

In the winter of 1967-68, with precipitation less than half that of either of the other 2 years, average December-to-March runoff from all treatments was 2 percent of the year's total compared with 70 percent for each of the other years. Nutrient loss from all treatments was extremely low, relative to losses in other years, and losses from the winter-manured plots were less than those from some of the other treatments.

Summer runoff from the unmanured plots exceeded the average runoff of all other treatments by 78 percent — a condition that worsened over the 3-year period (34, 48, and 155%) possibly because these plots had less organic matter. For the 3-year period the unmanured plots lost 50 percent more P than the spring-manured plots.

Several important conclusions and questions can be drawn from this research. It indicates that winter spreading on frozen ground may result in high nutrient losses, particularly if there is no snow cover and heavy rain. But the variability among years raises questions about how serious the nutrient losses from winter spreading really are. Does a situation like the 1966-67 winter occur once

[2] Throughout this publication, *runoff* refers to movement of water with suspended soil particles and dissolved material, whereas *nutrient runoff* or *nutrient loss* refers to only the movement of nutrients, without regard to the quantity of water acting as a vehicle for movement.

in 3 years or once in 20? The winter 1966-67 precipitation was 10 percent above average and that in 1968-69 was average, yet runoff in each year from experimental watersheds nearby was more than double the 25-year average. This undoubtedly influenced the results of the manure study. In addition, there were variations in the amount of snow cover on the plots. While this research implicates winter-spread manure as a source of N and P in stream water, it also suggests some positive effects of manure.

The Wisconsin study was primarily concerned with time of application of manure. Nutrient runoff from the fermented and liquid plots was nearly the same. The benefits of avoiding application of manure on frozen ground are not unique to liquid manure. *They can be achieved with any method that involves long-term storage and spreading in the spring.*

One must not conclude that the combination of long-term storage, no winter spreading, and spring application necessarily reduces the nutrient runoff from manure. Not all manure spread during the winter is applied to frozen ground. In fact, during some winters the ground is not frozen except in windswept areas of certain fields. Spring application, within a few days, of 6-months' accumulation of manure could result in substantial nutrient and organic matter losses, particularly if followed by periods of heavy rain. Winter storage, unless done in a way that entirely prevents seepage loss, could also lead to stream and ground water pollution.

Liquid manure systems with long-term storage and spring spreading have been recommended as practices that will substantially reduce stream pollution from manure (17, 41). Available data do not lead the authors of this publication to make the same recommendations. As will be shown later, it is difficult to justify liquid manure systems on purely economic grounds from the viewpoint of the dairy farmer. In addition the reduction in nutrient runoff by storage and spring spreading is not as great as assumed by other writers. Finally, the results of carefully controlled experiments are not directly transferable to dairy farms where spreading the accumulation of the winter's manure may not be properly done in the spring because of demands on the farmer's time and other resources for cropping and other farming activities.

This discussion of the relationship of liquid storage and handling of dairy cattle manure to nutrient runoff into stream water is necessarily incomplete because of the lack of research data. Long-term research is needed to allow more accurate assessment of this relationship. Liquid manure systems should not be looked upon as a cure-all for the adverse environmental effects of dairy cattle manure and may not even lead to a substantial improvement in such effects.

ECONOMIC EVALUATION

There are several economic reasons usually advanced as to why a dairyman might want to handle the manure from a free stall dairy barn in liquid form:

- Lower labor requirement.
- Elimination of a disagreeable everyday job.
- Change in labor distribution.
- Elimination of a separate system to handle manure and waste water from the milking parlor and milkhouse.
- Increased manure value. Less total cost.

The real question becomes: How important are these reasons and will they make a liquid manure system a profitable investment?

Labor Requirements

A comparison of the labor requirements of liquid and conventional manure handling is difficult to establish.

Three sets of estimates will be used. The first set of estimates is made by the authors based on an analysis of the work to be performed. The second set of calculations is based on a manure handling study in Michigan. The third set is data from a Minnesota study.

Assuming that the barn layout is the same and that slatted floors are not used, one would expect that to scrape the manure into a liquid manure storage tank would take the same amount of time as to scrape it directly into a conventional[3] manure spreader. Only when compared with a conventional system[4] that has not been appropriately designed for manure handling, one in which this sloppy substance must be pushed up a ramp into a spreader, would the liquid manure system be expected to require less scraping time.

This implies that if labor is to be saved by using a liquid manure system, most of the savings will come from the hauling operation. The amount of material to be handled with a liquid manure system is greater than that of a conventional system because water must be added to obtain a pumpable slurry. One day's manure from a 100-cow herd will amount to about 1635 gallons. This is about 1.2 loads with a 1400-gallon tank wagon.

[3] *Conventional spreader* throughout this publication refers to either the barrel type spreader or a box type spreader equipped with a gate so that manure of free stall barn consistency can be handled without undue spilling.

[4] ***Conventional manure handling system for a free stall barn*** throughout this publication refers to scraping manure from the alleys, pushing it off a lip (usually not an elevated ramp) directly into a conventional spreader, and daily disposal.

Table 2. *Labor required for manure handling, 16 Michigan free stall dairy systems, 1967*

Type of housing and manure system	*Number of farms*	*Scraping*	*Loading & hauling*	*Total manure handling*
		minutes per cow per day		
Open lot housing				
Conventional manure	5	.45	.52	.97
Liquid manure	3	.57	.47	1.04
Covered housing				
Conventional manure	3	.64	.63	1.27
Liquid manure	5	.40	.31	.71

Source: *Speicher, MacLachlan, Hoglund and Boyd* (35).

Estimates made by farmers and others indicate that about 3 loads of manure can be hauled per hour if the field is approximately V2 mile from the barn. This time includes loading, traveling, and unloading. In addition, some time would be required for positioning the pump, maintenance of the pump, and cleanup each time the storage tank is emptied. Most of the agitating can be done during the pumping operation but some would be required before pumping from the tank is started. If additional water is needed to create a pumpable slurry, it will likely take time to add it. The actual spreading time, at 3 loads per hour, would be equivalent to approximately 24 minutes per day for a 100-cow herd. If the agitation-pump-preparation-cleanup operation takes 4 hours each time the 90-day storage tank is emptied, this would be equivalent to about 3 minutes per day, making a total of 27 minutes per day.

The labor requirement for handling the manure with a conventional spreader on a daily basis depends to some degree on the size of the spreader in relation to herd size. Unless the herd size and spreader capacity are matched correctly, a partial load of manure may have to be hauled to the field each day. Although conventional spreaders of almost any size are available, the fact that daily spreading will frequently require traveling on soft ground will likely limit spreader size to 130 to 200 bushels. Spreaders of this size will not hold as much manure as most liquid spreaders now in use. For example, a 185-bushel spreader sold by one company has a level full capacity of 110 cubic feet. A 1400-gallon liquid spreader has a capacity of 187 cubic feet. At a production of 1.51 cubic feet[5] of excrement per cow per day, this 185-bushel spreader would require about 1.4 loads to haul one day's manure for a 100-cow herd. Thus, a farmer would have to haul 2 loads per day, with either this spreader or a smaller one.

It is reasonable to assume that travel and unloading time per load for a conventional spreader would be about the same as for a liquid spreader. In addition, some time will be required each day for hitching and unhitching the spreader — probably 5 to 10 minutes per day. Thus, about 45 to 50 minutes would be required for daily spreading of the manure from 100 cows, if 2 loads were necessary. If the spreader were large enough to handle all of the manure in one load, only 25 to 30 minutes would be required.

A comparison of the estimated labor requirements of the 2 systems indicates that if the manure from a 100-cow herd can be hauled in 1 conventional spreader load per day, little or no labor would be saved. If 2 loads per day are required by the conventional system, the amount of labor saved by the liquid system would average 18 to 23 minutes per day. At 23 minutes per day this would be 140 hours per year, which at a wage rate of $2.50 per hour, would amount to $350.

