



# **INTEGRATED**

## **Animal Waste Management**

CAST



The Science Source for Food,  
Agricultural, and Environmental Issues

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The Science Source for Food,  
Agricultural, and Environmental Issues

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# Foreword

Following a recommendation by the CAST National Concerns Committee, the CAST Board of Directors authorized preparation of a report on integrated animal waste management.

Drs. Alan L. Sutton, Department of Animal Sciences, Purdue University, West Lafayette, Indiana, and Jim F. Power, U.S. Department of Agriculture, Agricultural Research Service, University of Nebraska, Lincoln, served as cochairs for the report. A highly qualified group of scientists served as task force members and participated in the writing and review of the document. They include individuals with expertise in animal and poultry sciences, biological and agricultural engineering, botany and plant pathology, and soil science.

The task force met and prepared an initial draft of the report. They revised all subsequent drafts of the report and reviewed the proofs. The CAST Executive and Editorial Review committees reviewed the final draft. The CAST staff provided editorial and structural suggestions and published the report. The authors are responsible for the report's scientific content.

On behalf of CAST, we thank the authors who gave of their time and expertise to prepare this report as a contribution by the scientific community to public understanding of the issue. We also thank the employers of the authors, who made the time of these

individuals available at no cost to CAST. The members of CAST deserve special recognition because the unrestricted contributions that they have made in support of CAST have financed the preparation and publication of this report.

This report is being distributed to members of Congress, the White House, the U.S. Department of Agriculture, the Centers for Disease Control and Prevention, the Congressional Research Service, the Food and Drug Administration, the Environmental Protection Agency, the Agency for International Development, and the Office of Management and Budget, and to media personnel and institutional members of CAST. Individual members of CAST may receive a complimentary copy upon request for a \$3.00 postage and handling fee. The report may be republished or reproduced in its entirety without permission. If copied in any manner, credit to the authors and to CAST would be appreciated.

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# Interpretive Summary

## Integrated Animal Waste Management

The Council for Agricultural Science and Technology (CAST) created a task force to determine the state of knowledge about the effects of animal waste management systems on the environment.

### Review of Literature

With the livestock and poultry industries becoming more intensive and larger, significant amounts of manure are generated that must be collected, stored, and utilized efficiently. In certain areas of the United States, pressure on livestock producers is increasing because minimal land is available for manure utilization. Nutrient loadings of land with phosphorus and potassium often exceed the amounts needed for typical crop production.

Livestock and poultry producers have been given little incentive to implement current environmental practices and technologies, which entail increased operational costs while providing little evidence of benefits to the operation or society. Moreover, inaccurate or inconclusive information from various sources about the reliability of certain practices and systems is creating confusion, and the direction of regulatory affairs is ambiguous. Nor has there been an analysis of risks to benefits for current systems. Finally, in the free market system, the food animal production industry finds it very difficult to pass on environmental control costs to consumers.

If improperly managed, potential manure contamination of surface and ground water sources that results from leaching or runoff may include nitrogenous compounds (ammonia, nitrates), phosphorus, bacterial and viral agents, and other nutrients. Potential adverse soil effects from excess manure applications may cause mineral nutrient imbalances, excessively high accumulations of some minerals, and salt build-ups.

High concentrations of gases and other volatiles (odor), airborne bacteria, viruses, fungi, endotoxins, and dusts from livestock and poultry buildings and

manure storage facilities can affect the performance of animals adversely. When properly implemented, current design of facilities and management practices significantly decrease risks associated with these airborne agents.

A broad spectrum of integrated manure management systems are available to collect, transfer, store, treat and efficiently utilize a great variety of sources and nutrient qualities of animal manures. These systems provide the opportunity and flexibility to meet production units' individual, site-specific needs in an economically and ecologically sound manner.

Properly managed manure that is used as a plant nutrient source has been a very effective utilization strategy with little negative environmental consequence. Improved soil physical, chemical, and biological properties can result from manure application. Significant economic returns to livestock and poultry operations can result from the judicious use of manure as a plant nutrient resource.

Other forms of manure utilization practices include processing and recycling through feeding programs, biogas production as an energy resource using anaerobic digester technologies, pyrolysis processes to produce chars and industrial petrochemicals, microbial and algae production as an animal feed source, aerobic degradation to produce composted products, and mushroom production from composted manures. Each technology has been proved to be safe, but economic factors have limited the implementation of these as practices except in niche markets.

### Future Research, Education, and Regulatory Policy Needs

The following policy modifications would prove beneficial:

1. Direction of research to animal manure management in the following areas:
  - a. changing animal diets to decrease nutrient outputs and odorous compounds;
  - b. developing or improving manure treatment processes;
  - c. controlling nutrients and utilizing manures

- d. decreasing and controlling odor from buildings, storage facilities, and during land application;
  - e. conducting economic analyses of manure system alternatives; and
  - f. developing new technologies to process manures for feeding and value-added products.
2. Direction of educational initiatives to animal manure management in the following areas:
- a. training and educating environmental specialists,
  - b. developing methods to deliver technology to producers effectively,
  - c. communicating effectively with consumers and youth,
  - d. demonstrating technology to producers, and

## Integrated Animal Waste Management

- e. developing realistic computer models for use in decision making.
3. Development of positive relationships between producers, regulators, policy makers, scientists, and educators in the following areas:
- a. determining the risk/benefit for current and future best management practices;
  - b. encouraging a voluntary approach to meeting water and air quality standards;
  - c. initiating incentives to adopt integrated best management practices;
  - d. testing best management practices for a system, site specific, watershed approach; and
  - e. providing economical means to process animal manures for feeding and value-added products.

# Executive Summary

This report by the Council for Agricultural Science and Technology has focused on the accomplishments of animal manure management research and educational programs in the United States addressing environmental issues and concerns. The document (1) addresses manure management for current livestock and poultry production practices in light of the historical evolution of these industries and economic forces; (2) identifies potential environmental and public health concerns related to manure management practices; (3) reviews the components of integrated livestock and poultry operations and thus identifies the variety of manure management systems used, the potential uses of manure as a resource, and the principles of environmentally sound, integrated manure management; and (4) discusses current obstacles to improving animal manure management.

Livestock production is concentrated in certain regions of the United States, and conflict over land use often arises because of the expansion of animal industries and human populations in the same regions. At the beginning of the twentieth century, American society was largely rural. Today, it is largely urban, but people increasingly are moving to small acreages in rural areas. Rural inhabitants often have no connection to agriculture and likewise have little appreciation of the problems and practices associated with agriculture. At the same time, the general public, rural and urban, is becoming increasingly concerned about the environment.

Advances in research have been the basis on which the economic efficiency of animal production has improved dramatically. Significant changes in the structure of the livestock and poultry industries have occurred. A typical livestock farm 50 years (yr) ago was diversified, often containing several animal species at one location. Today, most production units are specialized and intensive, and often only one animal species is present. In some instances, little or no crop production is associated with the animal enterprise. Increased intensity and size of animal production enterprises in the United States create greater volumes of liquid and solid manure per production unit.

Before intensive production operations were devel-

oped, manure normally was distributed on land that was grazed or cropped (Figure E-1). But more sophisticated manure systems for collection, storage, treatment, and utilization have become necessary as livestock and poultry production industries have intensified. The estimated collectable and usable amount of manure (after storage) produced by confinement animals in the United States is estimated at more than 61 million tons (t) of dry matter/yr. The concentration of animals on limited landbases and the proximity of such operations to residences give rise to concerns about the environmentally acceptable management of animal manure.

## Economic Perspectives

Fundamental economic forces at consumer and producer levels have a powerful influence on livestock production and on control of both point and nonpoint pollution emanating from livestock facilities. Consumer preferences are reflected in the marketplace, which dictates the scale of economic activity of any industry, including the extent of associated nonpoint and point source pollution. Producer response to consumer preferences generally depends on technology and



Figure E-1. Traditional manure handling and application system in early animal agriculture. Photograph courtesy of Alan L. Sutton, Purdue University, West Lafayette, Indiana.

price but also is affected by current or proposed regulatory policies related directly to point and nonpoint source pollution control. Public policies such as regulations aimed at decreasing pollution play an important role in facilitating or constraining producer response to the economic environment. Other public policies such as government supported research and development efforts also directly affect pollution control activities.

The benefits and costs of alternative manure management systems are primary determinants in the selection of livestock manure handling systems. When faced with the added costs accompanying new pollution control regulations, many producers must decide whether it is economically feasible to remain in the livestock business. Typically, public policies forcing production units to control pollution without compensating them for additional costs result in some units—especially small ones—exiting the industry or increasing in size and intensity. Either outcome may have negative effects on local communities. For producers, benefits from livestock manure may be gained through the resource recovery processes. If utilized properly, livestock manure is a potential source of nutrients for plants or livestock feed and of energy.

Given current price relations and adoption ease, the primary benefit of manure for producers is as a nutrient source for crops. But substantial price increases for livestock feed ingredients or for fossil fuels could make livestock manure more attractive as a feed ingredient or as an energy source. The costs of land and water pollution seldom are assessed against an individual operation in economic analyses, and, if one ignores these costs, then the net costs of livestock manure management systems are underestimated.

A review of 244 livestock production technologies indicates that methods exist with which to control water pollution and odor nuisance (White and Forster, 1978). However, because acceptable control often requires substantial investment, from which little or no economic benefit is returned, producers have resisted adopting the necessary technology. Definition of *acceptable* control of water pollution and odors leads to controversy over proper management practice and design of manure management systems. Strict regulatory policies and major changes in livestock manure management systems could increase production costs significantly. Certain existing production systems, however, can be modified with appropriate management practices and technologies, at modest costs, to control runoff from exposed lot surfaces and from fields in which manure is applied, to lower manure application rates to acceptable levels, and to minimize

odor nuisances.

There have been no recent *net cost* (fixed and variable costs less nutrients benefits) analyses reported for common manure management systems. White and Forster (1978), however, identified five general principles: (1) Net system costs differ substantially by size of operation; generally, the larger the operation, the lower the cost per animal unit. (2) Net system costs are greater for confined systems than for open lot systems. (3) Storage cost is not recovered by the enhancement of manure nutrient concentration. (4) Incorporation of manure by injection or plowdown is cost effective when practiced in conjunction with storage of concentrated manure nutrient sources. (5) If runoff is to be controlled from open lots, runoff detention and irrigation systems increase net system costs substantially more than grass infiltration systems do.

*Industry structure*, i.e., size distribution of the industry's production operations, may be affected significantly by public policy regarding livestock manure management inasmuch as the capital to which livestock production unit operators have access is affected by lender response to environmental regulations. As a result of legislation and case law, livestock producer access to capital markets may be affected in three ways (Mazzocco, 1991). First, lenders may become liable when they exercise management control or acquire title to real estate. Because of this potential liability, lenders may limit lending to livestock facilities with the potential to impair water quality or to cause odor nuisances. Second, credit supply may be affected by lender knowledge if the judgments obtained by the government for environmental damage will affect repayment ability. Finally, cost of regulatory compliance has an impact on borrower financial strength and ultimately on borrowing capacity. A survey (Mazzocco, 1991) indicated that 62.5% of surveyed lenders had rejected loan applications and that 45% had discontinued certain types of loans because of potential environmental liability.

By the 1970s, a new theme—concern about agriculture's effects on downstream water users—emerged in agricultural policy. Feedlot runoff and erosive agricultural practices were linked to fish kills; excessive nitrate concentrations in both surface and ground waters; eutrophication; and river, lake, and stream sedimentation. Accordingly, a mandate to decrease point source pollution such as runoff from larger livestock facilities was included in the 1972 amendments to the Federal Clean Water Act (Public Law 92-500). The goal is to decrease point and nonpoint source pollution to reach more socially acceptable water quality levels. When some of the social costs of pollution

control (or the social benefits of resource conservation) are external, however, then natural resource management likely will be suboptimal from a social standpoint. Because society has provided those in agriculture with no strong economic incentive to control pollution, producers tend to promote suboptimal levels of pollution control to maintain economic viability.

