Chapter 5

Management of Dairy Cattle Manure

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Methods of collection, storage, and use of dairy cattle manure have undergone increased scrutiny during the last 15 to 20 yr. This is in response to local increases in manure quantities (from increases in herd size) and to heightened environmental awareness concerning adverse effects of manure on the quality of surface water and groundwater. Dairy cattle manure contains significant amounts of the primary nutrients (N, P, and K) as well as other essential plant nutrients and hence is an excellent nutrient source for crop growth. However, if excess amounts of manure are applied beyond the use capacity of the crops and soil or if manure is improperly applied, losses by surface runoff and leaching can contribute to eutrophication of surface water bodies or contamination of groundwater.

The primary issue with dairy cattle manure, both now and for the future, is development of management systems that use the resource without adverse environmental impacts. In a number of regions, the amount of dairy cattle manure produced exceeds loading capacity of soils available for manure application. Regulations have been passed in a number of states to protect surface water and groundwater quality from the impact of manure, but similar emphasis has not been placed on cropping systems to make efficient use of the material. More scientific research is needed to gain better information on cropping systems, manure application rates, and fermentation systems for producing methane gas so that manure is used wisely. Additional extension materials and other means are needed to inform cattle producers of best procedures for handling and using manure.

Methods of collection, storage, and disposal of dairy cattle manure have received increased scrutiny during the last two decades (Morgan and Keller 1987). The total number of milk cows and heifers calved in the United States has decreased from 11.2 million in 1975 to 10.2 million in 1991, while average milking-herd size increased from 75.7 to 103.8 cows/herd during these years (U.S. Department of Agriculture 1990, 1993). In 1991, 66 percent of the total cows were in the top 10 dairy states and 50 percent were located in 5 states (Wisconsin, California, New York, Minnesota, and Pennsylvania) (U.S. Department of Agriculture 1993). Over the last 10 yr, the top-10 states have remained relatively constant in ranking, although Michigan, Ohio, and Iowa dropped one place with the move of Texas from ninth to sixth and Missouri was replaced by Washington as the state with the tenth most cows. Large dairies (those having in excess of 1,000 head of cattle) account for a larger percentage of the cows in the South, Southwest, and Far Western states than in the Northeast and Midwest (Newton, personal communication 1995).

As dairy farm size has increased, so has the quantity of dairy cattle manure handled per dairy farm (Morgan and Keller 1987). The increased manure production plus heightened environmental awareness of associated soil and water quality problems has exacerbated the need for management systems that can use the biomass and nutrients in the manure without creating unacceptable air, soil, or water pollution. Problems with excess quantities of manure, however, are not limited to large dairy farms. States such as Wisconsin and Pennsylvania have many smaller dairies, but many of these small dairies produce more manure than they can handle. Regardless of dairy size, when the land use area is insufficient to handle the quantity of manure, problems with manure disposal occur.

Modern dairy management includes a proper balance of feed components so that milk is produced as economically as possible while the health and vitality of the animals are maintained. Nutrients are supplied through feed derived from pasture, hay, silage, and grains. Pasturing is done on either legumes or grasses, with grazing being the oldest and most common method. “Green chopping” or hauling the pasture to the cows is sometimes practiced. Forages used for green chopping may include any crop normally used for pasture or to make hay or silage.

Hay fed to dairy cattle may be made from legumes, grasses, or mixtures of the two. Many dairy farmers consider legume hay to be essential because it provides large amounts of high-quality proteins and calcium along with liberal quantities of vitamins A and D (Coletti 1963). Alfalfa is the most popular legume hay, while red, alsike, and crimson clover are also excellent sources of roughage for dairy cows. Hay made from grasses is generally inferior to legume hay (Coletti 1963).

Silages are used extensively as feed for dairy cattle. They provide succulent feed during the winter months when cows are restricted to dry roughage, make possible the utilization of the entire plant without much loss during bad weather, and can be used as a source of reserve feed during the summer months. The primary silage crop is corn, although acceptable silage can be made with sorghum. Silage also can be made from alfalfa, various clovers, soybeans, pasture mixtures, and oats or other small grains.

Dairy cattle often spend portions of their time in pasture areas, feeding and lounging barns, and milking parlors. From an environmental standpoint, manure dropped in any of these locations may be of concern. However, unless too many cattle are pastured per area of land or unless cattle are allowed free access to streams, lakes, or ponds, manure dropped in pasture areas may be of less environmental concern than that in barns and milking areas. Manure dropped by cattle while in the feeding and lounging barns and milking parlor is in effect a point source of nutrients that must be used. Point sources of pollution include such things as chemical spills, septic tanks, and so forth, and the manure dropped in barns and parlors is a point source in the sense that the land area where it is dropped does not have the capacity to filter the load. Water added from cleaning of tanks or utensils in the milkhouse also contributes to the total amount of manure load.