In a Michigan study of the labor requirements of 16 free stall dairy housing systems, a significant labor saving was found for liquid manure systems in covered free stall barns (table 2) (35). The major limitation of this study is the small number of herds studied. A single observation could markedly influence the average for its group. Further, the Michigan authors state that most of the conventional manure systems "loaded manure by pushing against a backstop with a front-end loader." This would not be as efficient as use of a manure lip. The labor saved by liquid handling in covered housing would be much less than that calculated below if scraping time were equal to that for conventional handling.

If the labor requirements indicated for covered housing actually represent typical requirements, the labor saved by liquid manure systems would be 56 minutes per day, or 341 hours per year, for a 100-cow herd. At a wage rate of $2.50 per hour this indicates an annual labor savings of $853.

Using several sources, a Minnesota study estimated the labor requirements for conventional manure handling systems to be .1466 hour per cow per week and the requirements for liquid manure systems to be .0980 hour per cow per week (5). This indicates a labor requirement reduction of 253 hours per year for a 100-cow herd or a saving, at $2.50 per hour, of $633.

[5] See page 11 for discussion of daily manure production.

The average of the above estimates (140, 341, and 253 hours) of labor saved is 245 hours. A wage rate of $2.50 per hour would result in annual labor savings of approximately $615.

Elimination of a Disagreeable Everyday Job

A liquid manure system would not entirely eliminate the daily manure handling job. The alleys still need to be scraped daily (unless slatted floors are used). Such a system could eliminate hauling on days with extremely bad weather. However, unless the storage tank is very large and (or) the hauling schedule carefully planned, some manure hauling likely will be done during bad weather, especially if the farmer is to avoid periods of heavy crop labor and to apply the manure where it will do the most good.

A liquid manure system could eliminate the job of hauling manure on Sunday. This could be particularly important to dairymen with hired labor who are attempting to operate with a shorter work week and less Sunday work. Although it is not accepted by health authorities, some dairymen with free stalls have accomplished this by not scraping and hauling manure on Sunday. In this case, a liquid manure system would not reduce Sunday labor.

Change in Labor Distribution

Most dairy farms have periods of the year when the labor load is very heavy. Most free stall systems are operated with year-round confinement and feeding from storage; thus the winter and summer daily labor requirements are nearly equal. This can mean that the cows and the crops compete for labor even more severely than with a stanchion barn where the cows are turned out to pasture. If the manure hauling job could be eliminated when the crop work load is heavy, this would be an important advantage of a liquid manure system, even if such a system requires as much total labor as a conventional manure system.

Corn planting, hay or hay crop silage harvest, and corn silage harvest are times of high labor requirements on a dairy farm. Crop yields and forage quality can be markedly reduced if these jobs are not done on time. A liquid manure system with several weeks' capacity offers the possibility of no manure spreading during such critical periods but requires careful planning of storage tank size and cleaning schedule. A large manure storage tank that becomes full on the day that corn planting should start eliminates any improvment in labor distribution provided by a liquid manure system.

Year-round confinement of dairy cows may create the problem of a place to spread manure during the summer months. Land planted to corn does not provide a place to spread manure between May and October. Hay fields generally provide a place only during part of the summer. A liquid manure system could either be a partial solution or accentuate this problem. With careful planning, the liquid manure storage could be emptied just before spring plowing and after corn harvest, thereby putting a large amount of the manure on corn land. In midsummer, manure could be spread on hay land, particularly fields from which a second or third crop will not be harvested. Spreading on good legume stands could harm the seeding and will certainly result in reduced nutrient value from the manure because of the inability of the crop to use applied nitrogen. Spreading a large amount of manure just before spring plowing may actually delay plowing and corn planting. On many farms, after the ground thaws it is not apt to be firm enough to support a 1500-gallon spreader much before (and possibly not until after) it is dry enough to plow. Thus manure spreading may have to be done during bad weather or at the time that plowing for corn should be done.

The actual value of a liquid manure system in allowing more timely planting and harvesting of crops is difficult to estimate. However, it may be an important consideration and can be of substantial value *if* storage tank capacity and spreading schedules are carefully planned.

Elimination of a Separate System to Handle Manure and Waste Water from the Milking Parlor and Milkhouse

If a liquid manure system is not used, a septic tank and disposal field are needed to handle the manure and waste water from the milking parlor and milkhouse. Such disposal systems may require an investment of $500 to $1500 or more. Usually these systems do not function perfectly and the septic tank must periodically be pumped out. The frequency depends on the size of the tank and the efficiency of the disposal field. Many farmers hire a commercial septic tank cleaning service to perform this operation which currently costs $15 to $45 per cleaning.

The elimination of this separate disposal system for parlor wastes usually would not be sufficient justification for installing a liquid manure system. But it does reduce the effective added investment and annual cost of a liquid manure system and thus should be considered.

If rest room facilities are included in the milking center, a separate septic tank system must be provided. Human waste cannot be added to either a liquid manure storage tank or to the parlor waste disposal system. Thus investing in a liquid manure system does not alter the cost of the human waste disposal system.

Value of Manure

Amount of Manure Produced

The amount of manure (feces or urine) produced per cow varies with the size of cow, level of feeding, level of production, type of feeds fed, and many other factors. The amount that must be spread or stored is further influenced by the amount of bedding that gets into the manure and the amount of moisture that evaporates or runs off. Estimates of the amount of manure, excluding bedding, produced per 1300-pound cow vary from 12.5 to 18.5 tons annually (9, 27, 28, 33, 34, 38). Most recent estimates place the amount at 15 to 18 tons.

Sources of Manure Value

The major source of manure value is usually considered to be the plant nutrients contained in the manure. Manure may have other valuable properties such as supplying organic matter and the ability to increase water infiltration and thus reduce runoff, soil erosion, and soil nutrient loss. These properties will be discussed first, followed by a discussion of the value of plant nutrients in manure.

The value of the organic matter in manure depends on the need for organic matter, the amount of organic matter supplied by manure, and the cost of organic matter from other sources. Fresh manure without bedding contains approximately 300-350 pounds of organic matter per ton (3). Although this organic matter may have important effects as a soil amendment and mulching material in some situations, the magnitude of these effects has long been in dispute. Frequently, experiments indicate no apparent value for this organic matter (38). A recent British study (39) found that 30 tons of manure every 5 years had a slight effect on soil structure, but 30 tons applied annually did improve soil structure. Manure applications were compared with a grass sod with the conclusion that "extra organic matter is better provided by a period under grass than by occasional dressings of farmyard manure."

However, under certain conditions, manure may increase the rate of infiltration of rainfall and thus reduce runoff; this in turn would reduce soil erosion and nutrient loss. Zwerman, et al. (42), in an experimental situation where 6 tons of manure per acre had been plowed down each year for the 14 preceding years on continuous corn plots, found that the infiltration rate on fallow plots was increased 27 percent compared with plots that had received no manure. Another experiment at the same location, including other rotations as well as continuous corn, showed that manure did not significantly increase rates of infiltration.

A study at Marcellus, New York, reported by Free (10) found that 20 tons of manure plowed down during a 3-year rotation of corn, canning peas, and clover resulted in 19.5 tons per acre of soil erosion loss in 41/2 years compared with 31.1 tons with 10 tons of manure. Manure top-dressed on the corn and peas at the same rates resulted in erosion losses of 4.5 and 11.0 tons. Total surface runoff (41/2 years) was 17.5 and 19.5 inches on the top-dressed plots, compared with 26.4 and 27.4 on the plowed-down plots. No comparison was made with unmanured plots. This research indicates that there may be other positive effects of manure in addition to the nutrients supplied.

In a 3-year research study, Minshall, et al. (25), found that fresh manure spread in January and February increased winter runoff from corn plots in Wisconsin about 10 percent more than when no manure was used, or when liquid or fermented manure was spread in the spring. However, these 3 treatments reduced summer runoff by 42 to 48 percent when compared with a no-manure regimen. The spring-manured plots lost somewhat less N, P, and K than did the nonmanured plots (table 1). The winter-manured plots lost about 3 times as much N and P and 5 times as much K as did the spring-manured plots. These data appear to show some positive effects of manure, either liquid or fermented, when spread in the spring.