Regulations can restrict current operations severely, and any new development can force additional animal production operations to other parts of the United States or abroad. This effect needs to be considered carefully by policymakers attempting to maintain viable livestock industries in specific regions of the United States. Direct mechanisms that governments can use to promote pollution control are (1) regulations of pollution emission levels, (2) levying of polluter taxes, (3) payment of subsidies or other incentives encouraging pollution reduction, and (4) funding of research-education programs. Because regulations can be costly to administer effectively, economic incentives often are advocated, when practical. Taxes on emissions, like subsidies for emission reductions, are less costly to administer than regulations. Taxes and subsidies also provide direct incentives for the development of new emission-control techniques while increasing producer benefits from pollution control, increasing level of control, and narrowing the gap of expectations between society and producers.

The marketing of so-called "pollution rights" often works in the point source context but is less successful in the nonpoint source context. It is costly and inexact to use runoff control regulations to monitor compliance from nonpoint sources, especially from livestock and poultry operations. Often no standards exist. Administration costs would be particularly burdensome in agriculture, in which nonpoint pollution may occur for hundreds of thousands of producers and affect a large watershed.

Partly because of the administrative costs of alternative policies, U.S. soil and water conservation policy has stressed *subsidization*, or cost sharing, along with technical assistance and education regarding agricultural practices. From 1984 to 1990, the U.S. Department of Agriculture Agricultural Conservation Program spent nearly \$1 billion on cost-sharing agricultural practices to control erosion, to conserve water, and to improve water quality (U.S. Department of Agriculture, 1991). Approximately \$40 million of this total went to animal manure management practices. These funds need to be targeted carefully and to take into account environmental and productivity effects (Ribaud, 1986).

Much of the public soil and water conservation and nonpoint pollution control effort in the United States has been based on a research-education approach. Many federal agencies have worked together to develop new soil conserving management practices, to educate producers about the effects of management practices on environmental quality, to encourage their adoption, and to develop total nutrient and resource management plans for farms. Such efforts should be continued.

## Environmental and Public Health Concerns

Because manure primarily is organic, it is largely biodegradable through microbial decomposition, which can produce gases, odors, and significant changes in nutrient contents. Livestock enterprises can affect surface waters through direct runoff of pollutants from livestock areas into streams, lakes, reservoirs, or estuaries and by fallout of pollutants originating in livestock areas as particulate matter, direct absorption, or precipitation. Surface runoff may originate from pastures, concentrated open feeding areas, poorly designed manure storage areas, or fields to which manure has been applied. Tile drainage from manured fields can deliver leachate to surface waters. Runoff may contain organic and inorganic compounds in solution, particles, and sediments including nitrogen (N), phosphorus (P), and other nutrients. Runoff also may carry fecal coliform, other bacteria, and viruses.

Because of enhanced disease control and current animal management practices, no disease incidences related directly to animal manure in water sources have been documented. Pathogenic bacteria and viruses cannot compete effectively outside the host animal for extended periods. Fecal coliform bacteria in water are indicative of fecal contamination because these bacteria are present universally in the feces of every warm-blooded animal. Their presence at elevated numbers generally suggests that enteric pathogens also could be present. Most waters, however, have a background level of coliform organisms resulting from wildlife and other animal activity. Properly managed livestock grazing or manured cropland generally does not significantly raise the levels of fecal coliform organisms in runoff. Generally, if manure is incorporated into the soil during or immediately after application, nutrient concentration and fecal coliform counts of runoff water from such fields are little, if any, greater than those from fields without manure.

Frequently, in many open confined feeding operations, greater than half the nitrogen (N) excreted by livestock is volatilized as ammonia ( $\text{NH}_3$ ), most of which returns to the soil-plant-water systems within a few miles of its origin. Usually, the problem is most serious in open lot operations in which manure is allowed to accumulate on the ground until annual or semi-annual removal. Few best management practices (BMPs) to control  $\text{NH}_3$  volatilized from manure have been developed. Ammonia volatilization might be decreased by means of certain additives such as bedding, superphosphate or phosphoric acid, sulfur-containing compounds (including alum), or calcium chloride (Miner, 1995).

For land application of manure, losses of manure N and P-containing compounds in field runoff are related to rate, timing, and application method; soil characteristics such as slope and texture; cropping management practices; and weather after application. The greatest runoff enrichment occurs when manure is surface applied to frozen soil, especially when a major runoff event, e.g., a snow melt, occurs shortly after application. Manure application methods affect nutrient loss because (1) surface applied manures undergo less rapid decomposition and therefore may contain a higher concentration of contaminants and (2) manure incorporation will improve soil physical condition and thereby decrease runoff volume and erosion. An effective method of attenuating nutrient runoff is the use of vegetative buffer strips.

The primary ground water pollutant associated with livestock manure management is nitrate-N. Because phosphorus and many other nutrients are absorbed readily by the soil through which percolating water moves, they seldom are a serious problem in the United States. Other salts and pathogens seldom are problems. Nitrate leaching is not a concern if earthen cattle-feedlots are managed properly, because an impervious seal beneath the feedlot results from salts excreted in manure and compaction by livestock hooves. If, however, the feedlot is abandoned or is grossly understocked, significant nitrate production and leaching can occur. Soil types used in lagoon construction greatly affect potential nutrient leaching (Huffman et al., 1994). To prevent potential leaching from lagoons and pits, many states now require that such structures be made impermeable by use of concrete, plastic liners, bentonite sealers, or other sources of clay.

Crop fields near feedlots that routinely receive high manure rates are a potentially important source of nitrate leaching. If significant mineralization occurs late in the growing season, after a crop has been harvest-

ed, nitrate N may leach to ground water in the early spring on sandy soils if excess water is present. Several studies, however, have measured unexpectedly low percolation N losses, as a result of high denitrification rates (Comfort et al., 1987; Cooper et al., 1984; Meek et al., 1974). More recent laboratory research has shown that with high P applications, some soluble P also may begin to move to lower depths in the soil profile (Provin et al., 1995).

Long-term application of manure, even at rates not exceeding the N needs of crops, results in soil build-up of plant available P and potassium (K). It is predicted, however, that long-term application of manure P is required before significantly affecting ground water. Most P degradation to surface water is from soil erosion. High rates of manure in semiarid and arid climates can result in accumulation of soluble salts in the soil profile. Because of the great amounts of sodium and K salts in some manures, soil physical condition, plant germination, and growth can be impaired. The effects of salt depend on soil texture, climate, and soil water-holding capacity. Although arsenic, copper (Cu), zinc (Zn), and P salts sometimes are added to poultry or to swine rations, no adverse effects of these nutrients have been found, and they generally serve as essential nutrients for crop growth. Manure application, if not excessive, will improve soil quality over time.

Proper control of temperature, humidity, and air distribution is an important means of decreasing the adverse effects of manure gases, odors, and airborne microflora in enclosed buildings. Principal airborne components in such environments are  $\text{NH}_3$ , volatile amines, hydrogen sulfide, certain volatile fatty acids, indoles and phenols, mercaptans, alcohols, and carbonyls (Curtis, 1983). These materials may pose a significant threat to animal health and welfare if buildings are designed and managed incorrectly. Certain principal components of odor—notably  $\text{NH}_3$  at high concentrations—can increase respiratory disease susceptibility and decrease growth rate of animals and have been implicated as a factor in respiratory problems in humans working in intensive livestock operations (Donham, 1990; Schiffman et al., 1995). Odors from housing systems ultimately are vented to the atmosphere, thereby potentially causing air pollution, potential health reactions, and public complaints (Schiffman et al., 1995).

The obvious solution to all these problems is that of decreasing production of odorous compounds within the house. Underfloor ventilation systems to remove the gases and odors generated, periodic rapid removal of manure from buildings, and other methods—e.g.,



scrubber systems, chemical treatments, and aeration systems—have been used to improve building air quality. Various types of covers have been used to control odors from open manure storage structures. Additional dilution water in lagoons or aeration of lagoons has reduced odors. Odorous emissions, including  $\text{NH}_3$  from land application of manure, can be decreased significantly by direct incorporation of manure into the soil.

Dust produced when animals are confined can cause increased animal respiratory problems. Dust can be a major problem in open beef-cattle feedlots, especially in dry regions. Sprinklers and tank wagons often are used to control dust. In confinement buildings, air filtering systems, ionically charged dust collectors, addition of 1 to 2% vegetable oils or animal fats in diets, and use of moist feeding systems have decreased dust in building air significantly.

Although no harmful effects of feeding processed manure have been observed, scientists were challenged to demonstrate both the safety of the practice to animals fed processed manures and the safety of the food product derived from these animals. Health issues raised by the U.S. Food and Drug Administration included concerns about pathogenic microorganisms, microbial toxins, mycotoxins, parasites, viruses, arsenicals, antibiotics and drugs, hormones, coccidiostats, pesticides, heavy metals, and trace minerals. Processing methods such as heat, acid treatment, fermentation, and chemical additions can eliminate from feedstuffs derived from animal excreta these and other biological agents: pathogenic microorganisms, mycotoxin-producing fungi, and parasites. Antibiotics pose no health hazards to animals consuming the processed excreta or to humans consuming the products of animals subject to a 15-day (d) withdrawal. No evidence of pesticide accumulations in the excreta of animals exists.

Specific feeding management guidelines have been developed to ensure safe feeding of processed manures. In the United States, the only documented incidence of a health hazard to animals fed processed manures occurred in sheep, which are sensitive to dietary Cu levels greater than 25 parts per million.

## Integrated Manure Management System Components

The objective of a manure management system integrated into a livestock operation is to collect, store, and utilize animal manure efficiently and to prevent contamination of water, soil, and air while producing,

within socio-economic constraints, food products for consumption or other uses by humans. Because of vastly different climatic conditions, animal species, manure characteristics, engineering technologies, and a wide range of other important parameters, a broad spectrum of integrated manure management systems exists. Their components can be arranged in a variety of ways to meet specific needs and site restrictions.

Collection devices include scraper, pipe, channel, diversion, and liquid flush systems. A variety of transferring pumps and other types of conveyance equipment is available for transferring liquid and solid manures to storage, loading of land application equipment, and irrigating. Runoff water from open lots often is diverted by earthen berms or dikes into earthen storage. These same earthen dikes can be used above the lot area to divert clean upland runoff from flowing across the lot and becoming contaminated. The hydraulic collection of manure by means of a flushing gutter is used commonly in swine, dairy, and certain poultry operations. As size of operations has grown, this component system has become an increasingly attractive, efficient, and economical alternative. Cleaning dairy gutters two or three times daily maintains the sanitary conditions required by milk inspectors.

Storage components are temporary holding containments for manure before it is spread on land. These units are designed to be emptied at frequencies of from every 7 d to 1 yr. Systems range from earthen storage, including lagoons for long-term manure storage, to aboveground and belowground tanks, which may be within the building. Use of slatted floors above storage pits improves the efficiency of manure collection and storage through direct deposit of manure into storage. Recent research has defined the soil sealing capabilities of manure slurries in earthen storage. Some soils have an unacceptably high infiltration rate, and alternatives such as plastic liners or other membranes placed in the bottom and side walls of an earthen structure may be required. Properly designed anaerobic lagoons significantly decrease the odor associated with anaerobic decomposition but require greater storage capacities than other units do.