Dairy cattle manure is a complex material containing feces, urine, bedding, rain or other water, and milkhouse or washing wastes (Midwest Plan Service 1975a). This material contains all of the macronutrients needed for crop growth and has particularly high amounts of nitrogen (N), phosphorus (P), potassium (K), and calcium (Ca). In addition to its nutrient value, application of dairy cattle manure to cropland is known to improve soil organic matter and tilth (Klausner et al. 1974, Christensen et al. 1981).

Surface runoff from dairy feedlots and holding areas has high potential to cause water pollution. Also, mismanagement in the land application of dairy cattle manure has been documented as a cause of water pollution. Both P and N contained in the manure may contribute to eutrophication of surface water bodies. Dairies are often located in regions where land accessibility for manure application is restricted during large portions of the year due to cropping patterns and climate. Therefore, the land application rate of animal manure or liquid from lagoons or holding ponds may often be greater than normally recommended for meeting crop nutrient requirements. Odor from lagoons, holding ponds, or surface application of manure is also an environmental concern.

Proper management of dairy cattle manure involves integrating dairy herd size, available land, topography, climate, soil type, and financial resources to determine the best system. Alternative uses for manure besides land application include composting, refeeding, and production of methane gas via anaerobic fermentation. Overall, dairy operations throughout the United States ideally should use the nutrients and organic matter from the manure to reduce fertilizer and energy costs, while at the same time using treatment systems that do not have negative effects on air quality, surface water bodies, or groundwater quality.

Manure Production and Composition

Because dairy cattle normally spend a large portion of their time in the feeding and lounging barn, milking parlor, and pasture areas, they deposit a large portion of their manure in those areas (Westerman and Overcash 1980). Manure dropped in pasture areas may or may not be of environmental concern, depending on herd size, pasture area and location, and amount of time the animals spend in the area. The major source area for dairy cattle manure, which must be handled, stored, and treated or used, is the building complex containing the feeding barn, lounging barn, and milking parlor.

The daily manure production (feces and urine) per 454 kg of body weight for Holstein cows is approximately 34 kg, of which about 70 percent, or 24 kg, is solids, and 30 percent, or 10 kg, is liquid (North Carolina Agricultural Extension Service 1973). On this basis, the daily manure production of a mature Holstein cow weighing 636 kg is about 48 kg. The properties of dairy cattle manure depend on several factors, including the digestibility and protein and fiber contents of the feed, and the animal's age, environment, and productivity. Table 18 shows estimates of daily manure production and manure properties for a range of animal sizes. Other sources of information on the properties of raw or liquid dairy manure include Information Services, Agriculture Canada (1979), Ghaley et al. (1986), and Van Horn (1990).

When estimates of annual per animal dairy cattle manure production (from Van Dyne and Gilbertson

Table 18. Dairy cattle manure production and characteristics. Values are approximate. The actual characteristics of a manure can easily have values 20 percent or more above or below the table values. The volume of waste that a waste-handling system has to handle can be much larger than the table values due to the addition of water, bedding, and so forth.

Animal size	Total manure production		Water	Density*	TS†	VS‡	BOD_5§	Nutrient content (kg day^{-1})		
(kg)	(kg day^{-1})	(L day^{-1})	(%)	(kg m^{-3})	(kg day^{-1})	(kg day^{-1})	(kg day^{-1})	N	P	K
68	5.9	6.0	87.3	994	0.8	0.7	0.12	0.03	0.006	0.019
114	10.0	9.8	—	—	1.4	1.1	0.20	0.04	0.008	0.034
227	19.5	19.6	—	—	2.7	2.3	0.39	0.10	0.018	0.064
454	39.0	39.3	—	—	5.4	4.5	0.77	0.19	0.034	0.128
636	54.5	54.8	—	—	7.6	6.4	1.08	0.27	0.048	0.181

* Density = best estimate, not ASAE data.
† TS = total solids.
‡ VS = volatile solids.
§ BOD_5 = the oxygen used in the biochemical oxidation of organic matter in 5 days at 68 °F. A standard test to assess wastewater strength.

Source: Midwest Plan Service (1993).

