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Project Summary

A Comparison of Alternative Manure Management Systems— Effect on the Environment, Total Energy Requirement, Nutrient Conservation, and Contributions to Corn Silage Production and Economics

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This study compares alternative dairy manure management systems operated under full-scale commercial conditions. The investigation included weight of manure handled per cow per year, labor and energy requirements, effect on the environment, nutrient conservation, corn silage production and total annual operating costs.

The dairy production facility used to study alternative manure management systems was a 13.41 m x 43.89 m confinement stall barn at the Agway Farm Research Center, Tully, New York. The insulated, mechanically ventilated barn included 60 tie stalls (cows positioned tail to tail) with rubber mats and grates over the gutters. Wood sawdust and shavings were used for bedding over the rubber mats throughout the study. Application rate averaged 0.027 m^3 per cow per day, or approximately 5.9 kilograms.

Only lactating Holstein cows were housed in the barn during the four year study (average population of 47). Cows were fed a total mixed ration with corn silage the basic forage input. Average milk production per cow was 27 kilograms per day, which equates to an annual production of 9,855 kilograms.

A chain gutter cleaner was used to collect and discharge manure at the west end of the barn. To complement the study, provisions were made to handle the manure from the barn in three ways: 1) directly into a spreader for daily spreading, 2) by gravity into a liquid manure storage tank for spring application and immediate plow down, 3) by hydraulic ram to a roof-covered, above-ground manure storage area for spring and fall spreading and immediate plow down.

Results of the study show that a manure storage system can reduce annual labor requirements by 65 percent and fuel requirements by 60 percent or more, compared to daily spreading. Stored manure, applied in the spring, and promptly plowed down produced 19 to 29 percent more corn silage than daily spread manure. The study shows daily spreading of manure to be the least cost system for herds up to approximately 60 cows. A roof-covered semisolid manure storage and handling system is the lower cost system for herds above 60 cows.

This Project Summary was developed by EPA's Robert S. Kerr Environmental Research Laboratory, Ada, OK, to

announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Manure, as a by-product of milk production systems, has significant value. Each dairyman has a constant supply of this valuable source of plant nutrients, which represents a substantial recovery of feed nutrient input. Over the years, dramatic changes in dairy manure management practices have impacted on environmental quality, energy requirements, and crop production efficiency.

During the middle and late 1800s, the popular dairy barn design in the Northeast housed cows in a stable above a basement manure storage. Manure was transferred to the storage by gravity through a scuttle located at the rear of the gutter. During this period, cows were pastured in summer, housed in winter. One hectare of pasture was required to meet the summer forage needs of one cow. At this stocking rate, the manure dropped on pasture posed no serious pollution hazard in most situations. However, the full fertilizer value of the manure dropped on pasture was not realized because of poor distribution and ammonia volatilization.

Manure dropped in the barn over winter and stored in the basement below the floor lost few nutrients in cold weather, but did pose a potential pollution problem in warm weather from run-off and leaching. Odor and fly breeding were also warm weather problems. The stored manure was usually spring applied and plowed down for corn. A popular rotation was corn, spring grain, and three years in hay or improved pasture. Limestone, manure and rock phosphate would be applied to the corn in this rotation.

This manure management scheme conserved and returned most of the organic matter, phosphorus and potassium to the soil. Indeed, because most dairy farms fed some purchased grain, there probably was a modest net gain in plant nutrients to the farm. Crop yield levels, by today's standards, were marginal.

In the mid-to late-1930s, concerns about milk quality prompted more stringent sanitary regulations. Manure could not be stored in the same building with cows producing Grade A milk. The energy efficient manure gravity flow from stable to basement storage below was disallowed.

Over a thirty-year period, from the 1930s to the 1960s, many devices and systems were developed to collect manure and move it away from the barn. Generally, these systems were labor and energy intensive and most did not work well during sub-freezing weather. Following World War II, fertilizer and fuel costs remained low for twenty years. The use of manure as a fertilizer was minimal during this period. Manure became not a by-product to be used, but a waste to be disposed of. Daily spreading evolved as the most common method for disposing of manure during this period. While it is a burdensome chore, labor and energy intensive, and the most costly method of handling manure for most dairies, the practice continues on the majority of dairy farms today. Basic reasons for this include: 1) historical practice, 2) natural resistance to change, 3) mechanical capability to perform the task with large tractors and PTO spreaders, 4) low investment required, and 5) lack of sound alternatives supported by research data.