Land application equipment is designed specifically for certain manure sources. Application methods include surface spreading with solid-manure box spreaders, liquid tanker wagons or trucks, and various irrigation systems; or tillage for soil incorporation of both surface-spread solid and liquid manure; or by direct injection of liquids. Irrigation systems include surface overland flow, spray irrigation, center pivot, and traveling guns.

Systems to treat manure include methane digesters, solid-liquid separation tanks or mechanical presses and screens, constructed wetlands, composting, vegetative filter strips, and aeration devices. Although vegetative filter strips are applied most commonly to runoff from nonpoint sources, they can be adopted for use with point sources. In certain systems with a high solids content in runoff, solids are allowed to settle out in a basin, and the liquid is allowed to run across grass fields, thereby irrigating and nourishing the grass. Aerobic treatment of liquid wastewaters from livestock operations generally is limited to applications with dilute wastes and is used to decrease odors. Even though technology is available for this type of treatment process, it is used primarily when odor control is mandated, because cost of installation and operation can be very high. Use of constructed wetlands is a relatively new technology currently being evaluated for the treatment of liquid wastewaters from livestock operations. The process has been used successfully in Europe and in the United States for treatment of municipal wastewater from small communities and from households in rural areas and more recently has been investigated for treating wastewater from livestock operations. Constructed wetlands are less costly to construct and to operate than municipal wastewater treatment plants and therefore are becoming popular in rural communities.

## Manure Nutrient Utilization through Land Application

Manure is an excellent nutrient source because it contains at least low concentrations of all the elements required to grow plants. Large volumes of manure often are available to producers, and although nutrient concentrations in manure tend to be low, its total potential value as a source of plant nutrients for crop production is great. For maximal nutrient value from manure, losses during land application, collection, and storage need to be minimized. In addition, timing and method of manure application have little direct effect on P or K transformations but greatly influence the potential for loss of these nutrients in runoff from sloping terrain.

Manure applications decrease sediment load in runoff by improving soil physical characteristics including structure, infiltration rate, permeability, bulk density, and water-holding capacity. These improvements may decrease crop water stress. Nutrients in dilute manure liquids, e.g., lagoon effluent or runoff water, applied to growing crops by means of irriga-

tion can be utilized readily by plants and can provide a source of water during drought.

The value of manure also has been recognized as a soil amendment to improve soil physical properties important for wind and water erosion control and aggregation. Large aggregates tend to decrease compaction and surface crushing and to increase large soil-pore space and permeability. Organic matter additions improve soil physical characteristics by stimulating soil microbial activity. Manure also affects soil pH and amounts and availabilities of major, secondary, and micronutrients.

Of all nutrients, nitrogenous compounds often are of greatest concern because high concentrations can lead to environmental problems, nitrogen availability is difficult to predict, and additions generally are required for optimal crop growth. When manure is applied at rates meeting crop N requirements, soil P often accumulates to excessive levels. Considerable research has shown that most soils have a great capacity to assimilate P from manure in the plow layer without detrimental environmental effect. Animal manures have been used to correct Zn, Cu, and iron deficiencies. Manure will produce crop yields equivalent or frequently superior to those attainable with commercial fertilizer. Similarly, crop-quality improvements have been associated with manure applications.

Historically, manure has been applied at a rate to fulfill crop N requirements without causing environmental problems. This strategy maximizes application rate but makes relatively inefficient use of manure P and K unless the field subsequently is rotated to other crops—such as legumes—which have a high P and K requirement. Rotation is the manure application strategy of choice when the amount of land available is limited. The amount of N available is the most common basis on which to determine manure application rate.

A regional analysis of manure's potential fertilizer value, based on estimated nutrient availabilities and recoverabilities of manure from livestock and poultry production, was conducted for the 48 contiguous states. An average of 15% of N purchased as commercial fertilizer is equivalent to nutrients available if the distribution was compatible with crop needs. On a nationwide basis, approximately 42% of crop P could be supplied by manure. Little potash fertilizer is purchased in certain regions due to less cropland production demand, thus, the relative amounts of manure nutrients available for crops are much higher than other regions in the United States. If properly distributed and utilized on productive cropland, manures

could significantly reduce commercial fertilizer costs and allow industry growth in many regions of the United States. Total potential manure fertilizer value from all livestock and poultry production nationally still would approach \$3.4 billion/yr. This figure, however, does not include costs for transportation, processing, or management. On the other hand, the aforementioned manure value does not reflect the economic benefits of improved soil quality, decreased runoff and soil erosion potential, or increased crop yield potential under water stress.

## Recycling and Utilizing Manure for Purposes Other Than Plant Nutrition

Several alternative processes and methods have been developed for the utilization of animal manures other than as plant nutrients. For example, manures can be used as energy resources, processed feed ingredients, composted soil amendments, and processed oils. The feeding of animal manures as a source of low-cost nutrients is not a new practice. Early reports demonstrated the presence of "growth promotants" in dried animal feces fed to rats. The observed benefit to rat growth was associated with growth factors such as vitamins in the feces. Early husbandry practices for feeding swine commonly provided swine access to cattle yards, where they could readily explore manure for nutrients.

Because both poultry excreta on an "as excreted" basis from laying hens and poultry litter from broiler chickens have higher concentrations of nutrients than manures from other livestock species do, poultry manures are the most valuable as feed resources. Moreover, because broiler litter is relatively dry and collectible, it has been used widely as a feed ingredient. The feeding of broiler litter is limited principally to ruminant animals because of its high contents of fiber and nonprotein N, primarily uric acid. When litter is available at low cost and beef cattle are produced in proximity to broiler poultry operations, the use of litter as a feed ingredient generally is viable.

Although low cost is the major reason that livestock producers feed processed litter to animals, other factors contributing to this practice are the value of litter during drought, when feed grains, pastures, and hay crops are in short supply. In the Southeast, feeding poultry litter as a supplement to cattle during winter decreases the need for other more costly feed ingredients.

As energy costs increased in the 1970s and the

1980s, livestock producers explored the potential of anaerobic digestion of animal manure to produce biogas, i.e., methane and carbon dioxide. Anaerobic digesters were constructed on 85 to 100 farm sites in the United States, but only a few on-farm digesters were operated for more than 2 yr. Most used designs developed by civil engineers for the treatment of municipal wastewater, but the nonhomogeneity of animal manures and the hydrogen sulfide produced in biogas presented major operational problems. High capital costs and major managerial inputs also were characteristic of many early agricultural digesters. Biogas production in low quantities is possible from anaerobic manure lagoons using floating covers.

Animal manures can be subjected to various pyrolytic processes producing chars and industrial petrochemicals. Although these oils and chars can be used for fuel or can be processed for production of carbon black, synthetic rubber, printing ink, and other products, they generally are not economical. Animal manures also can be used as a nutrient source for the production of yeasts and algae, which in turn can be used as animal feed ingredients although—again—not economically.

Substantial quantities of manures (especially horse and poultry) are used for commercial mushroom production. Approximately 45% of mushroom production in the United States occurs in Pennsylvania, where about 52,000 t of poultry manure and 240,000 t of horse manure are composted and used annually. Compost also is used for gardening and horticulture and is a soil amendment for field crops. Recycled litter and manure composts also have been used as bedding or litter in cattle and poultry production facilities.

## Animal Mortality Management

As large livestock and poultry facilities have become more concentrated, the task of farm animal mortality disposal becomes ever more critical. With the declining number of rendering firms and the public concern about ground water degradation from animal burial, new alternatives for animal mortality disposal clearly are needed. New methods that have been used successfully on farms include composting, incinerating, centralized collection, on-farm refrigeration, and contained burial.

Laws for dead-animal disposal have been enacted based on practical experiences or theoretical assumptions. Limited research has been conducted to compare the potential value, safety, and environmental threat of these methods. Guideline development and management parameters based on research and tech-

nical studies are needed. A thorough economic analysis of each method has yet to be conducted, and new technology to develop value-added products should be encouraged.

## Future Research, Educational Needs, and Regulatory Policy

### Research

Water-quality research, especially that focusing on nonpoint pollution effects on watersheds, and air-quality (odor) research is critical. Manure management research funding from all sectors decreased significantly after an initial support base in the early 1970s. Research areas likely to yield positive environmental benefits include (1) modification of animal diets, (2) development or improvement of manure treatment processes, (3) nutrient control and utilization of manures in soil-cropping systems, (4) reduction and control of odor, (5) economic analyses of manure system alternatives, and (6) development of and economic incentives for new technologies utilizing processed manures and value-added products.

### Diet Modification

Recent reports show the potential to decrease nutrient outputs in manure through dietary manipulation including (1) use of phytase to decrease P and other mineral excretions, (2) decreased protein levels in diets and supplementation with synthetic amino acids to decrease N excretion, (3) change in dietary carbohydrate content, and (4) use of growth promotants to increase protein accretion, to decrease fat accumulation, and to enhance nutrient digestibility (Adeola et al., 1995; Cromwell and Coffey, 1994; Cromwell et al., 1995; Jongbloed and Lenis, 1994; Mroz et al., 1994). A decrease in nutrient excretion also can decrease odors significantly (Sutton et al., 1995). Processing diets (grinding, pelleting, steam flaking, fermenting, and chemical treating), phase feeding, split-sex feeding, and other management techniques can improve nutrient utilization and decrease excretion.

Because many of these investigative areas are fairly new, continued research is needed to develop technologies that can be implemented by production agriculture. Significant genetic changes in animals require changes in dietary nutrient levels (Schinckel et al., 1988; Stahly et al., 1989). Research must continue to define nutrient requirements for optimal economic production potential of the animal without excess nutrient excretion. Additionally, biotechnological

genetic research and management technologies enhancing the digestibility and nutrient balance of feed resources to meet animal nutrient needs is vital to decreasing nutrient outputs. The greatest benefits from this type of research are increased food-production efficiency resulting in a reliable, low-cost food supply for the consumer, increased profitability for the producer, and lowered requirements for a sustainable landbase for manure application.

### Manure Treatment Technology

Most processes tested have required additional labor, equipment, and energy inputs and have generated little additional economic return. Odor control needs to be a major consideration in all new treatment developments. The use of new research tools in the investigation of highly technical opportunities should be encouraged. The genetic engineering of microorganisms and the bioremediation processes are examples of such new tools. Methods of extracting nutrients from manure and of producing value-added products that may be marketable seem a worthy area of research. Examples of treatment are flocculation, precipitation, electrolysis, ozonation, filtration, and chemical digestion. Attempts to derive and to concentrate nutrients by processing manures for feeding, converting to energy, and amending soil need to be continued so that economical solutions to manure management problems can be identified.

If management and design criteria for constructed wetlands create systems that sufficiently treat waste waters to meet water-quality standards for discharge, this technology will be adopted rapidly by many livestock producers. Opportunities to recycle the treated wastewater on farms also have environmental as well as economic benefits. The long-term impact of constructed wetlands on the environment, however, still is undetermined. Composting technology needs to be modified so that several biowastes composted together will produce a stable product, utilizable as a resource and completely recyclable. For example, recycled newsprint, cardboard, leaves, chopped shrubs, and other such waste materials could be combined with manures and other residues. Composting also has the potential to control noxious odors generated by manures and thereby to permit land application of manure in socially sensitive urban areas.

### Soil Amendment

Because of environmental pressures, considerable research must be conducted on runoff control and loading rate, site analysis, and pollution potential of P and possibly of K from manures. Some state regu-

lations are imposing P limits on manure applications, and this is common in Western Europe. The landbase required for manure application when P limits are specified is 2.5 to 4 times that required when based on crop N requirement. Debate continues about the solubility of P from organic sources such as manures, the loading limits for different soil types before leaching, the form in which P moves during runoff from soils, and the best methods of chemically or physically controlling P movement.