1978) were multiplied by the number of milk cows and heifers that calved in 1991 (10.2 million), the estimated national annual dry weight of manure produced was calculated to be 2.2×10^7 Mg. The estimated nutrient content of this material was 7.1×10^5 Mg N, 1.2×10^5 Mg P, and 5.7×10^5 Mg K (Van Dyne and Gilbertson 1978). After losses during storage, transport, and application, the economically recoverable amounts of these nutrients can be estimated as 4.2×10^5 Mg N, 1.0×10^5 Mg P, and 4.9×10^5 Mg K (Van Dyne and Gilbertson 1978).

The actual composition of any particular batch of dairy cattle manure as removed from the milking parlor, feeding, or lounging areas depends on the amount of moisture, the amount of bedding material present, and the rations fed. Bedding incorporated into the manure increases the total solids content, while water added during washing dilutes the material.

Manure Management Systems

Handling of manure

Dairy cattle are housed in buildings and secured using either stanchions or free-stalls. Stanchions limit the forward and backward movement of cattle. Manure from stanchion barns is allowed to collect in gutters where it is manually or mechanically scraped and stacked in storage areas until it can be hauled to fields for spreading and use (Merkel 1981). Farmers with stanchion barns generally use bedding such as sawdust, straw, or wood shavings for the animals. Manual or mechanical scraping of the manure from the rear of the stall or the main alley into a collection gutter is generally done daily.

Characteristics of stacked stanchion barn manure depend upon the length of storage, environmental conditions, and the type and amount of bedding used. Average values for stacked and stored dairy cattle manure are 50 kg day^{-1} animal^{-1} produced with 4,100 to 6,900 mg L^{-1} total N, 700 to 2,500 mg L^{-1} NH_3, and 3,800 to 6,900 mg L^{-1} P (Cramer et al. 1971). Liquid wastes seeping from the stacked manure average 4.5 to 11.0 L day^{-1} cow^{-1}, with 1,200 to 2,900 mg L^{-1} total N, 780 to 2,200 mg L^{-1} NH_3, and 64 to 500 mg L^{-1} P.

Manure produced by dairy cows housed in free-stall barns can be scraped by a front-end loader and stacked in a storage area for later use. In many of the newer setups, the manure is flushed by large volumes of water discharged a few times a day (Merkel 1981). The liquid waste from the flushing aisle is generally discharged to a series of lagoons for treatment. Effluent from the lagoon may be used as the flush water.

Manure collected by either scraping or flushing generally goes to a storage area. In some systems manure is immediately spread on land without storage, but this is not appealing to many dairy farmers primarily because of frequency of disposal. Transport of manure from the storage areas is dependent on the flow characteristics of the material. Dairy cattle manure can be classified as semisolid, semiliquid, or liquid (Sobel 1966). Semisolid manure will not flow with perceptible movement unless given mechanical assistance. Most fresh manure is in this category and, unless flushed, must be manually or mechanically transported. Semiliquid manure is material that has undergone dilution. This type of manure will slowly flow without mechanical assistance and contains between 5 and 15 percent total solids (Merkel 1981). Liquid manure generally contains less than 5 percent total solids (wet basis), flows freely without mechanical assistance, and is associated with feedlot runoff and effluents from milking parlors and treatment systems.

Dairy cattle manure in a solid or semisolid state can be transported mechanically by means of front-end loaders, conveyors, augers, or piston pumps. Hydraulic transport is generally used for handling liquid manure. Considerable information is available on the flow principles involved in hydraulic transport of liquid manure and on designing systems for moving the material via open channels or pipes to an initial storage facility (Merkel 1981, Midwest Plan Service 1985).

Alternative management systems for the manure from the initial storage facility include spreading in solid form, spreading in liquid form, immediate irrigation, and lagooning and irrigation. Storage and spreading in solid form usually involves short-term storage between the time of collection and land spreading. Land spreading in the liquid form has two major disadvantages: (1) cost of the system, and (2) odors associated with agitating and field spreading partially decomposed manure. Systems that use liquid from the initial storage area for irrigation also have the disadvantage of short-term storage availability, and hence wastes must be applied daily by irrigation regardless of weather conditions. Irrigation systems from lagoons allow for long-term storage and treatment of the waste prior to land application.