Determination of a dollar value of the benefits of manure for other than its use as fertilizer must be based on a limited number of experiments and would require many assumptions. Although such values may be substantial in certain situations, no attempt to calculate them is made here. This may at first appear to be a serious omission, but is not in terms of the objectives of this bulletin. The amount of manure spread rather than the method by which it is handled (liquid or conventional) would determine the amount of value obtained. Time of spreading might affect such benefits as increasing infiltration rates, but the same effect could be achieved without liquid storage and handling.

The major fertilizer elements of value found in manure are nitrogen, phosphorus, and potassium. Other minor elements such as boron, calcium, cobalt, copper, iron, magnesium, manganese, molybdenum, sulphur, and zinc are found in manure (3, 13) but would be of value only on soils deficient in one or more of these nutrients. In general, New York soils are not deficient in any of these minor elements; thus these elements are of no economic value.

The fertilizer content of cow manure varies with the level of production, type and amount of feeds fed, in-

Table 3. *N, P_2O_5 and K_2O content of manure from dairy cattle as reported by various researchers*

Reporting area	*Pounds per ton of fresh manure*		
	N	P_2O_5	K_2O
Michigan (3)	11.2	4.5	12.0
New York* (11)	11.4	3.1	9.9
Ohio & Penn. (15, 34)	10.3	3.1	8.1
Wisconsin* (12)	9.0	6.0	8.4
Northern Ireland (22)	11.2	2.8	9.2
Massachussets (38)	10.0	4.1	10.2
Average	10.5	3.9	9.6

* *May contain bedding.*

dividual animals, and other factors. The nitrogen (N), phosphoric acid (P_2O_5), and potash (K_2O) content of fresh cow manure as reported by several different researchers is shown in table 3.

Effective Value of Manure

The actual value of this manure depends on the price that the farmer has to pay for these fertilizer elements in other forms. The value of applied manure should be compared with the cost of these elements in the form of applied commercial fertilizer. Thus an application charge has to be added to the cost of the fertilizer. Throughout this publication western New York prices have been used and it is assumed that the farmer buys bulk fertilizer and hires someone to apply it.

Using the average fertilizer content of manure shown in table 1, this would provide a maximum value of $1.98 for 1 ton of manure. Another source (28), reporting the composite of a number of research reports, placed the *N*, P_2O_5, and K_2O content of fresh cow manure containing bedding at 10.7, 2.1, and 9.4 pounds, respectively. This would provide a maximum value of $1.79 per ton of manure.

Kimball, et al. (17), calculated fertilizer values of $1.45 and $2.50 per ton of manure, depending on the form in which nutrients were purchased, and used an average value of $1.95 per ton in their analysis for Wisconsin conditions, assuming that manure was promptly plowed down after spreading.

Table 5. *Effective value of cow manure per ton*

Basis	*Value*
Effective analysis 3.2–2.6–7.2	$ .99
Effective analysis 3.5–3.1–7.2	1.07
45% of $1.98 value of total composition	.89
65% of $1.98 value of total composition	1.29
45% of $1.79 value of total composition	.81
65% of $1.79 value of total composition	1.16
Average	$1.04

The maximum value for manure is based on its nutrient content at the time it is produced. The real value of the manure should be based on its effective fertilizer value. The effective fertilizer content of manure is influenced by runoff, volatilization of nitrogen, leaching, and the amount of the nutrients in unavailable forms. The fact that some of this material has resisted digestion gives some indication of the availability of the nutrients in it.

The National Agricultural Advisory Service of Great Britain (29) indicates that when manure is spread throughout the year the nitrogen in that manure is 33 percent as effective as the nitrogen in commercial fertilizers. Similar estimates of the effective value of P_2O_5 and K_2O are 67 and 75 percent, respectively. Other studies in Great Britian (39, 40) have found the nitrogen, phosphorus, and potassium in manure to be 30, 80, and 75 percent, respectively, as effective as those elements in the form of commercial fertilizers. Herriott (14) found the N, P_2O_5, and K_2O in manure spread throughout the year to be 45 to 65 percent as effective on grassland as commercial fertilizer applied at the same time as the manure. A Swedish study (4) reports that the N in dung is 40, and in urine 60, percent as effective as comercial fertilizer.

Assuming that the average values in table 3 represent the fertilizer content of fresh manure, the above figures indicate that the effective composition of a ton of manure, as opposed to its total composition, is 3.2 to 3.5 pounds of N, 2.6 to 3.1 pounds of P_2O_5, and 7.2 pounds of K_2O. At the previously stated New York prices for N, P_2O_5, and K_2O, the value of the nutrients actually effective in plant growth ranges from about $0.80 to $1.30 (table 5). The average value of the applied cow manure, as indicated by the studies mentioned above, is approximately $1 per ton.

Table 4. *Costs of fertilizer elements*

Element	*Source*	*Cost/ton*	*Application charge*	*Cost/lb element*
N	Anhydrous ammonia (82% N)	$120	$40/ton	9.8 ¢
P_2O_5	Superphosphate (20% P_2O_5)	$ 37	$ 6/ton	10.8 ¢
K_2O	Muriate of potash (60% K_2O)	$ 60	$ 6/ton	5.5 ¢

The Kimball study (17, p. 20) arrived at a value of $0.98 per ton ($20 per cow for 20.4 tons of manure) of manure handled conventionally by assuming that half of the nutrients produced by the cow were recovered.

Although it has been shown (38) that there is a residual or carry-over effect of manure in the years following application, it is not clear that this effect is greater than that found with commercial fertilizers. A recent Hungarian study (2) found that the residual effect in the second and third years was less with manure than with an equivalent amount of commercial fertilizer. Part of the exaggerated opinion of the value of manure probably results from the fact that nutrient application rates are often higher with manure than with commercial fertilizer. Fifteen tons of manure is equal in total composition to approximately 750 pounds of 20-10-20 and, in field effectiveness, to 500 pounds of 10-10-20.

Value of Manure When Handled in Liquid Form

To date few studies have compared the fertilizer value of liquid manure and manure handled by more conventional means. There is little reason to believe that adding water to the manure would make it any more or less effective in promoting plant growth. However, the added water might contribute to increased runoff when applied during the winter to soils that are at or near their water-holding capacity.

The Zwerman study (42) relates only to "manure" and thus does not give any information specifically relevant to liquid manure or time of spreading. No studies were found in the literature comparing the effect of liquid with other forms of manure on rates of infiltration or amount of soil loss. Infiltration rates could be inferred from the runoff data in the Minshall study, but the economic value of differing rates could not be calculated without additional research. This study found that the effects on runoff of liquid and fermented manure were similar when both were applied in the spring.

Estimates given here of the effect of liquid handling on the value of manure will consider nutrient values only. Available data does not indicate that liquid handling significantly affects other sources of value in manure.

Losses during storage in a liquid manure pit are almost exclusively nitrogen losses. Losses of phosphorus and potassium would not be expected unless there was runoff or leaching from the pit. About half of the nitrogen in manure is in soluble forms, and the remaining half is in organic forms (34). While the manure is stored in the pit, soluble nitrogen is lost to the air and organic nitrogen is broken down. In this way the percentage of soluble N in the manure remains relatively constant, although the total N decreases.

An experiment in Northern Ireland (22) found that when liquid manure stored in pots was exposed to the air, about 33 percent of the total N in cow manure was lost in 4 weeks. About 42 percent was lost in 12 weeks. When air was excluded from manure, losses were small. Since most liquid manure pits are opened daily to add manure, the effect may be the same as that of being constantly exposed to air.

Even if the N loss is less in a liquid manure pit, considerable nitrogen is lost after the manure is spread unless it is plowed under almost immediately. After manure is spread there are rapid losses of N through volatilization from freezing and (or) drying. One researcher (34) reported that N losses were 23 percent in 36 hours and 32 percent in 31/2 days.