The use of animal manures as fertilizer and soil conditioners was a focus of research by the USDA and land grant colleges during the 1920s and 1930s. Following 1939, virtually no research was directed at manure management until the 1960s, when environmental concerns prompted studies of the impact of animal manures on streams, lakes, and ground water.

The handling of dairy manure is one key factor in determining dairy farm profitability. Interest, depreciation and maintenance of equipment and structures, labor input, and energy use associated with the collection, storage and distribution of manure represents a significant percentage of the total cost of milk production. There are little reliable data comparing complete manure management systems in terms of influence on the environment and total annual operating costs. This study was undertaken to meet the need for long-term research comparing alternative manure management systems over several operating seasons in terms of a number of criteria important both to commercial dairymen and to society. Costs, energy use, nutrient conservation, efficiency of nutrient utilization and influence on the environment in terms of odor, nitrates in ground water and the biological oxygen demand (BOD) and pollution of streams were measured over three years of dairy farm operation.

In terms of environmental impact, it seems clear that storing manure over winter should be preferred to the alternative of daily spreading on frozen ground. Further, it was theorized that a storage and handling system that did not involve the addition of water would overcome the more objectionable features of liquid manure handling. Such a system became feasible with the development of a hydraulic ram capable of moving manure 76 meters underground to bottom load a roof-covered containment storage.

Three manure handling systems were studied: 1) daily spreading of manure, 2) liquid manure (water added) storage and handling, and 3) semisolid (no water added) storage and handling. Five field treatments were used: 1) daily spreading of fresh manure, 2) liquid manure stored from October to April, spread in the spring and immediately plowed down, 3) semisolid manure stored from October to April, spread in the spring and immediately plowed down, 4) semisolid manure stored from April to October, spread in the fall and immediately plowed down, 5) inorganic fertilizer spring applied and immediately plowed down as a control. The alternative systems were compared in terms of 1) influence on the environment and 2) total annual operating costs.

Conclusions

The following conclusions are drawn from this research investigation comparing alternative manure management systems in terms of weight of manure handled per cow per year, labor and energy requirements, odor control, nutrient conservation through storage, effect on the environment, corn silage production, and operating costs.

Weight of Manure Handled Per Cow Per Year

Decreasing the weight of manure to haul offers the potential of decreasing labor, energy, and machine use requirements. Further, soil compaction will be reduced by reducing the weight of each load and/or the number of loads hauled over the field. Weight of manure handled per cow per year is influenced by several factors including: breed and size of cow, stage of lactation, level of production, feeding program, bedding used, water added, and drying which may occur in storage.

Only lactating Holstein cows were used in this study. Milk production averaged 27 kilograms per cow per day. Manure production averaged 54.3 kilograms per cow per day including 5.9 kilograms of dry sawdust and shavings. Average dry matter of the manure including the bedding was 17.3 percent.

With daily hauling and spreading, 19.82 M tons of manure were handled per cow per year. Handling the manure as a liquid required the addition of water to create a 14 percent dry matter slurry resulting in 24.5 M tons of manure handled per cow per year. Had water been added to create a 10 percent dry matter slurry, 34.29 M tons of manure would have been handled per cow per year. Handling the manure as a semisolid through a roof-covered manure storage allowed natural drying and a reduction in weight of 8.9 percent resulting in 18.06 M tons of manure handled per cow per year.

Labor and Energy Requirements

Daily spreading of manure is a labor and energy intensive operation compared to using a six-month storage system. Based on a 100 cow lactating herd and a round-trip haul of 2.4 kilometers, a storage system can reduce annual labor requirements by 65 percent and fuel requirements by 60 percent or more compared to daily spreading.