Before regulatory policies are adopted, additional research is needed in soil microbiology, soil physical and chemical interactions, and materials to control the fate of certain nutrients, especially N. To understand the availability of nutrients for plant use and to determine proper management guidelines for nutrient usage without pollution, research must continue.

Genetically improved plant species and specific cropping rotations may be developed that increase nutrient use of manure sources, especially where the landbase for manure application may be limited. New on-farm methods of rapidly estimating nutrient levels in manures and soils are needed to assist producers in management decisions, manure application rate adjustments, and prescription techniques to control and to maximize nutrient efficiency for crop production. Additional research is needed to develop equipment for optimal, uniform, and accurate application and incorporation of manures into the soil.

Conservation compliance requirements of the Food Security Act of 1985 and the Food, Agriculture, Conservation and Trade Act of 1990 often prohibit tillage of erodible soils. Yet frequently such soils respond dramatically and positively to manure application. Historically, manures have been applied to highly eroded sites to control soil erosion. Whether manure can be surface applied to these soils without distributing the crop residue cover needed to prevent soil erosion and without diminishing environmental quality is a question needing research.

#### **Odor Control**

Odor studies should include the effects of animal diet; manure treatment; handling (management) systems; chemical, physical, and microbiological methods; weather components; facility design; and related factors on the quality and quantity of odor-causing compounds (Miner, 1995). Work is needed to accurately identify and measure major odor compounds and to correlate identifiable compounds with olfactometric methods. Storage-systems and animal-diet additives to control odors should continue to be developed

and scientifically tested. Although several filter systems have been investigated, additional research is warranted.

#### **Economics**

As the industry embraces integrated approaches to food and fiber production, producers need clear, concise, and accurate economic analyses of manure management alternatives, including realistic monetary returns to operations. Lending agencies and governmental regulations are requiring environmental impact statements and economic analyses of agribusinesses. Incorporated into this analysis should be descriptions of alternative manure management systems and of their potential integration into operations. Decision making can be fruitful only when data are valid and research information is available.

The most thorough evaluation of several manure management alternatives for all farm species was conducted in 1978 (White and Forster, 1978); this work needs to be updated, expanded, and made available to producers, policy makers, consultants, and educators. To affect adoption of realistic policy decisions, an evaluation of manure management systems also should involve a critical assessment of cost/benefit ratios and effects on water, air, and soil quality. Likewise, social aspects need to be addressed.

#### **Education**

One of the greatest needs in the implementation of new manure-management technologies is a broader and more thorough education of producers, consultants, policy makers, regulatory agency personnel, others assisting producers, and the urban public. Information needs to be communicated to the general public (the consumer) about environmental concerns and solutions in animal agriculture. The general public is dissociated from agriculture and may well not recognize the close relation between sustainable agriculture and environmental quality. Partnerships developed between Land Grant universities, the National Resource Conservation Service (NRCS), commodity organizations, agribusinesses, and regulatory agencies can be important sources of current and correct information for producers and can encourage adoption of technologies that will assist business while promoting a sustainable environment.

Although considerable effort has been expended in educating the livestock producer, the need for increased efforts is greater today than ever because of regulatory pressures, public concerns, and rapidly changing industry structures. Producers, often con-

fused by conflicting information from various sources, need to be aware of the potential consequences of animal manures in the environment. Similarly, risk assessment tools need to be provided to allow accurate operational analyses and corrective measures for problem areas. Best management practices, conservation practices, current technology adoption, expert systems development, and computer aided decision making programs need to be developed, demonstrated, and implemented. Educational materials need to target specific clientele levels, and resource materials and assistance sources need to be identified. Demonstrations of current and new technologies in production units can convince producers to adopt technologies and BMPs. Through the Land Grant university and college system, additional support for curriculum and staffing to train well-qualified individuals with B.S., M.S., and Ph.D. degrees to fill key responsibilities in production, regulatory policy, design, and management decisions is critical.

### **Regulatory Policy**

The National Pollution Discharge Elimination System (NPDES) program of the U.S. Environmental Protection Agency, the U.S. Clean Water Act of 1987, and the Coastal Zone Management Act have provided regulatory policies affecting livestock industries and their relations to water quality. As a result of such legislation, states have adopted or currently are adopting regulations involving permits or approvals of manure management systems and nutrient management plans for livestock operations.

Even though regulations are enforced to control water pollution, producers do not implement some BMPs because they are too expensive or labor intensive. The livestock industry would prefer a voluntary approach to meeting pollution requirements by implementing appropriate BMPs. For example, the Nation-

al Pork Producers Council has implemented an Environmental Assurance Program to train and to ensure that certified producers understand and use approved practices. This program includes a risk assessment identifying the payoff for a high level of environmental management practices, and development of a complete manure nutrient management plan integrated for the entire operation. In addition to the need for an educational thrust, incentives encouraging the initial adoption of BMPs would be helpful. Potential options are demonstration grants, cost-sharing facilities, "right to farm" protection from regulatory agencies for certified producers who meet facility design and BMP adoption standards, and tax incentives for proper BMPs.

In contrast, mandatory regulations of BMPs and other management restrictions may be enforced on the production sector. Such regulations may lead both to rigid procedures failing to account for variability between enterprises and to poor control. Mandatory restrictions may be necessary, however, if voluntary efforts fail. It is appropriate to establish and to enforce regulations and penalties in the case of willful mismanagement. Regulatory policies should be based on scientific evidence and on the latest technologies. Scientifically based monitoring practices and baseline water parameters for a watershed are essential to determine whether BMPs implemented to meet water-quality standards are effective. Watersheds need to be analyzed carefully and environmental controls implemented with practical, site-specific solutions.

With the advancements in science and monitoring technologies, combined with the effects of practices, methodological adjustments to improve or to sustain water quality will be identified and implemented. A similar scenario is needed to develop air-quality regulations. In this case, an "air shed" concept may be needed to control odors, dust and other air contaminants effectively.

# 1 Introduction

## Domesticated Animal Agriculture: An Overview

Animals are important sociologically inasmuch as humans depend on them for companionship, pleasure, recreation, work, and food. Before the United States became an independent nation, many different animals roamed the land and humans hunted them for food. Other animals like horses were domesticated and used to till the land. During the last two centuries, domesticated animal agriculture has become increasingly specialized, efficient, and sophisticated and now is a major component of U.S. and international economies.

Animals provide an abundant supply of high-quality protein, vitamins, minerals, and energy for human diets. Additionally, the byproducts of animal production and processing are used extensively by every society in the world.

Increased intensity and size of animal production enterprises in the United States create great volumes of liquid and solid manures including feces, urine, bedding, wasted feed, and excess contaminated water, all of which require collection, storage, and utilization. Before intensive production operations were developed, solid manure normally was distributed on the land that animals grazed. But systems for collection, storage, treatment, and utilization became necessary as livestock and poultry production industries intensified. Initially, little attention was paid to the potentially adverse effects of animal manure on the environment.

Livestock production is concentrated in specific sections of the United States, and conflict over land use in certain areas has arisen because of the expansion of animal industries and human populations. At the beginning of the twentieth century, American society was largely rural. Today, it is largely urban, but people increasingly are becoming interested in moving to rural areas on small acreages. According to the last Agricultural Census (U.S. Department of Commerce, 1992), only 1.9 million of the nearly 263 million people in the United States are farmers, and only about 1.1 million depend on farming as their prima-

ry source of income. People living in rural areas often do not have any connection with agriculture and therefore have very little background knowledge of it. Notwithstanding, the general public, including inhabitants of rural areas, is becoming increasingly concerned about the environment.

Conflicts arising from (1) the nuisance of odors emanating from livestock and poultry operations and (2) water pollution from surface runoff or leaching into ground water as a result of nutrient overapplication have created a strained relationship between animal agriculture and the general public. When citizens learn that agriculture contributes 65% of all nonpoint source pollution to U.S. rivers, lakes, and streams, their perceptions of agriculture become negative, and they call for stiffer regulations (U.S. Environmental Protection Agency, 1991). This cycle exacerbates the problems of producers, who already are challenged to integrate many components of business into an efficient food production system.

The purposes of this document are (1) to assess current livestock and poultry production practices in light of the historical evolution of industrial and economic forces; (2) to identify environmental and public health concerns related to manure management practices; (3) to review the components involved in an integrated livestock and poultry operation, and thus to identify the variety of manure management systems used, the potential uses of manure as a resource, and the principles of environmentally sound integrated manure management; and (4) to discuss current limitations on improving animal manure management. This document reviews briefly the state of the art of animal-manure management research over the last three decades in the United States.

## Historical Perspective

In the United States, meat, milk, and eggs are staple foods and major sources of protein, vitamins, minerals, and energy in human diets. Animal-products consumption (Table 1.1) has changed over the last 25 years (yr) (Putnam and Allshouse, 1993). Food produced by the animal industry accounts for \$90.6 bil-

Table 1.1. Selected Items: Average annual per capita consumption (lb), selected periods<sup>a</sup> (Putnam and Allshouse, 1993)