Disposal systems for liquid manure require separation of the liquid and solids fractions. Separation of settleable or suspended solids from liquid may be accomplished by gravity or employing mechanical devices. Gravitational separation includes sedimentation and flotation using tanks or lagoons; mechanical devices include liquid cyclones and screens. Use of screens is attractive to dairy operators for the following three reasons (Moore et al. 1975): (1) they reduce plugging of liquid handling equipment such as pumps, piping, and sprinkler nozzles, (2) they reduce biological loading on successive treatment components, such as anaerobic and aerobic lagoons, and (3) the solids removed by the screens can be recycled for bedding or feed. Hay, hayledge, silage, or other fibrous material removed from the manure by separator can be used as bedding material (Fairbank et al. 1975). Use of solids for bedding may negatively affect herd health (causing mastitis) and hence has had limited acceptance (Newton, personal communication 1992). The fiber is generally composted to reduce the level of mastitis-causing organisms in the bedding.

After liquids and solids from the manure are separated, the liquid portion is commonly transported to stabilization ponds (lagoons). In these ponds beneficial organisms stabilize the material so that it can be spread on the land or used as flush water for a recycle cleaning system.

Stabilization ponds can be classified according to the mode of degradation: aerobic, facultative, or anaerobic. Aerobic lagoons are aerated so that organic matter is oxidized by bacteria supported by free molecular oxygen. Aeration is most commonly supplied by mechanical aerators that provide sufficient agitation to ensure complete mixing.

Facultative lagoons provide an aquatic environment in which photosynthesis and surface oxygenation supply an aerobic zone in the upper strata. Two other zones exist below the aerobic zone—a facultative zone throughout the central portion and an anaerobic sludge layer at the bottom. The heavier suspended solids (including biologically formed floc) settle on the bottom and undergo anaerobic decomposition. Many lagoons used for treatment of dairy cattle manure were originally classified as aerobic, yet, in fact, they were truly facultative (Merkel 1981).

Anaerobic lagoons are stabilization ponds that can degrade organic matter in the absence of free molecular oxygen. Under anaerobic conditions, the microbial population derives its energy for cell synthesis by reducing oxidized compounds such as NO_3, SO_4, and carbohydrates. Reduction of NO_3 under anaerobic conditions is called denitrification, and considerable N may be lost by this process. For denitrification to occur in anaerobic lagoons the treatment system must have components where NH_4 is oxidized to NO_3 prior to entering the lagoon. Both facultative and anaerobic bacteria are present in anaerobic lagoons. When dairies have two lagoons, the first one generally is anaerobic and also serves as a settling basin, and the second one is facultative or aerobic using a mechanical aerator.

Nutrient losses during storage

Proper management of dairy cattle manure requires conservation of N for later use. Knowing where losses can occur is imperative to conserving N. High levels of NH_3 in freestall dairy barns have been measured, suggesting that manure in such barns might lose substantial quantities of N (Miner et al. 1975). The N is lost through hydrolysis of urea in the urine to NH_3, which is then easily lost by volatilization (Salter and Schollenberger 1939). Work by Muck and Steenhuis (1981) indicates that when barn temperature is greater than 20 °C and barn alleys are scraped only once a day, 80 percent of the urea N (which is approximately 40 percent of the total N in the manure) is lost by volatilization. The greatest N loss probably occurs on the barn floor from the time dairy manure is produced until the time it is spread (Muck and Herndon 1985).

Manure can be stored for months in bottom-loaded storage houses or tanks, and N losses will amount to less than 10 percent (Safley 1980, Muck et al. 1984). Nitrogen losses from anaerobic lagoons and storage have been studied by several investigators (Willrich 1966; Smith et al. 1971; Jones et al. 1973; Koelliker and Miner 1973; Booram et al. 1975; Safley 1980, 1981; Safley and Westerman 1981). However, the wide range of results reported makes it difficult to compare one storage design with another. Bottom-loaded manure storage, because of its crust, is generally believed to conserve N better than top-loaded storage (Muck and Steenhuis 1981).

The Midwest Plan Service (1993) gives estimates of typical N losses between excretion and land application as adjusted for dilution based on the waste handling system. For systems handling solid manure, estimated N losses for daily scrape and haul, manure pack, or open lot are 20 to 35, 20 to 40, and 40 to 55 percent, respectively. Estimates of N losses during land application based on application method are 15 to 30 percent for liquid broadcast, 1 to 5 percent for both solid and liquid broadcast with immediate cultivation, 0 to 2 percent for knifing of liquid, and 15 to 40 percent for sprinkler irrigation of liquid.