There is one set of circumstances under which the value of liquid manure may be greater than the value of the same manure when spread daily as a semiliquid. This is when a liquid system allows manure storage during periods when high losses can be expected and spreading at a time or under conditions when losses would be less. Research in Vermont in 1936-44 by Midgley and Dunklee (24), using plots with 8, 10, and 20 percent slopes upon which manure was spread at 10 and 20 tons per acre on snow cover, indicated that rather large amounts of N, P, and K were lost in the spring runoff. No comparison was made with loss of nutrients when manure was spread at other times.

The Minshall study indicates that manure spread in winter on frozen ground will probably result in an increased nutrient loss that may enter stream water. If this is true, a liquid manure system with enough storage for the entire winter may reduce nutrient runoff, if the manure is properly handled at spreading time. This reduction is an economic advantage that a liquid manure system could offer to both the farmer and society. The farmer could profit from the fertilizer value for crop production, and society would benefit by having water less contaminated by nutrients from farmland. The results of the Minshall research apply almost equally to liquid and fermented manure spread in the spring. *Thus the economic benefit is from storage and spring spreading, not from liquid manure* and could be attained by methods of storage and handling in a nonliquid form. The economic implications of the Minshall results for liquid manure handling will be discussed in a later section.

Storing during nearly any period and plowing down immediately after spreading may also reduce nutrient losses. However, it must be remembered that plowed-down manure is subject to the same losses as commercial fertilizers when applied during a period untimely for plant growth. Agronomists (8) have found losses to be high when fertilizer, particularly nitrogen, is plowed down in the fall. Although there is no specific research data available on this subject, it appears that the amount of fertilizer available to spring-planted crops from manure stored during the summer and plowed down in the fall is not significantly greater than from manure spread daily during the summer.

The research results and discussion above indicate that about the only time that a significant saving in manure value can be expected is when manure is stored during the winter months and spread in the spring. This eliminates spreading manure on frozen ground or just before the heavy runoff and leaching period of early spring and allows for application more timely for plant growth. The amount of this saving depends on the amount of manure that can be stored and the amount of the fertilizer value that can be saved by storing.

Because of the difficulty in placing a value on liquid as compared with conventional manure, 2 methods have been used to calculate such a value.

Method 1. Herriott (14) found that winter-applied liquid manure is 20 to 80 percent as effective as summer-applied. The 20 percent figure was obtained during an excessively wet winter and the 80 percent during a dry winter. These figures cover the complete winter period. This implies that under average conditions winter-applied manure would be about 50 percent as effective as summer-applied. Therefore, one might conclude that a liquid manure system would double the value of winter-produced manure — a logical assumption, provided the storage was large enough to accomodate the entire winter's manure and no losses occurred in storage. However, most storages will hold at most the accumulation of only the last 3 or 4 months of winter and early spring. Manure spread daily during this late winter and early spring period would be subject to less loss than that spread earlier in the winter. Thus manure spread daily during this period should be more effective in promoting plant growth than the average for the complete winter period.

Partially offsetting the losses due to time of spreading with conventional methods are the nitrogen losses taking place in the pit during storage. As stated previously, these might be as high as 40 percent of total nitrogen and thus would decrease the value of manure stored during the winter and spread in the spring.

These figures do not provide a complete picture of the actual savings in manure value with a liquid system. However, they do give an idea of the magnitude of the savings and allow some reasonable estimates to be made. Although some judgement is involved, the work of Herriott (14) and McAllister (22) suggests that manure applied daily during the last 3 winter months is about 80 percent, and that applied during the entire winter is 70 percent, as effective as manure stored in a pit during those months and spread in the spring.

The following example is used to show the increased manure value that may be expected with a liquid system. Assume that a pit is constructed that is large enough to store the manure for a full 3-month period. This would hold the manure for a three-month period before spreading in April or early May. Approximately 4.25 tons of manure per cow (1/4 X 17 tons/year) would be stored. Assuming that the manure spread daily is 80 percent as effective as that collected and stored in the pit for 3 months, the net saving is about 20 percent of the value of the manure stored. Twenty percent of the previously determined value of about $1 per ton provides a saving of $0.20 per ton.[6] When this is multiplied by the 4.25 tons per cow, a value of $0.85 per cow is obtained. This means that a liquid system with a storage capacity for 3 months would provide an increase in manure value of approximately $0.85 per cow per year. For 6 months' storage, increased manure value would be $0.30 per ton or on 8.5 tons stored per cow, $2.55 per cow.

Method 2. Calculations based on the Wisconsin study by Minshall provide a basis for a partial estimate of the effect of liquid handling on the value of nutrients in manure. Nutrient loss (average of N, P, and K) from plots receiving fresh manure in the winter was 15.5 percent of the nutrients applied. For plots receiving liquid manure in the spring, loss was 4.2 percent of the nutrients applied or a difference of 11.3 percentage points. Assuming 17 tons of manure with a fertilizer value of $1.95 per ton, the potential value of manure per cow is $33.15. If 11.3 percentage points less nutrients are lost with liquid handling, the added manure value per cow would be $1.85 (half of $3.70) assuming 6 months' storage and $0.92 for 3 months' storage. This estimate must be considered rather tentative. It depends on one 3-year study with some variable circumstances as described above. It implies that all manure spread daily during the 6 winter months would be spread on frozen ground. It also implies that losses in transit from the cow to the field are the same regardless of whether the manure is handled in conventional or liquid form. In fact, losses are likely to be higher with conventional handling because of the possibility of leakage of liquids from conventional spreaders, but no data is available on the extent of such losses.

Comparison. The figure of $1.85 added value of manure per cow determined from our calculations based on

6 An exact calculation would recognize that the $ 1 figure represents an average of summer and winter conditions. Thus, if the summer and winter periods are approximately equal in length, the $1 equals 90 percent of the summer value of manure. This would provide a value of $0.22 per ton. The $0.20 is used for ease in calculation and because all figures are approximate.

the Wisconsin study is lower than the figure of $2.55 per cow for 6 months' storage obtained by the alternative method used in the previous section. The figures of $0.92 and $0.85 for 3 months' storage are nearly equal. Averaging these figures gives an increased manure value of $2.20 per cow for 6 months', and about $0.90 for 3 months', storage.

Because of the lack of data on which to base the change in value of manure when handled as a liquid, a look at other possible values may be instructive. Most of the available data indicates that the effective value of the nutrients in manure is about half the value of the nutrients produced by the cow. Presumably these data are based on "conventional" handling. If liquid handling saved *all* the nutrients produced by the cow that are lost with conventional handling, the maximum increase in value, based on our data, would be $16.58 (50% of $1.95 X 17) per cow. No evidence has been found that liquid handling could possibly result in this much increased value. If the savings were double our estimates of $1.85 and $2.55 per cow ($3.70 and $5.10), the increased manure value for a 100 cow herd, assuming 6 months' storage capacity, would be $370 and $510 per year. Even if quadrupled, the savings are $7.40 and $10.20 per cow. In light of the data presented these latter levels of increase in manure value are extremely unrealistic.

It must also be noted that the increase in manure value attributed to liquid handling is based almost entirely on storage to avoid winter spreading. Essentially the same thing could be accomplished by other methods of storage and handling. Manure stored on a concrete slab with sides or curbs to prevent runoff and spread at appropriate times with conventional handling equipment would probably require less added investment and might result in lower annual costs of manure handling.

It should be noted that these calculations assume that the manure is spread after the spring thaws. This may be in direct conflict with efforts to schedule spreading to achieve improved labor distribution.

When a storage pit is constructed to hold less than 3 months' volume of manure, the fertilizer value saved would be disproportionately less. A pit to hold the manure for a 2-month period will contain only 2/3 as much. In addition, the manure that is stored would otherwise have been spread during the very last part of winter and the first part of spring when losses may be somewhat lower. Thus a 2-month storage pit probably would not save more than $0.40 to $0.45 per cow or $40 to $45 per year for a 100-cow herd. When manure is spread monthly or more frequently there probably would be no savings in value because the period of exposure would be nearly the same as with daily spreading.