	1970-1974	1975-1979	1980-1984	1985-1989	1990	1991	1992	1993
Meat, poultry, and fish <sup>b, c</sup>	176.5	177.7	178.9	185.1	183.3	184.7	188.8	187.9
Red meat <sup>b, d, e</sup>	130.2	128.6	123.8	120.0	112.3	111.9	114.1	111.9
Beef	79.1	82.8	73.1	70.5	64.0	63.1	62.8	61.5
Veal	1.7	2.3	1.4	1.3	0.9	0.8	0.8	0.8
Pork	47.6	42.4	48.3	47.1	46.4	46.9	49.5	48.7
Lamb and mutton	1.9	1.1	1.1	1.0	1.0	1.0	1.0	1.0
Poultry <sup>b, e</sup>	34.1	36.3	42.2	49.7	56.0	58.0	60.0	61.1
Chicken	27.4	29.4	33.7	38.4	42.2	43.9	45.9	47.1
Turkey	6.7	6.9	8.4	11.3	13.8	14.1	14.2	14.1
Fish and shellfish <sup>b, f</sup>	12.1	12.8	13.0	15.4	15.0	14.8	14.7	14.9
Fresh and frozen	7.0	7.8	8.1	10.0	9.6	9.6	9.8	10.1
Canned	4.7	4.5	4.5	5.1	5.1	4.9	4.6	4.5
Cured	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3
Eggs <sup>e</sup>	38.3	34.9	33.9	32.0	30.1	30.0	30.2	30.1
All dairy products, including butter <sup>g</sup>	554.2	542.3	558.6	586.9	570.7	565.3	564.9	572.2
Fluid milk and cream	270.7	256.7	239.3	238.2	233.4	233.1	230.9	226.6
Fluid milk products	265.6	251.3	233.3	230.7	225.8	225.4	222.9	218.6
Beverage milks	264.3	249.0	230.4	226.3	221.7	221.2	218.7	214.2
Plain	249.8	233.8	216.8	212.3	208.8	208.3	205.9	201.6
Whole	198.6	161.6	131.7	107.6	87.6	84.7	81.5	77.8
2% fat	34.2	46.8	59.0	73.6	78.4	78.9	78.5	76.6
1% fat	4.2	13.8	15.1	15.8	19.9	20.8	21.0	20.4
Skim	12.8	11.6	11.1	15.3	22.9	23.9	25.0	26.7
Flavored	9.3	10.7	9.4	9.8	9.4	9.5	9.6	9.6
Whole	6.6	6.3	3.7	3.4	2.8	2.7	2.7	2.7
Lowfat and skim	2.7	4.4	5.7	6.4	6.6	6.8	6.9	6.9
Buttermilk	5.2	4.5	4.2	4.1	3.5	3.4	3.2	3.0
Yogurt	1.2	2.3	2.9	4.4	4.1	4.2	4.3	4.3
Fluid cream products	5.2	5.4	6.0	7.5	7.6	7.7	8.0	8.0
Cheese <sup>b, h</sup>	12.9	16.0	19.5	23.5	24.6	25.0	26.0	26.3
American <sup>i</sup>	7.7	9.1	10.9	11.8	11.1	11.1	11.3	11.4
Other <sup>i</sup>	5.2	6.9	8.6	11.6	13.5	13.9	14.7	14.9
Frozen dairy products <sup>k</sup>	28.1	27.5	26.7	28.1	28.4	29.3	29.0	29.3
Ice cream	17.6	17.8	17.7	17.7	15.8	16.3	16.3	16.1
Ice milk	7.6	7.5	6.9	7.6	7.7	7.4	7.1	6.9
Sherbet	1.6	1.4	1.3	1.3	1.2	1.2	1.3	1.3
Condensed and evaporated milk <sup>b</sup>	10.7	8.1	7.1	7.8	7.9	8.2	8.5	8.2
Skim milk	4.5	3.6	3.3	4.3	4.8	5.0	5.2	5.2
Canned whole milk	5.1	3.3	2.7	2.2	2.2	2.1	2.1	1.9
Bulk whole milk	1.2	1.2	1.2	1.4	1.0	1.1	1.1	1.1
Nonfat dry milk	4.9	3.3	2.4	2.4	2.9	2.6	2.7	2.4
Fats and oils, fat content <sup>b, l</sup>	52.7	54.5	58.3	63.0	62.2	63.8	65.6	65.0
Vegetable fat	39.6	43.7	46.3	51.4	52.5	54.2	55.2	54.9
Animal fat	13.1	10.8	12.0	11.6	9.7	9.5	10.4	10.1
Fats and oils, product weight <sup>b</sup>	55.9	57.5	61.4	66.1	65.3	66.8	68.6	68.0
Butter	5.0	4.4	4.6	4.6	4.4	4.2	4.2	4.5
Margarine	11.0	11.4	10.8	10.6	10.9	10.6	11.0	10.8
Lard (direct use) <sup>m</sup>	3.8	2.7	2.4	1.8	1.9	1.7	1.7	1.8
Edible tallow (direct use) <sup>m</sup>	NA	NA	1.4	1.1	0.6	1.4	2.4	2.0
Shortening	17.2	17.6	19.0	21.9	22.2	22.4	22.4	22.9
Salad and cooking oils	16.7	19.5	21.7	24.6	24.2	25.2	25.6	24.3
Other edible fats and oils <sup>n</sup>	2.2	1.9	1.6	1.4	1.2	1.3	1.4	1.7



Table 1.1. (continued)

	1970-1974	1975-1979	1980-1984	1985-1989	1990	1991	1992	1993
Fresh fruit <sup>b</sup>	93.3	96.6	102.6	113.2	111.5	107.7	117.0	118.6
Citrus	26.9	25.7	23.8	22.9	20.6	18.4	23.5	25.0
Noncitrus <sup>b</sup>	48.2	53.7	60.1	67.9	68.5	68.1	71.3	71.4
Apples	15.6	16.9	17.3	18.7	19.0	17.5	18.5	18.7
Other noncitrus	32.5	36.8	42.8	49.3	49.6	50.6	52.8	52.7
Melons	18.2	17.3	18.7	22.4	22.4	21.2	22.2	22.1
Frozen fruit	3.3	2.9	2.8	3.4	3.5	3.4	3.6	3.5
Dried fruit	2.5	2.4	2.6	3.1	3.4	3.1	2.8	3.2
Canned fruit	19.2	18.5	16.6	16.4	16.5	15.4	17.8	16.1
Selected fruit juices <sup>o</sup>	51.7	59.0	64.7	69.5	60.0	69.0	63.6	73.2
Selected commercial fresh vegetables <sup>p</sup>	80.3	83.2	86.4	98.3	103.3	100.8	104.9	103.9
Processed vegetables (farm weight) <sup>b,q</sup>	115.7	114.2	113.5	116.8	129.7	132.8	129.6	132.8
Vegetables for canning <sup>b</sup>	97.4	95.3	94.6	95.2	107.2	109.4	107.2	107.9
Tomatoes for processing <sup>f</sup>	63.0	62.7	62.5	64.5	75.4	77.4	73.8	76.3
Other vegetables for canning <sup>s</sup>	34.4	32.6	32.1	30.7	31.8	32.0	33.4	31.6
Vegetables for freezing <sup>t</sup>	17.0	17.5	17.5	19.9	20.5	21.8	21.0	22.8
Mushrooms	1.2	1.9	2.5	2.9	3.1	3.0	2.9	3.2
Fresh potatoes	53.3	47.5	46.5	46.6	43.9	44.6	47.0	49.8
Frozen potatoes	14.9	20.2	19.8	23.0	25.1	25.6	25.5	25.7
Sweet potatoes (farm weight)	5.0	5.1	4.8	4.5	4.6	4.0	4.3	3.9
Dry edible beans (farm weight)	6.5	6.2	5.8	6.3	6.9	7.6	7.5	6.8
Dry edible peas (farm weight)	0.7	0.5	0.4	0.5	0.5	0.5	0.4	0.5
Tree nuts (shelled basis)	1.8	1.8	2.1	2.3	2.5	2.2	2.4	2.3
Peanuts (kernel basis)	5.7	5.8	5.7	6.6	6.0	6.5	6.2	6.0
Flour and cereal products <sup>b</sup>	134.9	141.2	146.8	167.9	183.3	185.6	187.0	189.2
Wheat flour	111.0	116.3	117.3	128.2	135.6	136.6	138.1	139.4
Rye flour	1.2	0.8	0.7	0.6	0.6	0.6	0.6	0.6
Rice (milled basis)	7.2	7.4	10.1	12.8	16.2	16.8	16.9	17.5
Corn products <sup>u</sup>	10.2	11.8	14.1	20.2	21.7	21.9	21.9	22.1
Oat products <sup>v</sup>	4.4	3.9	3.6	5.0	8.2	8.6	8.5	8.6
Barley products <sup>w</sup>	0.9	1.0	1.0	1.0	1.0	1.0	0.9	0.9
Coffee (gallons) <sup>x</sup>	33.1	29.0	26.4	26.7	27.0	27.1	26.9	26.0
Tea (gallons) <sup>x</sup>	7.2	7.4	7.1	7.0	6.8	6.9	7.1	7.1
Cocoa (chocolate liquid equivalent)	3.2	2.7	3.0	3.8	4.3	4.6	4.6	4.6
Total sweeteners <sup>b,y</sup>	129.9	131.2	135.5	152.6	161.8	164.9	NA	NA
Caloric sweeteners <sup>b,y</sup>	124.5	124.6	124.7	133.4	139.6	140.6	143.8	147.1
Refined sugar	100.5	91.5	74.7	62.0	64.4	63.8	64.5	64.2
Corn sweeteners	22.6	31.7	48.6	70.0	73.8	75.4	77.9	81.5
Low calorie sweeteners <sup>z</sup>	5.4	6.6	10.8	19.2	22.2	24.3	NA	NA

NA = Not available

<sup>a</sup>Retail-weight equivalent unless otherwise indicated. <sup>b</sup>Total may not add due to rounding. <sup>c</sup>Boneless, trimmed equivalent. <sup>d</sup>Excludes game meat and edible offals. <sup>e</sup>Excludes shipments to U.S. territories. <sup>f</sup>Excludes game fish. <sup>g</sup>Milk equivalent, milk-fat basis. Items shown separately are product-weight basis. <sup>h</sup>Natural equivalent of cheese and cheese products. Excludes full-skim American, cottage, pot, and baker's cheeses. <sup>i</sup>Cheddar, Colby, washed curd, stirred curd, Monterey, and Jack. <sup>j</sup>Italian cheeses and such miscellaneous cheeses as Swiss, Gouda, blue, and cream. <sup>k</sup>Includes mellorine and nonstandard frozen dairy products. <sup>l</sup>Fat content of butter and margarine is 80% product weight. <sup>m</sup>Direct use excludes use in margarine and shortening. <sup>n</sup>Specialty fats used mainly in confectionery products and nondairy creamers. <sup>o</sup>Single strength equivalent. <sup>p</sup>Artichokes, asparagus, snap beans, broccoli, Brussels sprouts, cabbage, cauliflower, celery, sweet corn, cucumbers, eggplant, escarole/endive, garlic, head lettuce, romaine and leaf lettuce, onions, bell peppers, radishes, spinach, and tomatoes. <sup>q</sup>Includes dehydrated onions. <sup>r</sup>Includes use in such tomato products as ketchup, tomato sauce, and canned tomatoes. <sup>s</sup>Asparagus, snap beans, beets, cabbage for kraut, carrots, sweet corn, cucumbers for pickling, green peas, chili peppers, and spinach. <sup>t</sup>Asparagus, lima beans, snap beans, broccoli, carrots, cauliflower, sweet corn, green peas, spinach, and miscellaneous vegetables. <sup>u</sup>Corn flour, meal, hominy, grits, and cornstarch; excludes corn sweeteners. <sup>v</sup>Oatmeal, oat cereal, oat flour, and oat bran. <sup>w</sup>Barley flour, pearl barley, and malt and malt extract. <sup>x</sup>Fluid equivalent. <sup>y</sup>Dry-weight basis. Includes honey and edible syrups. <sup>z</sup>Sugar sweetness equivalent.

lion of the total \$175 billion agricultural economy. Today, an agricultural producer in the United States feeds 123 people; in 1970, an individual producer fed only 48. Additionally, the food, plant, and animal agricultural system provides one of every five U.S. jobs.

Advances in research have been the basis for dramatically improved efficiency of animal production. Production units have grown in size, production intensity, and output efficiency. For example, total poultry meat and egg production changed from 2.2 million operations producing 5.8 billion pounds (lb) of meat and 5.3 million dozen eggs/yr in 1960 to 91,000 operations producing 28.8 billion lb of meat and 6.2 million dozen eggs/yr in 1990. Similarly, larger volumes of milk and milk products are produced today, by many fewer dairy cows, than were produced in 1965

(Figures 1.1a and 1.1b). The net result of the past 50 years' scientific and technological advancements is much greater animal protein production from less inputs at a much lower cost to the consumer. As production per animal unit increased, the need for fewer animals also decreased the impact of animal agriculture on the environment. Moreover, improved technology for wool production and animal byproducts such as leather, animal feeds, and other materials have contributed greatly to the standard of living.

Great changes in the structure of the livestock and poultry industries have occurred. A typical livestock farm 50 yr ago was diversified and often contained several species at one location. Today, most production units are specialized and intensive, often with only one species present. Similarly, over the last 30

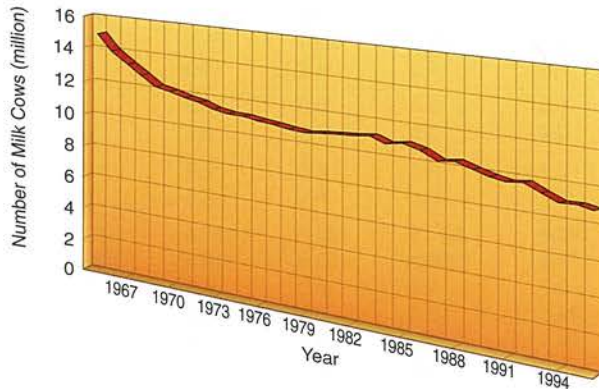


Figure 1.1a. Number of U.S. milk cows (U.S. Department of Agriculture, U.S. National Agricultural Statistics Service, 1965–1991).