Nutrient Conservation Through Storage

Agitating manure to create a pumpable slurry in a liquid manure storage is a primary cause of nitrogen loss through volatilization of ammonia gas. Bucket loading of semisolid manure does not create the same conditions. Average nutrient loss through the liquid manure storage and unloading was 10.3 percent nitrogen, 9.1 percent P_2O_5 and 7.9 percent K_2O. Considerable agitation was required to handle the high solids manure which probably contributed to the nutrient loss, particularly of the nitrogen. Average nutrient loss through the semisolid manure storage and unloading was 4.6 percent nitrogen, 6.4 percent P_2O_5 ad 6.7 percent K_2O.

Environmental Impact

Animal manures impact the environment in a number of ways. Clearly, there are positive benefits to the integration of manure organic matter and soil. However, poorly designed and/or managed systems can cause a negative impact. A key objective of this investigation was to measure and document the impact of the manure management systems studied on the environment. Concentrations of nutrients (nitrogen, phosphorus and potassium) and coliform bacteria were measured in the stream water adjacent to the treatment field, run-off water from the fields and percolation water. Odor was measured by a panel made up of equal numbers of farm and non-farm persons.

Stream Water

The concentration of nitrogen, phosphorus, and potassium in stream water appeared related to the stream flow rate. The highest concentrations were measured in late summer when stream flow is minimal. At no time during the study did stream water levels of ammonium or nitrate nitrogen exceed the maximum limits considered safe for potable water (0.5 mg/l NH_3 and 10 mg/l NO_3).

Coliform counts in stream water collected downstream from the experimental site never exceeded those of samples taken upstream from the site. Thus, it seems safe to conclude that the performance of this experiment had no adverse effect on the stream water. The site is well suited to continuing studies of the environmental impact of crop management practices.

Run-off Water

Run-off water provides the best single measure of the influence of the treatments studied on the environment. The treatments can be listed in declining order of merit (from least run off to most run off) as follows: semisolid spring, liquid spring, daily spread, semisolid fall, inorganic fertilizer. These findings are in agreement with reports that the organic matter in manure has a profound effect on reducing run off and subsequent loss of soil. Of the twelve storms resulting in measurable run off, one occurred in July, three in August, six in September, and two in October. Since it is known that organic matter in the soil diminishes over time and that manure organic matter reduces run off, then it is logical to expect that the soils to which manure was spring applied and plowed would have the highest manure organic content and least run off while those to which manure had been applied earlier or not at all would have the lowest manure organic matter content and greatest run off.

Percolation Loss of Nutrients

It was observed that the highest concentration of nitrate nitrogen in percolation water occurred shortly after the application and incorporation of each treatment. All treatments contributed levels of ammonium and nitrate nitrogen to percolation water in excess of established safe limits for drinking water (0.5 mg/l NH_3 and 10 mg/l NO_3). There is reason to believe that in most situations these concentrations will be reduced to safe levels as a result of plant and microorganism uptake, soil retention and dilution by the time the percolate reaches the ground water table.

Odor Control

Common sense management in handling and spreading manure can minimize the odor impact on the environment. Manure storages loaded through the bottom usually form a crust over the top during warm weather and a frozen top layer during cold weather. These conditions prevent the release of any significant odors during the storage period. Odors are released from manure during the loading and spreading operations. Reducing the amount of agitation of liquid manure at the storage will lower the odor level. Loading semisolid manure with a bucket loader disturbs the manure only slightly, thus minimizing odor release. Field spreading for uniform coverage breaks up the manure, thus increasing the release of odor. Early incorporation of the manure into the soil by harrow or plow will control the duration of odor release. Same day incorporation of manure into the soil is not practical with a daily spreading system.

Contribution To Corn Silage Production

The relative efficiency of the several manure management systems is compared in the most meaningful way to dairy farmers in Table 1.

Here, the corn silage produced by 3,472 kilograms per hectare of manure dry matter or 129 kilograms per hectare of inorganic fertilizer nitrogen is recorded.