No evidence has been found to indicate an increased manure value from liquid storage and handling during the summer months.

Total Cost

Equipment and Storage Needs

The 3 major items needed for a liquid manure system are a storage tank, a pump capable of handling cow manure, and a tank wagon.[7] Costs of these items vary greatly depending on size or capacity of each. It is assumed here that a dairyman wants a tank wagon large enough to keep the number of trips to a minimum, a pump that will handle manure at a rapid rate, and a storage tank large enough in relation to herd size to permit relatively infrequent cleaning.

Investment Required

Tank wagons of many sizes are available. A 1400-gallon tank wagon is a common size being purchased by New York dairymen. Larger tanks are available, but even the 1400-gallon size weighs 6 or more tons when loaded, this weight making tandem or flotation tires necessary and precluding hauling a full tank load when the ground is extremely soft. A 1400-gallon tank wagon will usually cost $1800 to $2300. In comparing with a conventional manure system, the cost of a conventional spreader could be subtracted from the cost of a tank wagon to determine the net increase in investment if all animals were serviced by the liquid system. However, most dairymen will need to maintain a conventional spreader to handle manure from young cattle that are not included in the liquid system. This spreader might have a longer life or a lower purchase price than one used for a free stall barn in the absence of a liquid manure system.

Pumps are available in many types and capacities. If a vacuum-type tank wagon is used, a pump is not required, but a separate agitator is needed. Small, low-horsepower pumps also require purchase of a separate agitator.

Large tractor-driven recirculating pumps with a chopper-impeller perform both the pumping and agitation operation. Although these recirculating pumps are more expensive than the combined pump and agitator required with the other two pumps, it appears that they are the only type that will do a satisfactory job with cow manure.[8] Several makes of this type of pump are available with an initial investment of $1700 to $2000.

Storage tank investment will vary with the size of the storage, tank design, and the amount of farm labor used in construction.

[7] *Tank wagon* or *liquid manure spreader* throughout this publication refers to a trailer-mounted tank (nonvacuum) with a power-driven, rear-mounted rotary deflector.

[8] For discussion of pumps and agitation systems, see page 17.

The size of storage needed will depend on the number of cows, length of the storage period, manure produced per cow, bedding used, hay and silage wasted, water added, and unusable capacity in the top and bottom of the tank.

Recent estimates place the amount of manure produced per 1300-pound cow at 15 to 18 tons. The average of these 2 figures plus 0.5 ton per cow for bedding and wasted feed gives a total of 17 tons per 1300-pound cow per year or 93 pounds per day. Because of the high moisture content, manure weighs only slightly less per gallon than water. At 8.2 pounds per gallon, the manure production amounts to 11.36 gallons or 1.51 cubic feet per cow per day.

Additional water will be required to allow pumping of the manure. The exact amount of additional water needed is not known; some estimates put this at about 5 to 15 gallons of water per cow per day. Ten gallons of water per cow per day would nearly equal the original volume of excrement, and thus nearly double the volume to be handled. The amount of water added should be carefully controlled to keep pumping and hauling time to a minimum and yet have a pumpable substance.

On some farms, waste water from the milking parlor and milkhouse has provided adequate additional water. In a 1966 study of liquid manure systems in New York State conducted by the authors, the water from the milking parlor and holding area was being directed into the pit on all 11 farms surveyed (6). On 4 farms this provided sufficient water for satisfactory pumping. The other 7 farmers indicated that they did add some water, but the amount varied considerably and was difficult to measure. About 5 gallons per cow per day is sufficient if a good pump is used. Five gallons of water requires 0.67 cubic foot of storage space. Adding this to the 1.51 cubic feet needed for the manure gives a total requirement of 2.18 cubic feet per cow per day of usable storage capacity.

Most pumps cannot remove the last foot of manure in the bottom of the pit. Usually at least 6 inches at the top of the pit will be unusable if the water from the parlor is to drain into it. This adds up to a minimum unusable portion of 1.5 feet or 15 percent of the total capacity of a pit 10 feet deep. Adjusting the 2.18 cubic feet needed for manure and water storage for 15 percent unusable space results in a total capacity requirement of 2.56 cubic feet per cow per day.

In the New York survey conducted by the authors, it was found that the average total capacity requirement was approximately 3.0 cubic feet per cow per day. About 2.4 cubic feet of this capacity was actually usable space; thus 23 percent of the total capacity was unusable.

Calculations in a New England study (37) are based on 70 cubic feet of usable capacity per cow per month. Although the basis for this figure is not given, this amounts to 2.30 cubic feet per cow per day. Adjusting this figure for 15 percent unusable capacity gives a total capacity requirement of 2.71 cubic feet.

Another source recommends 2 cubic feet of storage capacity per 1000 pounds of animal weight per day (30). This implies a requirement of 2.6 cubic feet per cow per day for a herd with an average weight of 1300 lbs. per cow. However, this source also recommends that if spreading every 3 months is desired, a tank with a capacity of 4 months should be constructed. This suggests that either 2.0 cubic feet are inadequate or that the authors were attempting to provide for flexibility in the timing of spreading.

A recent Wisconsin survey of liquid manure systems found that farms with free stall barns where all the manure was handled in liquid form used 2.50 cubic feet per cow per day (17). A comparison of the amount hauled with total capacity indicated that approximately 14 percent of total capacity was unusable.

The estimated storage requirements in this publication are calculated on the basis of 2.6 cubic feet of total capacity per cow per day. This is in line with the recommendations of the Cornell Department of Agricultural Engineering and approximates the most frequently mentioned requirements found in the publications reviewed. It is less than the 3.0 cubic feet found in the New York survey. However, this figure may be slightly high because nominal rather than inside dimensions were used in calculating the capacity of these storages. They were also among the first built and may have more unusable space than is required by newer designs.

To allow manure hauling to be scheduled at nonpeak periods of crop labor and to achieve any real saving in manure value, a storage period of at least 3 months would be required. Although capacity for shorter periods would be less expensive, the only real advantages would be the elimination of the daily job and possibly some labor saving. To avoid spreading manure during the winter months and allow spreading on ground firm enough to hold relatively heavy equipment, a storage period of approximately 6 months would be required. Estimated storage capacity needed for periods of various lengths are listed in table 6.

For convenient pumping, tanks probably should not be more than 10 to 12 feet deep. Wide tanks with tops strong enough to support cattle and equipment may be difficult or costly to construct. Some possible tank dimensions for a 100-cow herd with 30- to 180-day capacity are shown in table 7.

Satisfactory watertight storages require competent engineering and construction.[9] Concrete should be thick enough and reinforced adequately to insure that the storage performs satisfactorily over a period of years. Concrete

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[9] Plans for rectangular and circular storage tanks are available from the Department of Agricultural Engineering at Cornell and at other agricultural colleges.

Table 6. *Estimated storage capacity required for 1300-pound cows*

Days	Per cow		50 cows		100 cows	
	Cu ft	Gals	Cu ft	Gals	Cu ft	Gals
1	2.60	19.4	130	972	260	1,945
30	78	583	3,900	29,172	7,800	58,344
60	156	1,167	7,800	58,344	15,600	116,688
90	234	1,750	11,700	87,516	23,400	175,032
120	312	2,334	15,600	116,688	31,200	233,376
180	468	3,501	23,400	175,032	46,800	350,064

Table 7. *Possible tank sizes and dimensions, 100-cow dairy herd, 1300-pound cows*

Days stored	Cu ft needed	Rectangular tank D × W × L	Round tank Depth × approx. diam.
30	7,800	10 × 20 × 39 or 8 × 12 × 81	10 × 32
		10 × 10 × 78 or 8 × 16 × 61	12 × 29
60	15,600	10 × 10 × 156 or 8 × 20 × 98	10 × 45 or (2) 10 × 32
		10 × 20 × 78 or 8 × 24 × 81	12 × 41 or (2) 12 × 29
90	23,400	10 × 10 × 234 or 8 × 32 × 91	10 × 55 or (2) 10 × 39
		10 × 20 × 117 or (2) 8 × 20 × 73	12 × 50 or (2) 12 × 35
120	31,200	10 × 10 × 312 or (2) 8 × 20 × 98	10 × 63 or (2) 10 × 45
		10 × 20 × 156 or (2) 8 × 24 × 81	12 × 58 or (2) 12 × 41
180	46,800	10 × 20 × 234 or (3) 8 × 20 × 98	10 × 77 or (3) 10 × 45
		10 × 30 × 156 or (3) 8 × 24 × 81	12 × 71 or (3) 10 × 41

silo staves and concrete blocks have been used in the construction of storage tanks. Construction costs with these materials may be lower than with reinforced poured concrete, but whether the storage is watertight is not yet known.