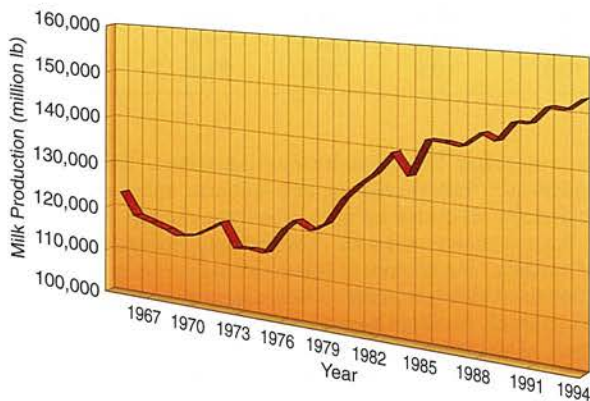


Figure 1.1b. Pounds of U.S. milk production (U.S. Department of Agriculture, U.S. National Agricultural Statistics Service, 1965–1991).

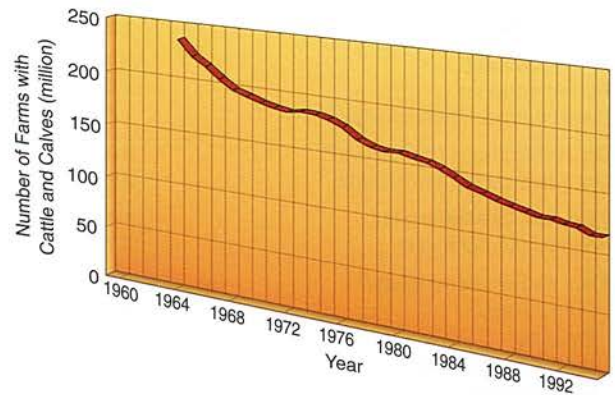


Figure 1.2a. Number of U.S. farms with cattle and calves (U.S. Department of Agriculture, U.S. National Agricultural Statistics Service, 1964–1992).

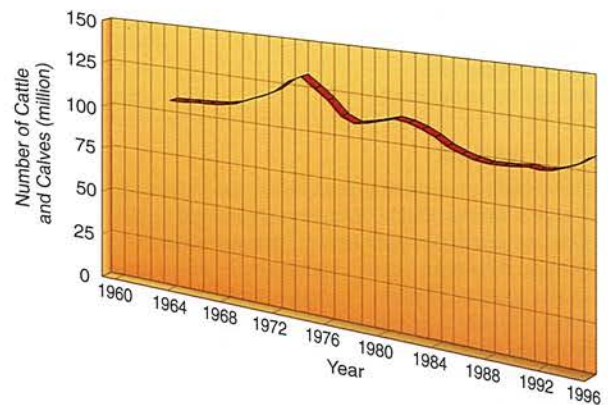


Figure 1.2b. Number of cattle and calves in the United States (1,000) (U.S. Department of Agriculture, U.S. National Agricultural Statistics Service, 1964–1992).

yr, cattle/calf and swine numbers have increased or held steady as the number of operations has decreased significantly (Figures 1.2a and 1.2b; 1.3a and 1.3b). Early in the twentieth century, diversified farms were located throughout the United States. Today, livestock and poultry production tends to be concentrated in areas with the necessary climatic conditions, feed resources, and processing industries. Figure 1.5 identifies the major livestock and poultry producing states.

With increased operation size and management intensiveness, significant volumes of manure are produced. The estimated collectable volume of manure produced by confinement animals in the United States is estimated at more than 61 million tons (t) of dry matter/yr (Table 1.2). This estimate is based on the annual inventory of livestock and poultry in intensive

production units. Manure produced from livestock in pasture systems is not collected easily, so such data are not included. The potential nutrient value of manure is determined according to the management systems used for manure collection, storage, treatment, utilization, and replacement value. Additional information about landbase available, potential manure nutrients available, crops grown, and commercial fertilizer usage, by region of the United States, appears in Tables A1–A6 (see Appendix A).

The concentration of animals on limited landbases and the proximity of such operations to residences have raised concerns about the environmentally acceptable management of animal manure. Major problems concerning nuisances and/or potential health effects have been caused by overapplication of manure

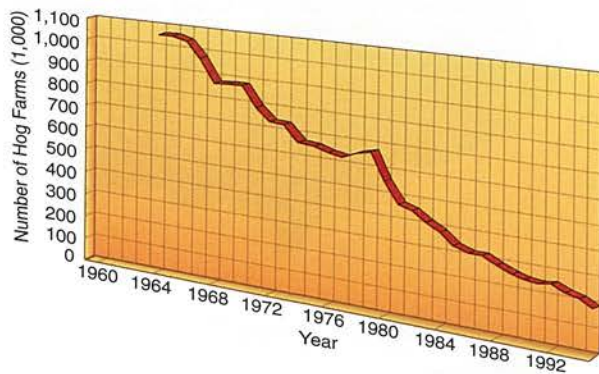


Figure 1.3a. Number of U.S. farms with hogs (U.S. Department of Agriculture, U.S. National Agricultural Statistics Service, 1964–1992).

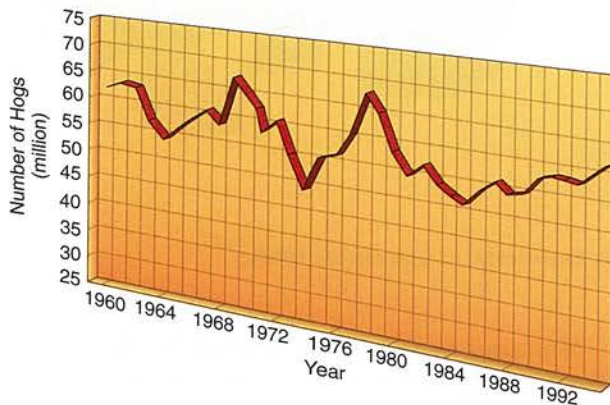


Figure 1.3b. Number of hogs in the United States (1,000 head) (U.S. Department of Agriculture, U.S. National Agricultural Statistics Service, 1964–1992).

Table 1.2. Livestock and poultry manure production in the United States<sup>a</sup> (tons dry matter x 1,000)

Class of animal	Total production	Estimated collectable
Beef cattle (range)	46,678	1,699
Feeder cattle	18,364	17,998
Dairy cattle	26,738	23,626
Swine	8,496	8,325
Sheep	2,996	1,603
Layers	3,038	2,978
Turkeys	1,250	1,225
Broilers	4,168	4,084
<b>Total</b>	<b>111,728</b>	<b>61,538</b>

<sup>a</sup>Based on average annual animal inventory, manure dry matter production values, and estimated recoverable amounts of manure for land application (Midwest Plan Service, 1985; Sutton et al., 1985).



Figure 1.4. Broiler production with litter manure management system. Photograph courtesy of Don D. Jones, Purdue University, West Lafayette, Indiana.

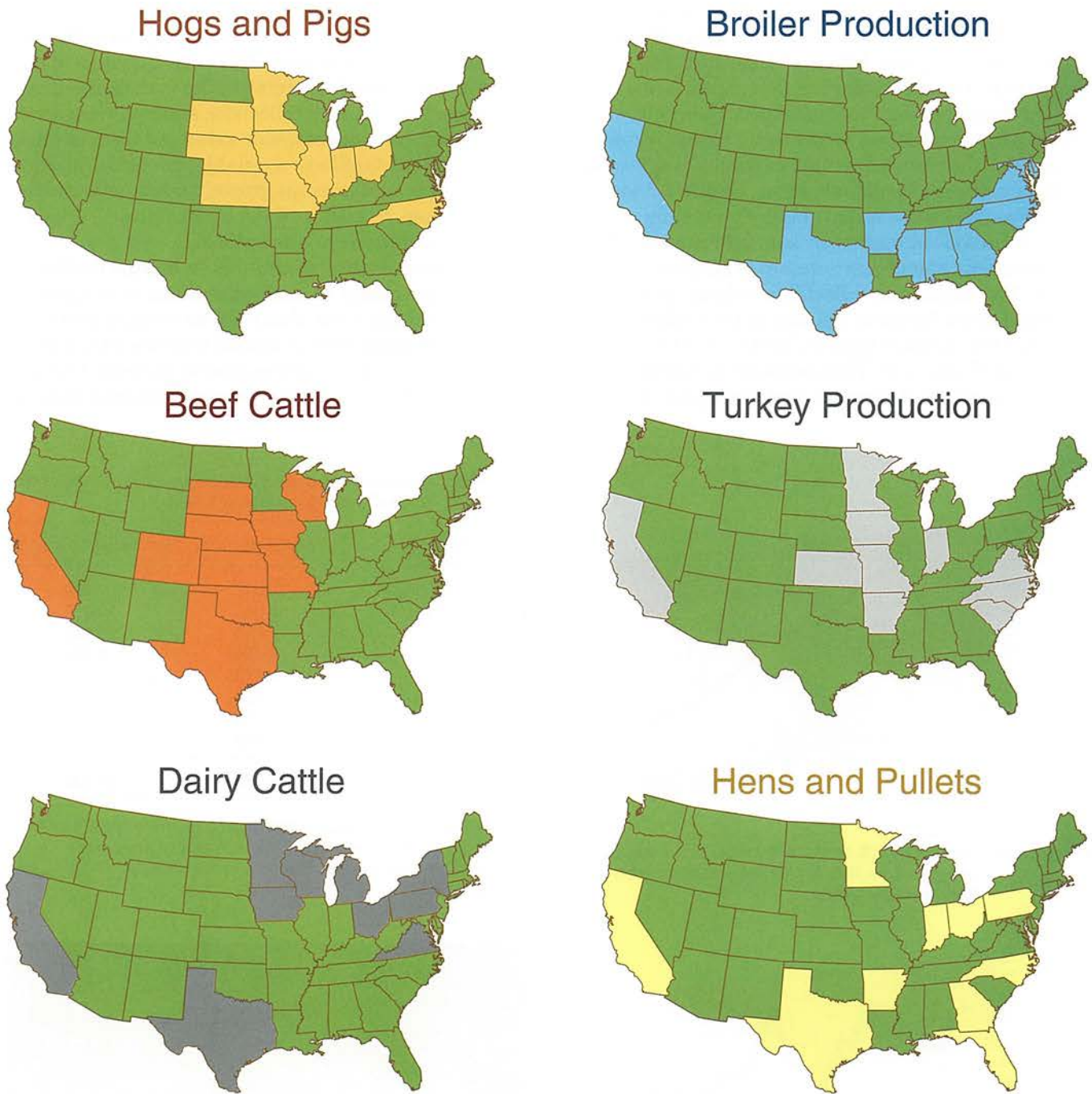


Figure 1.5. Top-ten animal producing states in the United States (U.S. Department of Commerce, 1992).

to soils—a practice potentially resulting in salinization, nutrient movement into ground water, surface water eutrophied by feedlot runoff, transmission of disease organisms potentially affecting animal and human health, and excessive fly populations and odor emission from livestock and poultry enterprises.

Manure composition is affected by the diet fed to livestock, manure collection and storage method, and extraneous materials added, e.g., spilled feed, excess water, and bedding. Extremes in manure management can range from minimal treatment and maximum conservation of nutrients to maximum treat-

ment with minimal conservation of nutrients. Because of the variability of manure nutrient composition after storage, producers have been reluctant to utilize manure as a nutrient resource on land. In fact, distinctly different management systems and practices are required for the successful utilization of diverse types of manures.