Proper management of dairy cattle manure also requires an understanding of where P and K losses occur during handling and storage. Phosphorus and K losses during storage are considered negligible except for those from open lots or lagoons (Midwest Plan Service 1993). In open lots about 20 to 40 percent of the P and 30 to 50 percent of the K can be lost by runoff and leaching. However, much of this P and K can be recovered by runoff control systems such as settling basins and holding ponds. Up to 80 percent of the P in lagoons can accumulate in bottom sludges and hence is lost as a nutrient supply unless the sludge is removed from the lagoons and applied to land.

Land Application of Manure

Land application of animal manure has been practiced for centuries in the temperate zones. The practice developed partly because there was no other place to put the material but also because of the agronomic benefits. Application methods for dairy cattle manure depend on the fluidity of the material. Liquid manure containing less than 5 percent solids can be handled by most irrigation systems (Midwest Plan Service 1975b). This level of solids is typical of that found in feedlot runoff or effluents from a lagoon system or milkhouse. The type of irrigation system selected depends upon topography, soil type, and cropping practice. Disadvantages of irrigation include a high initial investment, high operating costs for pumping, the necessity for good management to avoid runoff or groundwater pollution, high labor demand with low-cost irrigation equipment, odor problems, and NH_3 loss by volatilization.

Liquid manure with 4 percent solids or less can also be applied to land via irrigation known as surface spreading. Material from pipeline systems can be spread by gravity using open ditches, flat irrigation tubing, or gated pipe (pipe with openings at set distances apart). Types of surface irrigation for dairy cattle manure in the surface spreading category include border irrigation, furrow irrigation, corrugations, and wild flooding. In all cases the material should not be applied to a wet area. The system also should be shut off before water reaches the low end of the field to eliminate runoff. Of the four types of land spreading systems for dairy cattle manure, wild flooding has the most uneven water distribution (Midwest Plan Service 1975b).

Semisolid dairy cattle manure, or slurries, have 4 to 15 percent solids and can be applied using manure guns or tank wagons. Large-bore irrigation nozzles can handle heavy slurries (up to 15 percent solids) as well as liquid materials with low solids content. These large sprinklers generally have a capacity of 23 to 91 $m^3\ hr^{-1}$ and can cover from 0.2 to 0.8 ha (Midwest Plan Service 1975b). Tank wagons are available for transporting fluid slurries and have capacities ranging from about 1.6 to 11.3 m^3. Slurries must be agitated in the storage tank before they can be satisfactorily pumped into tankers. Tank wagons may either apply manure to the soil surface or inject the manure into the soil with chisel-type injector shanks or moldboard plow attachments. Injection is desirable both for conserving nutrients and to reduce odor problems.

Manure with 20 percent or more solids is generally handled as a solid. Most solid manure spreaders are box type, although open-tank spreaders are available. Ideally, manure should be distributed evenly to the land, but the effectiveness of this distribution depends on the characteristics of the material being spread.

Proper land application of dairy cattle manure should include crediting of the fertilizer value of the material. Manure management system designs are generally based on N excretion loads for a dairy and accepted land application rates for N. Application rates are based on N rather than P for two reasons: (1) the total N content of manure is higher than the total P content and (2) P tends to bind to soil particles (except on very sandy soils) and hence is primarily of environmental concern only if erosion occurs, whereas N is less likely to bind and is therefore more likely to contaminate groundwater.

The most effective method for gauging the nutrient content of a manure is to have samples analyzed by a commercial or university laboratory. Large farm-to-farm variation can occur in nutrient content due to storage, handling, livestock feed, or other farm management differences. Several investigators (Good et al. 1991, Bundy et al. 1992, Wolkowski 1992) have developed methods for calculating the total nutrient contribution of manure, which is derived by multiplying the amount applied by the nutrient content from standard tables. The Midwest Plan Service (1993) gives the approximate fertilizer values for N, P, and K in solid dairy manure as 4.5 g kg^{-1}, 0.7 g kg^{-1}, and 2.5 g kg^{-1}, respectively. For liquid pit manure, the approximate fertilizer values for N, P, and K are 3.7 g L^{-1}, 0.7 g L^{-1}, and 1.9 g L^{-1}, respectively. The approximate values for N, P, and K in lagooned dairy manure are 0.5 g L^{-1}, 0.1 g L^{-1}, and 0.4 g L^{-1}, respectively (Midwest Plan Service 1993).