Costs of building 20 concrete manure storage tanks were obtained in a New England survey (37). Costs range from $0.09 to $0.50 per cubic foot of total capacity, with an average of $0.31. This does not include a charge for the farm labor used in constructing many of them. The average volume was 12,890 cubic feet.

Data obtained from 8 of the 11 New York farmers contacted in a 1966 survey indicated a cost range of $0.22 per cubic foot of total capacity for a concrete silo stave storage to $0.52 per cubic foot for a reinforced poured concrete storage. The average cash cost was $0.34 per cubic foot; in addition, farm labor was used in storage construction on some farms. The average size of these storages was 9450 cubic feet.

In a recently reported Wisconsin study a linear function was generated, using construction costs for liquid manure storage tanks on 43 farms. The function was: Investment in storage capacity = $166 + $0.04224 (gallons). This amounts to $0.30 to $0.35 per cubic foot of capacity (17).

The authors of the New England bulletin (37) state that "the actual or estimated costs were somewhat nebulous as some of the tanks were included in a 'package' contract for complete dairy facilities or were constructed by farm labor without assigning a value to labor costs." This statement would apply equally well to the New York and Wisconsin surveys.

Storage tank prices listed by one major commercial firm that installs pre-cast concrete liquid manure tanks range from $0.59 to $0.79 per cubic foot. After adding $0.03 per cubic foot for excavation and backfill, this provides an installed price of $0.62 to $0.82 per cubic foot of storage space. Costs for tanks large enough for most farm situations range between $0.62 and $0.75.

Storage tank investment in this publication is based on costs of $0.50 and $0.70 per cubic foot. The $0.50 exceeds the cash costs reported by the New York and Wisconsin farmers surveyed; it includes some allowance for the value of farm labor used in construction, increased construction costs since the time many of the storages were built, and for the fact that the capacity of many of the New York storages was calculated on the basis of outside rather than inside dimensions. It approximates the minimum investment that could be achieved on most dairy farms. The $0.70 figure represents the approximate cost that most dairymen would have to pay for storage capacity when the entire tank construction is contracted. Costs exceeding this amount can be expected where tanks with less than 10,000 cubic feet of capacity are constructed, where the construction site terrain is irregular, and where more elaborate structures are built.

These investments in most cases would not allow construction of a tank of as good quality as implied by the tank designs distributed by the Agricultural Engineering

Table 8. *Estimated investment and annual cost*, liquid manure system, 100-cow dairy herd*

Cost item		*Storage capacity cost†*			
		$0.50 per cu foot		*$0.70 per cu foot*	
		Investment	*Annual cost*	*Investment*	*Annual cost*
Pump — high-capacity chopper-impeller		$ 1,900	$ 475	$ 1,900	$ 475
Annual cost as a percent of new cost					
Depreciation (7-year life)	14.3				
Interest (7½% on ½ of cost)	3.7				
Repairs	6.5				
Insurance	0.5				
Total	25.0				
Spreader — 1400-gallon		2,100	420	2,100	420
Annual cost as a percent of new cost					
Depreciation (7-year life)	14.3				
Interest	3.7				
Repairs	1.5				
Insurance	0.5				
Total	20.0				
Storage — 90-day capacity 2.6 cu ft/cow/day = 23,400 cu ft		11,700	1,370	16,380	1,915
Annual cost as a percent of new cost					
Depreciation (15 years)	6.7				
Interest	3.7				
Repairs	0.3				
Taxes	1.0				
Insurance	‡				
Total	11.7				
Total — With 90 days' storage		$15,700	$2,265	$20,380	$2,810
Storage — 180-day capacity 46,800 cubic feet		$23,400	$2,740	$32,760	$3,835
Total — With 180-days' storage		$27,400	$3,635	$36,760	$4,730

* *Does not include labor cost or variable cost of tractor operation.*
† *Rounded to nearest $5.*
‡ *Insurance would probably be little if any greater with than without liquid manure storage tank.*

Departments at Cornell and other universities. Since construction costs vary widely, it is advisable for each farmer to be sure what his construction costs will be before making the decision to build a liquid manure storage tank.

Annual Costs

Estimated investment and annual costs for a liquid manure system with 90 and 180 days' storage for a 100-cow herd are given in table 8. A 180-day storage period is required if winter spreading is to be avoided. A 90-day storage period provides most of the nonpollution-related advantages and allows elimination of spreading during part of the winter.

The life of liquid manure pumps and tank wagons is unknown at present. Most dairymen with large herds have been buying a new conventional manure spreader at least every 5 years. The design and lower frequency of use of liquid manure spreaders may give them a somewhat longer life. In these calculations a 5-year life has been used for conventional manure handling equipment, and a 7-year life for liquid equipment. A 10-year life for manure pumps and tank wagons would decrease the annual costs of a liquid manure pump and tank wagon by about $82 and $91, respectively.

From the estimated investments listed in table 8 could be subtracted the investment in items made unnecessary by the liquid manure system (table 9).

The net increase in estimated investment for a liquid manure system with 90 days' storage is $12,800 ($15,700 less $2900), if storage tank construction costs $0.50 per cubic foot, and $17,480 ($20,380 less $2900), if storage tank construction cost is $0.70 per cubic foot. For a 180-day storage period the corresponding net increase in investment is $23,800 and $33,160, respectively. The net increase in estimated annual cost is $1835 and $2380 for 90 days', and $3120 and $4215 for 180 days', storage.

No estimate has been made of changes in cost of tractor operation. Since fewer loads of manure may be hauled, a

Table 9. *Estimated reduced investment and annual costs due to replacement of conventional manure system with liquid manure system.*

Cost item	Percent of new cost	Investment	Annual cost
Septic tank system (15-year life)		$1,200	$175*
Manure lip (15-year life)		600	65
Manure spreader (5-year life)		400	110
$1,200 investment (⅓ saved) †			
Depreciation (5 years)	20.0		
Interest	3.7		
Repairs	3.0		
Insurance	.5		
	27.2		
Concrete floor replaced by top of manure tank (¾ of tank top surface area @ $0.40/sq ft) 90-day capacity (¾ of 20′ × 117′)		700	80
TOTAL — With 90 days' storage		$2,900	$430
Concrete floor — 180-day capacity (¾ of 32′ × 146′)		$1,400	$165
TOTAL — With 180 days' storage		$3,600	$515

* *Includes cost of pumping out septic tank once per year @ $45.*
† *Calculated on basis that dairyman will still maintain conventional manure spreader for handling heifer manure; thus saving would be due to less frequent spreader replacement or maintenance of less expensive spreader.*

somewhat lower variable cost of manure handling might be expected. However, the manure must be agitated and pumped from the storage, and a larger tractor likely would be needed on the liquid manure spreader so the net difference in variable cost of manure hauling would be small. More important, perhaps, than the variable cost of tractor operation, is the fact that the manure pump and the spreader both require tractors of relatively large horsepower. On most New York dairy farms, this means tieing up the 2 largest tractors. With one spreader, the pumping and hauling is usually a one-man job. However, if the 2 best tractors are being used for manure hauling, it may prevent other work such as plowing from being carried on at the same time.