Table 1. *Effect of Treatment on the Yield of 32% Dry Matter Corn Silage Three Year Average 1977-79*

Treatment	*Yield, Metric Tons/Hectare*
Spring applied liquid	*35.13*
Spring applied semisolid	*38.20*
Fall applied semisolid	*31.92*
Daily spread	*29.60*
Spring applied inorganic fertilizer	*41.90*

On average, over the three years of the study, the five treatments can be listed in declining order of merit (from most efficient to least efficient): spring applied inorganic fertilizer, spring applied semisolid manure, spring applied liquid manure, fall applied semisolid manure and daily spread manure.

Daily spreading of dairy manure remains the most common practice in the Northeast. Assigning a value of 100 to daily spread it is possible to calculate the relative value of the other manure management systems as shown in Table 2.

On this basis, storing manure, applying it in the spring, and promptly plowing was 19 to 29 percent better than daily spreading. Storing manure in the semisolid form (without added water) was 9 percent more efficient than a liquid storage system to which water is added.

Semisolid manure was applied in both spring and fall treatments. The fall application was consistently inferior to spring applications, producing just 84% as much corn silage when averaged over the three years of the study. However, the fall application of stored semisolid manure produced more corn silage than the daily spread treatment.

Chemical Analysis of Corn Silage

Both the nitrogen and the phosphorus content of corn silage showed a positive linear relationship to yield (R = .77 and R = .65 respectively). This supports the use of corn silage yield as a reliable and practical measure of the economic impact of manure management systems compared in terms of nutrient utilization efficiency when the rate of application is less than that needed to produce the highest yield the growing season will support.

Annual Operating Costs and Returns

A key focus in this study was analyzing annual costs and returns of the three manure management systems used, based on actual performance data generated through the conduct of the project.

Annual costs are partitioned between fixed costs for *equipment and facilities* and operational costs for *labor, electrical and tractor use costs.* Generally, as fixed costs increase operational costs decrease, which underscores the importance of analyzing *total* annual costs when comparing systems. While tax implications have a significant effect on annual costs, favoring systems with higher fixed costs, no attempt was made to factor them in. The actual effect of investment tax and depreciation tax credits on annual operating costs will vary widely from farm to farm, depending on the overall profitability of the farm enterprise.

Table 2. *Relative Efficiency of Three Manure Management Systems Compared to Daily Spread, 1977-79*

Treatment	*Yield of 32% DM Corn Silage, metric tons/hectare*	*Relative Efficiency Compared to Daily Spread, percent*
Daily spread	*29.60*	*100*
Spring applied liquid	*35.13*	*119*
Spring applied semisolid	*38.20*	*129*
Fall applied semisolid	*31.92*	*108*

An economic life was established for each piece of equipment and structure based on experience at the Agway Farm Research Center and generally accepted practice. The depreciation term and/or loan term was considered to be the same as the economic life. Residual value of all equipment and structures was assumed to be zero.

Investment costs are fall 1982 costs of equipment and structures delivered and installed in central New York. Interest rates of 14% and 12% were established for equipment and structures, respectively. Annual level payments for principal and interest were calculated using Comprehensive Mortgage Payment Tables published by Financial Publishing Company, Boston, Massachusetts.

Gutter cleaners, pumps, rams, spreaders and storages were totally assigned to the respective manure management system investment costs. Tractors were not treated as part of the system investment because only a fraction of their annual operating hours are required for manure handling. An hourly use cost, including fuel, was determined for tractors required for each system. This cost remains constant when calcuated on a kw hour basis. A cost of $0.221 per kwH was used for all systems.

Annual costs for insurance and taxes were taken at 1.5% of the original investment. Annual costs for repairs were taken as a percent of original investment and varied from 2% to 10% based on generally accepted practice.

A labor rate of $5 per hour was established for all labor functions. Electrical costs were calculated for each motor, using recorded kilowatt draw and annual hours used. An electrical rate of 6¢/kilowatt hour was applied.

Table 3 compares in summary the fixed, operating, total and per cow costs of handling daily manure with three different manure management systems. Cost data are presented for three herd sizes to show the effect of herd size on per cow cost of handling manure. Table 4 summarizes the potential annual improvement to farm enterprise profit with a manure storage system considering fertilizer nutrient recovery as measured by crop yield in this study.