The nutrients contained in dairy cattle manure (other than those in lagoon effluent) are not immediately available to crops but are released over time. The rate of release depends upon the amount of organic matter applied along with nutrient content, climate, and soil type. Wolkowski (1992) indicates that the N credit increases each successive year of application (up to 3 consecutive years) by approximately 30 percent. The Midwest Plan Service (1993) indicates that organic N released by mineralization during the second, third, and fourth cropping years after initial application is usually about 50 percent, 25 percent, and 12.5 percent, respectively, of that mineralized during the first cropping season. Their worksheet requires calculation of the residual N released by mineralization from previous years as part of the overall N budget. In warm, humid locations with well-aerated, sandy soils, mineralization is rapid and essentially complete in 1 year. However, when manure is applied to grain crops at planting, the availability of N from mineralization does not correspond to plant needs over the season. In contrast to N availability, nearly all of the P and K in manure is available for plant use during the year of application. After a few years of regular waste applications, the amounts of P and K available are about the same as they were after 1 year of application (Midwest Plan Service 1993).

Worksheets provided in Midwest Plan Service (1993) for crediting nutrients in dairy cattle manure provide instructions for calculating the nutrient requirements of the crop and then determining the amount of land necessary to use all of the available waste. Applying enough manure to meet N requirements more than adequately meets crop needs for P and K (Midwest Plan Service 1993). Over time this may cause high accumulation of P, K, and salt in the soil. The economic value of manure fertilizer can be calculated from its available N, P, and K and determining the equivalent commercial fertilizer prices. The equivalent values will change over time as the costs of commercial fertilizer and handling practices change.

One concern with manure applications is soil salinity. Heavy manure applications can increase soil salinity, especially in arid regions where little or no leaching occurs. Salts can inhibit plant growth and depress yields. Sodium and K can alter soil structure and reduce water movement rates. Use of heavy manure wagons can also affect yields by compacting wet soils.

Alternative Uses Of Dairy Manure

In the past few years biogas generation from animal manure has received more attention. Methane production from livestock manure has been shown to be an easily established fermentation process (Stafford et al. 1980, Van Brakel 1980). One-third of the total energy content is released in the form of methane (Sobel and Muck 1983). Hashimoto et al. (1979) and Hill (1982) report that although dairy cattle manure is less readily biodegradable than beef, poultry, or swine manure, the potential for methane production and the benefits of its use on dairy farms are substantial. One problem with using dairy cattle manure for methane production is the large fraction of settleable and floating solids, causing difficulties in pumping the liquified manure as well as accumulation of solids in the base of the reactor vessel (Ecotope Group 1977, Bartlett et al. 1977, 1980; Abeles et al. 1978).

Anaerobic digesters have been successfully used to produce methane in the psychrophilic (below 20 °C) (Lo and Liao 1986), mesophilic (30 to 40 °C) (Lo et al. 1984, 1986; Erdman 1985; Summers et al. 1987), and thermophilic (50 to 60 °C) (Wohlt et al. 1990) temperature ranges. Major concerns about using dairy cattle manure to produce methane include (1) the necessity for and difficulty of mixing, (2) the current lack of process controls for daily operation that are needed to minimize management time and provide the operator with sufficient warning of impending biological upset, (3) the impracticality of long-term methane storage, and (4) the effects of antibiotics in the manure on methane production (Midwest Plan Service 1982). The land area needed for using dairy manure nutrients is not reduced by digester systems because the total amounts of N and P remain in the digester effluent.

Two other alternative uses for dairy cattle manure are composting and refeeding. Composting is a process in which the volatile solids are digested by aerobic microorganisms. Because the process is aerobic, it is relatively free of offensive odors. Dairy cattle manure from stanchion or free-stall barns is considered to be a good material for composting because the addition of the bedding brings the material to a favorable moisture content. Stable compost can be obtained in 19 to 56 days depending on moisture content, air distribution, and temperature (Willson and Hummel 1972). The primary potential benefit of composting is that a value-added product is produced. This product (compost) is useful not just on the farm, but also off the farm, such as in the horticulture industry.

Research on the feeding value of screened manure solids (SMS) obtained from dairy cattle has shown that the SMS are lower in crude protein and higher in lignin and other fiber constituents than the manure prior to screen separation (Johnson et al. 1974a, 1974b). Digestibility and feeding trials have shown that dairy cattle can successfully use this recycled material when it is included as a small percentage of the diet (University of Kentucky 1979). However, the solids are a low-quality feed ingredient, and therefore their use is limited to nonlactating cows or heifers. Hence overall usefulness of the material is limited (Newton, personal communication 1995).

Although methane generation, composting, and refeeding have been shown through research to be successful uses of dairy cattle manure, none of these techniques are currently important on a regional or national scale (Newton, personal communication 1995).