Economic Summary

Increased manure value and labor saved (at prevailing wage rates) will not pay for the estimated additional cost of a liquid manure system (table 10). For labor saving alone to be equal to the estimated net increase in annual cost of a liquid manure system, the wage rate would need to be over $7.50 per hour with 90 days' storage capacity and over $12.80 with 180 days' storage.

Throughout this publication all estimates have been based on a 100-cow herd. Although this provides a good indication of the desirability of liquid manure systems, some variation can be expected for smaller or larger herds because the costs of the pump and tank wagon would be

Table 10. *Annual costs of a liquid manure system, estimated Fall 1971*

Cost item	100 cows, 90-day stor.		100 cows, 180-day stor.	
	@ $0.50 per cu ft	@ $0.70 per cu ft	@ $0.50 per cu ft	@ $0.70 per cu ft
Annual cost of system	$2,265	$2,810	$3,635	$4,730
Annual costs saved	430	430	515	515
Additional annual costs	$1,835	$2,380	$3,120	$4,215
Increase in manure value *	90	90	220	220
Net annual cost increase	$1,745	$2,290	$2,900	$3,995
Labor saved (@ $2.50/hr.) *	615	615	615	615
Annual cost of advantages other than manure value and labor saving	$1,130	$1,675	$2,285	$3,380

* *Average of estimates, rounded to nearest $5.*

spread over fewer or more cows. However, the largest part of the investment is in storage which cannot be spread over more cows and still maintain the same storage period. An increase in herd size to 200 cows would reduce the investment per cow by approximately $20; from a range of $157 to $204 down to a range of $137 to $184 for a 90-day storage period. For a smaller herd of 50 cows, investment would be approximately $40 per cow higher.

In total, if a liquid manure system is to be justified, such justification will have to be based on other advantages in addition to increased manure value and reduced labor requirement. The primary other advantages are: the possibility of not hauling manure at periods of peak labor demand for planting and harvesting crops, and the potential of reduced pollution due to reduction or elimination of winter spreading. To actually reap any benefits from improved labor distribution, a dairyman must carefully plan his cleaning schedule and be limited in the amount of labor available during peak labor demand periods. If additional labor can be hired during peak labor demand periods for the assumed rate ($2.50 per hour), the change in labor distribution will be of little value.

As previously indicated, the amount of reduced runoff that would be brought about by a liquid manure system is limited at best and may even be zero. Further, in order for there to be an environmental advantage, the social value of reduced runoff into streams and lakes must exceed the social cost of the increased air pollution caused by a liquid system by more than the cost indicated in the last line of table 10. That is, if a liquid system with a 180-day storage capacity is constructed for a 100-cow herd at a cost of $0.70 per square foot, the value of the pollution reduction must equal or exceed $3461. This is its cost to the farm operator. It is unlikely that any reduced pollution that could be achieved would be valued this high. This evaluation is further complicated by the fact that the farm operator receives little, if any, actual private monetary return for pollution control that is achieved. The costs of pollution reduction via a liquid manure system are both private and social costs while the returns are primarily social.

PHYSICAL CONSIDERATIONS

Location of the Storage Tank (Pit)

The most desirable location for a liquid manure storage tank is affected by a number of factors. Some of these factors are: placement of the parlor-milkhouse area, location of water supplies, and barn layout.

The storage tank should usually be placed as close to the milkhouse-parlor area as possible. One of the primary advantages of a liquid system is that it provides a convenient and reasonably trouble-free way to dispose of the water from the parlor and milkhouse.

A grade is required for the pipe carrying the water from the parlor to the pit. Placing the pit close to the parlor means that the fall required to provide this grade is held to a minimum and the pipe will enter the pit as near the top as possible. The point at which this pipe will enter the pit is the maximum point to which the tank can be filled. Otherwise the manure will back up into the parlor. When the pipe enters the pit at the top, the full capacity of the tank is usable. When the pipe enters the pit 18 inches or 2 feet below the top of the tank, the top 18 inches or 2 feet of the pit are not usable.

One disadvantage of placing the pit next to the parlor is the odor. Although odors will usually not be offensive during periods of storage, there will be a high level of odors during agitation and clean out. If the pit is cleaned during or just before milking time, odors could contaminate the milk. Cleaning the pit only between milkings offers a logical solution to this problem. As an alternative solution, the pit could be extended outside the barn and a pumping port provided outdoors. This would tend to keep at least part of the odors outside.

A watertight storage tank will contain the liquid part of the manure and prevent it from entering the water supply. However, there is some question as to whether all pits are actually water tight and there is no reliable way of checking them. Water did seep from one silo tank when it was being added before the first filling. Another dairyman dug a well hole beside the pit to drain away water while the tank was being constructed. For a short time, when the tank was first used, there was seepage from the tank into the hole. Both of these farmers stated that the manure soon sealed the tank so that they thought seepage had stopped. Sanitarians recommend that the pit be located 100 feet downhill from the water supply.

The liquid manure pit should be located so that the manure can be conveniently scraped into it. Because this manure is sloppy and difficult to move around corners, a good arrangement provides a scrape-in opening at the end or, for long alleys, in the center of each alley. If a pit is to be in an outside lot, it should be located on the lower side of the lot so that the manure can be scraped into it.

Placing a storage tank in a poorly drained low spot should be avoided if possible. A nonwatertight storage placed in a poorly drained area will allow water to leak into the tank and reduce its effective capacity. A watertight tank in a similar location may have sufficient ground-water pressure exerted on the outside of the walls to cause the walls to collapse.

The pit should be located so that it can be easily cleaned. When the pit is inside the barn the clean-out openings must be located near enough to doorways to allow easy movement of the spreader in and out. Also, adequate space is required at each pump-out hole to maintain one tractor inside the barn for agitation and pumping. Placing the pit outside the barn or extending the end of the pit outside might make it more accessible.

Agitation

Three methods of liquid manure agitation are used in New York State. One system makes use of a vertical pad dlewheel placed in the center of the pit and 2 baffle walls, extending lengthwise in the center of the pit from near the paddlewheel to approximately 4 feet from each end of the pit. With this system, the paddlewheel is supposed to agitate the manure by moving it in a figure-eight pattern. The agitator is run daily to mix the fresh manure with that in the tank. Dairy farmers using this system have found that it does not have enough positive action to keep the manure particles in suspension. The pit slowly fills up with heavy particles which tend to accumulate in the bottom of the pit and cannot be removed by the pump used with this system. Thus, the usable capacity of the pit will continue to decrease until the manure has to be removed about as fast as it is put in.

Augers are used as agitators with some systems, but they are relatively ineffective in agitation unless the pit is at least half full. They also have the disadvantage of a relatively fixed position in the tank. This means that islands of solid matter that form on the top of the manure must be pushed over to the auger. Agitation of the manure in corners or very far from the auger is difficult. In general, augers usually are not very effective in agitation although both they and the paddlewheel-baffle agitator have the advantage of being relatively low in cost.

Recirculating pumps with a capacity of 1000 to 2000 gallons per minute appear to provide the best method of agitation now available. They are usually tractor driven and either stationary or attached to the tractor drawbar. With these pumps the direction of the recirculating flow can be changed so that agitation can take place in any direction from the pump. The velocity of the recirculating flow provides positive action that can form a homogeneous material of the water and manure solids. Agitation is done only immediately before emptying the storage.

Pump-out hatches should be located so that all areas of the tank can be reached by the recirculating flow. It is recommended that these hatches be no more than 30 feet apart (30).

This type of an agitating system has a higher cost than the 2 previously mentioned, but it can do a good job of agitation, and the same pump is used for pumping the manure into the spreader.

Pumping

Some farmers use a low horsepower (5-7$^{1/2}$) pump that is usually driven by an electric motor. This pump will not work as fast as the recirculating type, but some do operate at an acceptable rate in well-agitated manure. A dairyman should not buy one of these until he has given it a trial. It requires a separate agitation system but has the advantage of being lower in cost than some other types.