Table 3. *Summary of Total Annual Costs for Three Manure Management Systems and Three Herd Sizes*

	Annual Costs			
Type of System	*Fixed*	*Operating*	*Total*	*Per Cow*
Daily spreading of manure from barn				
50 cows	*$ 5,867*	*$ 4,680*	*$10,547*	*$211*
100 cows	*7,915*	*9,099*	*17,014*	*170*
150 cows	*9,576*	*14,578*	*24,154*	*161*
Handling liquid manure through an above-ground tub silo storage				
50 cows	*12,814*	*2,131*	*14,945*	*299*
100 cows	*16,257*	*3,790*	*20,047*	*200*
150 cows	*20,183*	*5,476*	*25,659*	*171*
Handling semisolid manure through a roof-covered storage				
50 cows	*10,337*	*1,652*	*11,989*	*240*
100 cows	*12,083*	*3,107*	*15,190*	*152*
150 cows	*14,762*	*4,618*	*19,380*	*129*

Table 4. *Potential Annual Improvement to Farm Enterprise Profit with a Manure Storage System*

Type of System	Per Cow: Total Fixed & Operating Costs	Fertilizer Nutrient Recovery	Net Costs	Profit Gain or Loss Over Daily Spreading
Daily spreading of manure from barn				
50 cows	*$211*	*$ 68*	*$ 143*	—
100 cows	*170*	*68*	*102*	—
150 cows	*161*	*68*	*93*	—
Handling liquid manure through 6 months tub silo storage				
50 cows	*299*	*81*	*218*	*-75*
100 cows	*200*	*81*	*119*	*-17*
150 cows	*171*	*81*	*90*	*3*
Handling semisolid manure through 6 months roof-covered storage				
50 cows	*240*	*88*	*152*	*-9*
100 cows	*152*	*88*	*64*	*38*
150 cows	*129*	*88*	*41*	*52*

The study shows daily spreading of manure as the least cost system for herds up to approximately 60 cows. A roof-covered semisolid manure storage and handling system is the lower cost system for herds above 60 cows. A liquid manure storage and handling system will improve profit potential over a daily spreading system with herds above 150 cows, but is not as cost effective as semisolid manure handling. Calculating annual costs of manure handling systems can be done with a high degree of reliability if performance data and investment data are at hand. Projecting the dollar return through nutrient recovery as crop fertilizer is subjective. Variations in existing soil fertility, soil type, rate of manure application, crops grown and climatic conditions are some of the factors which will influence actual dollar return through fertilizer nutrient recovery. In this study, nutrient recovery from each manure handling system as measured by corn silage yield can be listed in declining order of merit as follows: 1) semisolid manure storage and handling, 2) liquid manure storage and handling, 3) daily spreading.

Recommendations

1. Manure from dairy production facilities should be stored in containment structures, loaded from the bottom, unloaded and field spread when field and environmental conditions are favorable and incorporated into the soil the day of application. This management practice will have a net favorable impact on the environment.
2. Dairy manure should be handled as a semisolid (as produced manure with no water added) through a roof-covered storage to attain least cost operation and minimum soil compaction.
3. Transfer manure into the bottom of storages to minimize odors, nutrient loss, freezing and fly problems during the storage period.
4. Agitation of liquid manure (as produced manure with water added) should occur below the surface of the stored manure to decrease release of objectionable odors and nitrogen loss through volatilization of ammonia gas.
5. Further work is recommended on:
   a. developing practical equipment to bottom load storages, which will minimize stratification of manure in storage,
   b. methods of unloading manure storages, which will reduce release of odors and nutrient loss, and
   c. design of lower cost containment manure storages, particularly for small herds.

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The complete report, entitled "A Comparison of Alternative Manure Management Systems—Effect on the Environment, Total Energy Requirement, Nutrient Conservation, and Contributions to Corn Silage Production and Economics," (Order No. PB 83-258 765; Cost: $16.00, subject to change) will be available only from:

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