Agronomic and Environmental Effects of Dairy Cattle Manure Application

Application of dairy cattle manure to land affects both the physical and chemical properties of the soil. Manure application, regardless of form, improves tilth, increases water-holding capacity, lessens wind and water erosion, improves aeration, and promotes beneficial organisms (Midwest Plan Service 1985). When manure is applied to the soil surface, it tends to help prevent soil crusting. When injected or mixed with the soil, the manure decomposes more rapidly and the products of decomposition improve soil structure and the general physical condition of the soil (North Carolina Agricultural Extension Service 1973). Application of dairy cattle manure to cropland increases the organic matter content of the soil which in turn improves long-term aggregate stability and decreases bulk density. The result is increased infiltration. Unger and Stewart (1974), Kumar et al. (1985), and Sommerfeldt and Chang (1987) all noted an improvement in soil water retention (in the range of 0 to 15 bar matric potential) for soils receiving manure application.

Dairy cattle manure contains significant amounts of the primary plant nutrients (N, P, and K) as well as other essential plant nutrients, including Ca, S, Mg, and Cl. Considerable research has been done on using dairy cattle manure for crop production (University of Kentucky 1979). Unfortunately, dairy cattle manure has often been applied to land with disposal of the material being the main objective and use of it as a nutrient resource being a secondary concern. The primary objective in using dairy cattle manure should be safe, pollution-free recycling of the manure nutrients. Considerations for proper use of dairy cattle manure should include the texture and fertility level of the soil, the nutrient requirements of the crop to be grown, the nutrient content of the manure, and local climatic factors that will affect the fate of each of the major nutrients. Dairy cattle manure is commonly used for corn production (Safley et al. 1984, Beauchamp 1986) and on grasslands (Hubbard et al. 1987, 1991).

The major environmental concern with land application of dairy cattle manure is possible contamination of surface waters and groundwaters with excess N and P. Heavy applications of dairy cattle manure have been linked to eutrophication of surface water bodies. Phosphorus is the primary cause of eutrophication, although N may also contribute to this problem. One area of the country where eutrophication has been clearly linked to dairy cattle manure is the area near Lake Okeechobee, FL. Since the early 1970's, dairies north of the lake have been cited as the number one source of P (Sauber 1989). Nitrate leaching is the primary concern for groundwater contamination. Both Hubbard et al. (1987) and Sewell (l975) observed NO_3 leaching to shallow groundwater where excess quantities of dairy cattle manure were applied.

Problems with dairy cattle manure also may occur from surface runoff and leaching in feedlot or land application areas, or by leakage from lagoons. Rainfall-induced surface runoff may carry urine and feces into adjacent streams, rivers, or lakes. Hubbard et al. (l987) showed that as land application rates increased, proportionately more N was lost by surface runoff than by leaching. Dairy cattle manure applied to the soil surface is immediately available for movement by surface runoff, particularly if it has been applied to frozen land. During the spring thaw and snowmelt, nutrients from manure may move freely with runoff.

Water contamination from manure application can occur when application rates are greater than the assimilative capacity of the soil and crops, or when manure is left on the soil surface rather than being incorporated and hence is subject to movement by surface runoff. Application rates may exceed assimilative capacity of the soil when the land area available for manure application is too small relative to the number of cattle or where manure is repeatedly applied to fields closest to the barns or feeding areas. Surface water or groundwater can also be contaminated by farm managers applying commercial fertilizers without accounting for the nutrient value of the applied dairy cattle manure. Unfortunately, some major dairy operations still do not account for nutrients in manure applications when calculating commercial fertilizer application rates. A contributing cause to environmental contamination from dairy cattle manure is the need to get rid of the material on a daily basis. Since milking and feeding areas must be cleaned daily, manure that is generated must go somewhere. Once the holding tank or lagoons are full, the material within them must be applied to land regardless of weather, soil, or crop conditions.

Air quality within or surrounding dairy facilities or where manure is land applied is also a concern. Odors can be a nuisance to producers and can cause complaints and even lawsuits from neighbors. Organic compounds from uncontrolled decomposition of manure include odorous gases such as amines, amides, mercaptans, sulfides, and disulfides (Midwest Plan Service 1985). Noxious gases can irritate both livestock and operators and can be harmful and even lethal. Preventing production and accumulation of gases in the livestock area is accomplished through frequent cleaning of floors, not overfilling storage tanks, not storing manure in facilities for longer than 6 months, and providing adequate ventilation. Immediate plowdown or injection of manure spread on the field will reduce odors.