A second type is a vacuum pump which is operated as part of a vacuum spreader. This model creates a vacuum in the tank which pulls the manure through a hose into the spreader. During spreading, the pump creates a pressure which helps push the material out. Vacuum tanks have been used for hog manure with reasonable success but do not work well with dairy cattle manure because the material is fibrous. Auger agitators which are usually used in conjunction with this type of pump will not chop up long straw or hay — materials that clog vacuum pumps. However, the vacuum type, which is sold as part of the spreader, has the advantage of costing less than the recirculating pumps.

The one that appears to do the best job is the high-horsepower recirculating pump. This pump is used for both pumping and agitation and is usually equipped with a chopper-impeller, which will chop a limited amount of straw or hay. This allows agitation and pumping of material which other models cannot handle.

It should be remembered that these pumps will handle only a limited amount of hay or straw and will not pump items such as wrenches, stones, and blocks of wood. Farmers with gravel in the bottom of their free stalls are finding that the stones work up through the bedding, are dragged out into the manure, and then scraped into the pit. The stones will severely damage the chopper on recirculating pumps; consequently those planning liquid systems should use only sand or clay under the bedding in free stalls.

It should be pointed out that there is considerable variability in the effectiveness of the various makes of recirculating pumps. Some companies appear to be further advanced in pump design than others.

Frozen Manure

Frozen manure should not be scraped into the storage tank. It will remain frozen for a long time and prevent removal of the manure from the tank. If manure is likely to freeze in the free stall barn, an alternative method of handling it should be provided. In fact, dairymen planning a liquid manure system should have some alternative way of handling the manure in case there are problems with the liquid system. Most New York free stall systems with liquid manure have not provided a lip where manure could be pushed directly into a conventional spreader, thus requiring the use of a manure loader. In this case a wall should be provided as a backstop to use in filling the loader bucket.

Outside Lots

Outside exercise or feed lots create special problems in handling liquid manure. In summer, evaporation may leave manure so dry that considerable water will have to be added to the storage tank. Even more serious, rain water from the lot may drain into the tank and necessitate excessive hauling. Precaution must be taken to prevent such excess water from draining into the storage tank.

Many free stall systems in New York are completely enclosed and roofed. Rain and evaporation should change the moisture content of the excrement but little throughout the year. If manure from an outside yard is placed in the tank during part or all of the year, the problems mentioned may arise.

OTHER POSSIBILITIES FOR HANDLING MANURE FROM FREE STALL BARNS

Oxidation

Experiments are being carried on at several locations to determine the physical and economic feasibility of reducing the volume of manure by oxidation. This process consists of using a recirculating channel or ditch (which could be part of either a liquid manure storage tank or a slatted floor system) with a power driven paddlewheel or "surface aeration rotor". The rotor mixes air (oxygen) with the manure, thereby aiding the digestion of manure by bacteria. If this operation is performed properly, digestion is done by aerobic rather than anaerobic bacteria; thus there is no odor.

It is well established that an oxidation ditch can significantly reduce both the volume and the odor level of manure. In a recent study using poultry manure, total solids were reduced 53 percent (volatile solids were reduced 62 percent) and "when the odor of a beaker of mixed liquor from the oxidation ditch and a beaker of tap water was compared, the difference between the two was rarely noticed" (21). In addition, the BOD_5 pollutional value of the manure was reduced 83 percent. In summarizing the research to date on swine, beef cattle, and dairy cattle, Jones, et al. (16), indicated that an oxidation ditch system has "practically no odors from manure pit to field," reduced the BOD_5 pollutional value of waste by about 90 percent, and reduced the volatile solids by about 40 to 50 percent.

The above results were derived from experimental facilities designed to determine the physical possibility of using an oxidation ditch. The manure facilities used were often excessive in proportion to the animal numbers housed. Most of the research to date has been done with hog manure. Several hundred oxidation ditches are being used for hog production in the Midwest with apparent success. Additional research is required under farm conditions to determine the design requirements necessary for successful farm operation with cattle manure. Because of the tentativeness of oxidation ditch design recommendations, realistic economic evaluation for dairy cattle situations is difficult.

Open Pits

An alternative to liquid manure handling which is being experimented with by certain universities and tried by some farmers is an open pit. This is a large pit, constructed from concrete, treated posts, or other material, in which the manure is deposited daily. Manure is removed from the pit with conventional spreader and front-end loader. The frequency of spreading depends on the size of the pit and the desires of the farm operator. This technique may allow less expensive storage construction than that for liquid manure and permits spreading with conventional equipment.

If the manure pit is watertight and large enough, runoff could be controlled to the same extent that is possible with liquid manure. The odor level would be similar to that experienced with manure piles forced by poor weather; little odor would be expected except during spreading. At spreading time, odor levels might be similar to that of liquid manure.

The efficiency and applicability of the open pit is unknown. Precipitation accumulation, insect propagation, and odor all could cause problems. Additional information is required before an economic evaluation can be made.

Slatted Floors

The use of slatted floors and subfloor storage could practically eliminate scraping of manure. These are allowed only by special permit and add substantially to the cost of a free stall barn. Little research information is available on slatted floor facilities for dairy cows in the

United States. Swedish studies conducted during the early 1960's indicate cost increases of $93 to $230 per cow if slatted floors and subfloor storage are added to free stall barns (32). Part of this increase is due to the cost of insulation. A warm barn is necessary because freezing temperatures make the slats slippery and also restrict the manure from dropping through the slats.

The labor saving attributable to a slatted floor system has been estimated (32) to be approximately 0.2 to 0.3 minute per cow per day. This does not appear to be sufficient additional saving to make a slatted floor liquid manure system a profitable investment.

Improved Manure Spreaders

For many years, most manure spreaders in the United States had basically the same design. A chain conveyor in the bottom of a box moved the material to the rear where 1 to 3 beaters did the spreading. In recent years, spreaders with other designs have been manufactured.

Probably no manure spreaders on the market today are designed for efficient handling of sloppy manure scraped directly from a free stall dairy barn. Rear-beater or flail-type spreaders, even when equipped with a gate, are not completely satisfactory. The gates do not fit tight enough and the spreader cannot be filled level full without spilling if there is any grade in the route over which the manure must be hauled. They may not spread manure of this consistency in a pattern that is acceptable on hay fields. Barrel-type, side-opening spreaders have some of the same problems: they cannot be filled level full and the spreading mechanism often does not clean sloppy manure from the bottom of the spreader at an acceptable rate. In addition, farmers report that these spreaders throw manure in such a pattern that the tractor driver gets spattered unless he is driving into a strong wind.

Spreaders that would handle manure of the consistency found in free stall barns could be designed. The same type should satisfactorily handle chicken manure from cage layer systems.

SUMMARY

Although a properly operated liquid manure system with at least 6 months' storage capacity could reduce environmental pollution by eliminating the need to spread manure in winter, a reduction in pollution will not always occur. Large quantities of manure spread in the spring just before a heavy rain could cause more stream pollution than small quantities spread daily during the entire winter. In addition, the odor created by liquid manure at spreading time is more offensive than that from daily spreading.

The investment required for a liquid manure system with 6 months' storage is large ($27,000 to $37,000 for 100 cows). Although some reduction in the labor requirement can be achieved and there is a slight increase in the manure value obtained, these savings offset only a small part of the annual costs of a liquid manure system. The annual cost of any improvement in environmental quality, and any other advantages which could be attributed to the system, is estimated to be $2300 to $3400 if a system with 6 months' capacity for a 100-cow herd is constructed. If storage with 90-day capacity is constructed, the added annual cost is $1100 to $1700.

From the nebulous nature of the environmental quality benefits generated by a liquid manure system, and the fact that these benefits tend to be social rather than private, it seems that the total return to a farm operator will rarely offset the costs incurred. Even if all costs and benefits could be internalized to the farm level, costs would usually exceed benefits.

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Received for publication Dec. 23, 1971

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