## Economic Perspectives

Fundamental economic forces at consumer and producer levels have a powerful influence on livestock production and on both control point and nonpoint pollution emanating from livestock facilities. Consumer preferences are reflected in the marketplace, which dictates the scale of economic activity of any industry, including the extent of associated nonpoint and point source pollution. Producer response to consumer preferences generally depends on technology and price but also is affected by current or proposed regulatory policies related directly to nonpoint and to point source pollution control. Public policies such as government regulations aimed at decreasing pollution play an important part in facilitating or constraining producer response to the economic environment. Other public policies such as government supported research and development efforts also affect pollution control activities directly.

### Financial Considerations of the Livestock Production Sector

Benefits and costs of alternative manure management systems are a primary determinant in the selection of a livestock operation system. When faced with the added costs accompanying new pollution control regulations, many producers must decide whether or not to remain in the livestock business. Public policies forcing production units to control pollution without compensating them for additional costs usually result in some units' (typically those of small to moderate size) exiting the industry or increasing in size and intensity. Either outcome may have negative effects on local communities.

For producers, benefits from livestock manure may be gained through the resource recovery processes. That is, properly utilized livestock manure is an economical source both of nutrients for plants or livestock feed and of energy. Given current price relations and adoption ease, manure's primary benefit for producers is as a nutrient source for crops. But substantial price increases for livestock feed ingredients or for fossil fuels could make livestock manure more attrac-

tive as a source of feed ingredients and energy (Huang, 1979). Benefits from humus, nitrogen (N), phosphorus (P), potassium (K), and minor element contents of manure depend greatly on livestock species, as well as on the handling, storage and application technologies, and nutrient needs of plants.

Benefits from nutrients occur only when they are utilized effectively. Ineffective utilization occurs when, to decrease transportation costs, manure is applied generally to nearby fields at high application rates. Generally, high application rates decrease the economic benefits of manure (Schnitkey and Miranda, 1992) and increase the potential for pollution. If land is available, most producers have an economic incentive to apply manure at rates low enough to utilize available nutrients effectively and to incur additional transportation costs. Negative values for high application rates resulting in land and water pollution seldom are assessed against the individual operation in economic analyses.

If one ignores the costs associated with land and water pollution, then the net costs of livestock manure management systems are underestimated because manure collection, storage, and utilization are integral to the overall livestock enterprise. Direct costs of controlling pollution from livestock facilities generally are underestimated inasmuch as resources such as labor are valued at a standard wage rate rather than at opportunity cost (Pherson, 1974). For example, winter storage of manure runoff may be costly from a labor standpoint whereas time used for spring application of stored manure may be taken from field operations critical to a successful crop. Manure system budgets may underestimate direct economic costs to the producer by as much as 40% (Ashraf and Christensen, 1974). Regrettably, the authors have no acceptable methods of calculating *true costs*, in which all costs associated with pollution control are factored.

A review of 244 livestock production technologies indicates that methods exist with which to control water pollution and odor nuisance at acceptable levels (White and Forster, 1978), but this level of control often requires a substantial investment. Definitions of *acceptable levels* for control of water pollution and odors lead to controversy over the proper management practice and design of manure management systems. Strict regulatory policies and major changes in livestock manure management systems could increase production costs significantly. Most existing production systems can be modified, at a modest cost, to control runoff from exposed lot surfaces and from fields in which manure is applied, to lower manure application rates to acceptable levels, and to use appropri-

ate management practices to minimize odor nuisances.

Other practical problems or costs associated with manure utilization include the compaction of soil by application equipment, the perceived need to till a field more than once when incorporating manure into the soil, and the nonuniform composition and distribution of manure during application (Badger, 1977). These concerns are excluded from most analyses but do influence producer choice regarding a manure management system.

There has been no recent *net cost analysis* (fixed and variable costs less nutrient benefits) reported for common manure management systems. A study by White and Forster (1978), however, identified five general principles. (1) Net system costs differ substantially by size of operation; but, generally, the larger the operation, the lower the cost per animal unit. (2) Net system costs are greater for confined systems than for open lot systems. (3) Storage cost is not recovered by the enhancement of manure nutrient concentration. (4) Incorporation of manure by injection or plow-down is cost effective when used in conjunction with storage of concentrated manure nutrient sources. (5) If runoff is to be controlled from open lots, runoff detention and irrigation increase net system costs substantially more than grass infiltration systems do.

Manure handling system costs usually are an important cost component—especially for small producers, but these costs tend to constitute a small proportion of total production cost. A more important issue is that manure management and control of pollution from livestock facilities tend to exacerbate the competitive disadvantage of small production units because smaller producers face higher per-unit costs for manure management. In the end, *industry structure*, i.e., size distribution of the industry's production operations, may be affected significantly by public policy regarding livestock manure management.

The capital to which livestock production unit operators have access may be affected greatly by lender response to environmental regulations. The financial community has been awakened by a series of recent federal laws and court decisions speaking to the necessity of sound manure management and pollution control practices (Olena, 1991). The Comprehensive Environmental Response, Compensation, and Liability Act, or *Superfund*, enacted in 1980 authorizes the U.S. Environmental Protection Agency (EPA) to clean up contaminated sites and to recover cleanup costs from those responsible. Although the act offers lenders some liability protection if they do not participate in facility management, later court rulings have in-

terpreted this liability protection narrowly. Lenders have been held accountable for cleanup costs of environmentally damaged sites at which the lender exercised management control over the borrower or to which the lender acquired title by foreclosure and failed to sell the property within a reasonable period.

As a result of legislation and case law, livestock producer access to capital markets may be affected in three ways (Mazzocco, 1991). Lenders may be liable, as just discussed, when they exercise management control or acquire title to real estate. Because of this potential liability, lenders may decrease lending activities to livestock facilities with the potential to impair water quality or to cause odor nuisances. Second, credit supply may be affected by lender knowledge that judgments obtained by the government for environmental damage will affect repayment ability. Finally, cost of regulatory compliance has an impact on borrower financial strength and ultimately on borrowing capacity. A recent survey (Mazzocco, 1991) indicated that 62.5% of surveyed lenders had rejected loan applications and that 45% had discontinued certain types of loans because of potential environmental liability.

### Societal Concerns and Economic Impacts

The environmental consequences of agricultural production began attracting widespread attention in the United States in the 1930s. Both policy makers and the general public were interested primarily in safeguarding soil and water resources as a means of safeguarding future agricultural production. Moreover, in the United States, soil and water conservation policy was designed almost from the beginning to enhance agricultural income, to control commodity production, and to accomplish other agricultural policy goals (Rasmussen, 1982; U.S. General Accounting Office, 1983).

By the 1970s, a new theme—concern about agricultural effects on downstream water users—emerged in agricultural policy. Runoff from feedlots and erosive agricultural practices were linked to fish kills, excessive nitrate concentrations in both surface and ground waters, eutrophication, and river, lake, and stream sedimentation. Accordingly, a mandate to decrease point source pollution such as runoff from larger livestock facilities was included in 1972 amendments to the Federal Clean Water Act (Public Law 92-500).

Most nonpoint and point sources of pollution are consequences of economic activity—especially of food production. It is estimated that all agricultural sources are responsible for 66% of total suspended solids,

74% of total P, 81% of biological oxygen demand (BOD), and 95% of pesticide loading in surface water (Crosswhite and Sandretto, 1991). Nevertheless, a community would eliminate *all* pollution only under the rarest circumstances and then only if the community takes a “not in my back yard” approach to livestock enterprises. To do so would decrease food production significantly and/or escalate the price of food for consumers. A more typical problem is that of decreasing point and nonpoint source pollution so as to approach a positive but more socially acceptable level. To develop a policy accomplishing this objective, understanding of why individuals choose practices that may produce minimal levels of pollution but are still potentially excessive from a social standpoint is essential.

Economic performance can be suboptimal because individual economic factors often fail either to pay the full social costs of required activities or to capture the intended social benefits (Meade, 1973). Specifically, when some of the social costs of pollution control (or the social benefits of resource conservation) are external, then natural resource management will be suboptimal from a social standpoint. For example, if a farmer fails to adopt surface water pollution control measures, then recreators, public utilities, and other downstream users incur the cost of meeting water-quality standards. On the other hand, by decreasing the rate at which soil or animal manure runs off treated land, a producer benefits other members of society but at a significant cost to his/her own operation; there is no opportunity to transfer this cost to the consumer.

Because society provides those in agriculture with no strong economic incentive to control pollution, farmers tend to promote suboptimal levels of pollution control to maintain economic viability. Regulations can restrict current operations and new development severely, thereby forcing animal producers to move operations to other countries. This effect needs to be considered in efforts to maintain the viability of livestock industries in certain areas of the United States.

### Nonpoint Source Pollution

Direct mechanisms that governments can use to promote pollution control are (1) regulation of pollution emission levels, (2) levying of polluter taxes, (3) paying of subsidies or other incentives to encourage pollution reduction, and (4) funding of research-education programs.

Because regulation can be costly to administer ef-

fectively, economic incentives often are advocated when practical (Baumol and Oates, 1975). Both taxes on emissions and subsidies for emission reductions are less costly to administer than regulations. Both also provide direct incentives for developing new emission control techniques. Taxes or subsidies increase producer benefits from pollution control, increase level of control, and narrow the gap of expectations between society and producer.

The marketing of so-called “pollution rights” often works in the point source context but is less successful in the nonpoint context. It is costly and inexact to use runoff control regulations to monitor compliance from nonpoint sources, especially from livestock and poultry operations. Often no standards exist. Administrative costs would be especially burdensome in agriculture, in which nonpoint pollution may occur for hundreds of thousands of producers and affect a large watershed.

The public sector must take into account how policies affect income distribution. For example, a tax at the producer’s expense to decrease runoff from agricultural land to a socially acceptable level would put some financially unsteady producers out of business; in this sense, a tax would give larger producers an advantage. This scenario generally is unacceptable to policy makers and to the general public.

Using a linear programming model of agriculture in a watershed located in the State of New York, Jacobs and Casler (1979) found that a \$100/kilogram (kg) tax on soluble P runoff would decrease nonpoint P runoff in no more than 20% of cases. Simultaneously, the tax would cause annual agricultural income in the watershed to fall by \$1 million, adding a huge economic cost for runoff monitoring. These results suggest that taxing nonpoint source pollution involves concerns of equity and efficiency.

Partly because of the administrative costs of alternative policies, U.S. soil and water conservation policy has stressed *subsidization*, or cost-sharing, along with technical assistance and education regarding certain agricultural practices. From 1984–1990, the U.S. Department of Agriculture’s Agricultural Conservation Program spent nearly \$1 billion on cost-sharing agricultural practices to control erosion, to conserve water, and to improve water quality (U.S. Department of Agriculture, 1991). About \$40 million of this total went to animal manure management practices. These funds need to be allocated in instances when environmental impacts can be balanced with productivity (Ribaudo, 1986).

Much of the public soil and water conservation and nonpoint pollution control effort in the United States

has been based on a research-education approach. Many federal agencies have worked together to develop new soil conserving management practices, to educate producers about the effects of management practices on environmental quality, and to develop total nutrient and resource management plans for farms. Federal government efforts to enhance farm income and to control farm production require that producers use these conservation plans before receiving commodity payments. Sometimes, farm program plans conflict with water quality goals. For example, some counties do not allow farmers participating in commodity programs to spread animal manure on cropland idled by the Federal Acreage Reduction programs. This restriction may prevent timely application of manure on cropland. Another example is the restriction on incorporation of manures into soils requiring specific levels of residue cover. Addition of manures decreases erosion, and incorporation diminishes N losses and odors to the atmosphere.