A relatively new air quality concern is the emission of gases from livestock manure sources. A general warming of the atmosphere due to increases in gases that adsorb radiant energy is called the greenhouse effect, and these gases are known as greenhouse gases. Methane, which is released from decomposing animal manures, is a greenhouse gas. Methane losses from all livestock manure sources account for 37 percent of all greenhouse gas emissions from U.S. agriculture based on carbon dioxide warming equivalents (Center for Rural Affairs 1992). The manure management system is critical in determining the amount of methane emissions. Approximately one-fifth of all methane from U.S. livestock sources is derived from anaerobic lagoons.

Improving Management of Dairy Cattle Manure

Dairy cattle manure must be thought of as a resource and must be managed and used economically without adverse environmental impacts. Unfortunately, many manure managers still think of this material as a waste, that is, something to get rid of, so the material is often disposed of without careful attention to matching crop, soil, and environmental constraints to the manure supply. There is ample evidence, however, that properly managed dairy cattle manure can be used to supply some or all of the nutrients to crops with economic profitability and no environmental harm.

Government regulations have been passed and are enforced in a number of states to protect surface water and groundwater quality from adverse impact by dairy cattle manure. These regulations may specify the size of land-use areas needed in relation to the number of cows and may also require monitoring of wells. For example, the state of Texas requires producers milking herds of more than 250 cows to have a permit stipulating that their dairy produces no nutrient discharge. In south Florida, the State's Department of Environmental Regulation reviews permit applications with the goal of balancing each dairy's nutrient use and discharge. Producers are required to have adequate land disposal resources for manure (Sauber 1989). One weakness of such regulations is that in some states they apply only to new dairies or dairies over a certain size and hence do not protect surface water and groundwater quality from existing or smaller operations.

As discussed in this report, a number of different options exist for using dairy cattle manure without adverse environmental impact. Education and transfer of these technologies to dairy producers is critical so that the manure can be used for supplying nutrients or obtaining energy. Once the material is viewed as a resource rather than a waste and is properly managed, it will be easier to meet government regulatory standards on air and water quality. Also, use of the manure as a resource should lower commercial fertilizer and energy costs and hence result in improved cost/benefit ratios as compared to earlier manure disposal practices.

Research is needed to improve the efficiency and safety of management practices for handling and using dairy cattle manure. Such research should be geared toward developing or improving (1) methods for reducing N losses from manure while in the barn or in storage, (2) methods for using the manure for energy, (3) uniform and efficient application procedures for applying manure to land, (4) cropping systems that efficiently use the manure while providing feed for dairy cattle, and (5) application rate guidelines that result in adequate nutrients for crop growth without adversely affecting the quality of the air, surface water, or groundwater. The most critical information needed at this time pertains to loading rate guidelines. Current research with a triple cropping system (coastal bermudagrass, abruzzi rye, and corn) at Tifton, GA, is being used to determine environmentally safe and economically sustainable liquid dairy manure rates for center pivot application. This information can only be developed by simultaneously determining both crop response and water quality effects under a range of manure application rates (Hubbard et al. 1991, Vellidis et al. 1991, Williams et al. 1991). Similar research is needed for other cropping systems over a range of soil and climatic conditions.

Concerns about environmental impacts of dairy cattle manure have caused changes in laws and management practices in a number of states. In some states new laws now require farmers to use best management practices including monitoring surface water and groundwater quality. These laws have resulted in new dairies purchasing more land on which to use the manure than was previously common practice, and in some states dairies that were unable to meet environmental standards have either moved or gone out of business. Along with the research needs, education-extension packages are needed to aid both existing and new dairies in developing cropping and manure-use systems that meet environmental standards. Extension publications from Wisconsin (Good et al. 1991, Bundy et al. 1992, and Wolkowski 1992) are good examples of information for dairy producers that show how to credit manure applications for nutrient management and protection of water quality. Similar information is needed in all states to help dairy producers use manure as a resource.

Along with research and education-extension packages, economic incentives are needed to accomplish widespread use of dairy cattle manure. A program in Lancaster County, Pennsylvania, currently connects manure producers with interested buyers and could serve as a countrywide model (Anonymous 1992). Farmers are purchasing the manure as a replacement for commercial fertilizer, with some of the manure being transported as far as 500 km from the source. Economically the marketing area is generally limited to about a 150-km radius (Anonymous 1992). Similar programs could work well elsewhere, although some type of subsidy (free material, transportation, or application) may be necessary initially.

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