In recent years, however, federal support for research and education programs in soil and water conservation has been a low priority, and funding has decreased accordingly. As a result, very little research and education support has been directed to animal manure management. If the public is serious about addressing these issues, then it will need to empower government to make a larger investment.

### Other Factors and Government Policies Affecting Nonpoint Source Pollution

Public policies often have more effect on nonpoint source pollution than explicit pollution control policies do (Henderson and Barrows, 1984). For example, the demand for downstream water resources provides an economic incentive to control pollution. The "proper" level of pollution is driven as much by downstream-user demands for water with low pollutant concentra-

tions as it is by factors within agriculture. Because of differences in demand, the definitions of *good* and *bad* water quality change from one watershed to the next. But the federal government "one size fits all" mandate results in decreased economic returns with little benefit to the environment.

Many elements in society advocate that nature should be tended and nurtured rather than dominated, that technology must be considered in relation to the natural environment, and that the effect of human production activities on nature must be examined. These values affect government policies and producer attitudes governing soil conservation, land preservation, chemical use, and animal manure management. At the same time, consumer preferences for low-cost and high-quality animal protein products require that grain-fed livestock be concentrated in operations producing significant quantities of manure, with the potential for polluting nearby streams and other bodies of water. Often, citizens want to have it both ways, with someone else paying the bill.

Tenure of producers and size of farm operations also influence nonpoint source pollution. Producers with short-term tenure arrangements have little incentive to control nonpoint source pollution. Large producers may approach pollution from a purely economic standpoint. On the other hand, debt-free producers using family labor and capital typically consider conservation and environmental as well as economic goals in their decision making.

Finally, the managerial talent of producers is an important factor. Higher education, strengthened entrepreneurial abilities, and improved information systems make producers more flexible in using resources, less resistant to change, and more willing to decrease nonpoint source pollution when given the proper incentives and information about economically viable alternatives.



## 2 Environmental and Public Health Concerns

Ecological components of agriculture, e.g., soil, water, climate, crops, nutrients, bacteria, and animals, all are related in unique cycles. These close relationships are illustrated by the hydrologic cycle (Figure 2.1) and by the N cycle (Figure 2.2). In a livestock production system, manure management directly affects ecology. Nutrients in livestock manure should be recycled for crop growth or be processed and utilized in an environmentally sound fashion. The age-old practice of spreading manure on cropland is well founded, but poor application practices can cause problems such as odor, water pollution, and soil pollution. Other appropriate methods of manure utilization will be described later in this document.

Because manure is primarily organic, it is largely biodegradable through microbial decomposition, which can cause gases, odors, and significant changes in nutrient contents. Manures may produce other

potential pollutants and animal diseases transmissible between humans and animals. The objective of livestock waste management is the economical creation of end-products that are free from objectionable odors and transmissible diseases, that are biologically and environmentally stable, and that do not contaminate air, water, or soil resources. A discussion of potential pollutants and health issues related to manure management systems follows.

### Water Quality

A major environmental and health concern associated with integrated manure management systems is the effect of animal manure on water quality. If improperly managed, manure can affect quality of both surface and ground waters adversely. For example, manure deposited on a typical beef cattle feedlot in

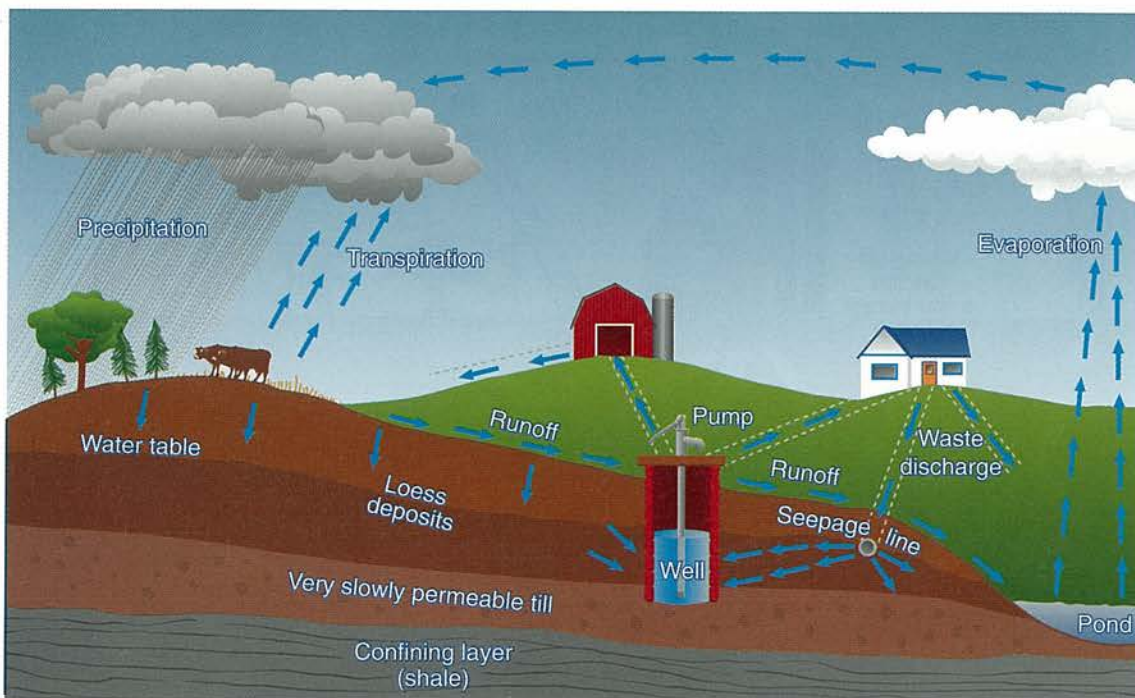


Figure 2.1. The hydrologic cycle from a farmstead viewpoint; a shallow well and a farm pond (Dickey and Lembke, 1978).

Nebraska contains 25 to 37 t of N/acre (a./yr (Loehr, 1974) and can result in respective runoff losses as great as 1,430 lb N/a./yr and 555 lb P/a./yr. Runoff from manured fields carries sediments, nutrients, and other contaminants to surface waters, and ground water can be threatened by leaching of soluble materials from the manure. In contrast, manure deposited from beef cattle herds' grazing pastures would be 0.06 t of N/a./yr. Data on nutrient runoff from manure in pasture systems are limited.

Although this discussion presents the impact on surface and ground water qualities separately, in many instances, surface and ground waters are interconnected and can interchange water sources. Thus, polluted surface water infiltrating into ground water can cause degradation. On the other hand, polluted ground water providing base flow to streams through seepage, springs, or tile drains can degrade surface water.

### Surface Water

A recent U.S. EPA (1991) survey showed that agriculture was the major source of nonpoint pollution of rivers and lakes and that nutrients and organic en-

richment were two of the top three pollutants of surface waters. Livestock enterprises can affect surface waters in several ways. These include direct runoff of pollutants from livestock areas into streams, lakes and reservoirs, or estuaries, and by fallout of pollutants originating in livestock areas as particulate matter, direct absorption, or precipitation.

Surface runoff may originate with pastures, concentrated open feeding areas, poorly designed manure storage areas, or fields to which manures have been applied. Tile drainage from manured fields can deliver leachate to surface waters. In all instances, this runoff may contain organic and inorganic compounds in solution, particles, and sediments, along with the N, P, and other nutrients. Runoff also may carry coliforms, other bacteria, and viruses. The potential for humans to develop, through exposure to water by consumption or recreational means, chronic zoonotic diseases is a societal concern.

Examples of potentially transmissible diseases related to humans (Diesch, 1969) are

1. bacterial diseases: salmonellosis, leptospirosis, anthrax, tularemia, brucellosis, erysipelas, tuberculosis, tetanus, and colibacillosis;

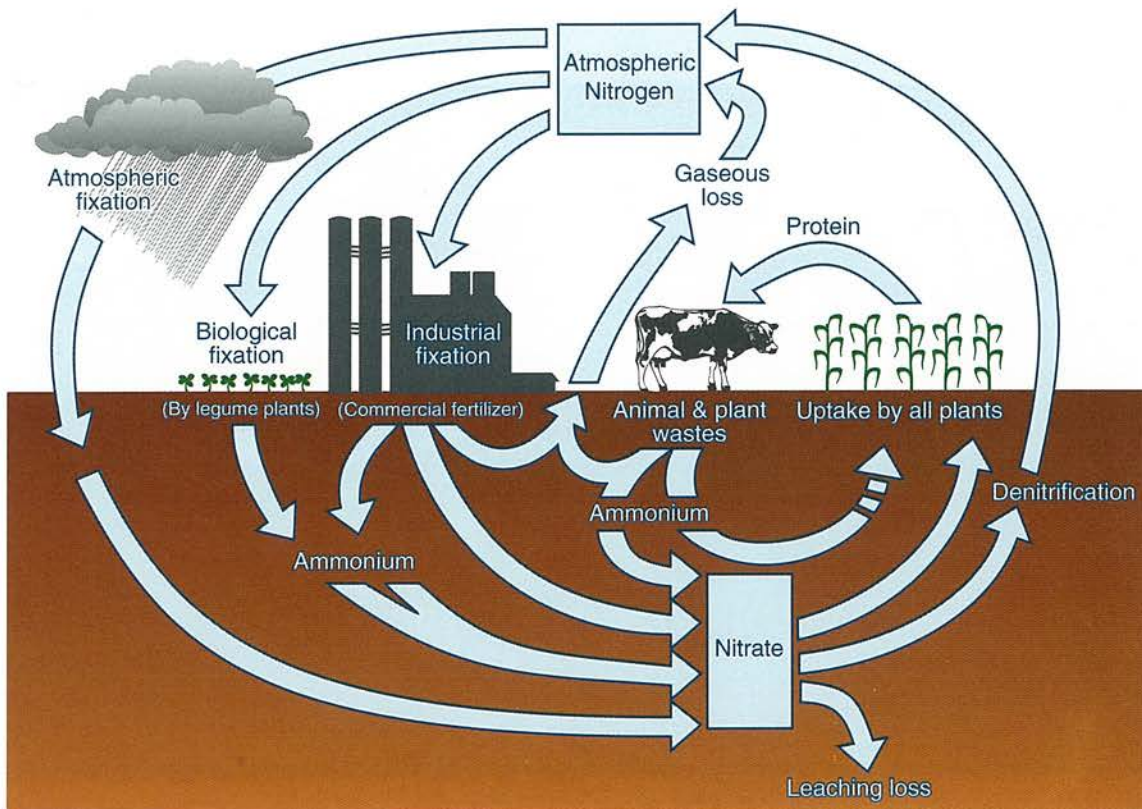


Figure 2.2. The nitrogen cycle.

2. rickettsial diseases: Q fever;
3. viral diseases: Newcastle, hog cholera, foot-and-mouth, and other viral-like diseases;
4. fungal diseases: deep systemic mycosis, histoplasmosis, and superficial mycoses-ringworm; and
5. parasitic diseases: balantidiasis, toxoplasmosis, ascariasis, strongyloides, cryptosporidia, and taeniasis-beef tapeworm.

Because of enhanced disease control and current animal management practices, however, very few of these listed are of any concern to human health. Pathogenic bacteria cannot compete in a saprophytic bacterial environment and are overgrown unless the pathogen has an environmentally resistant form. Epidemiological problems usually do not occur when bedding is used, for stacked manure with bedding develops temperatures sufficient to destroy pathogens (Strauch, 1977b). In modern animal confinement facilities, however, e.g., open lots, bedding is used rarely and much manure is handled and stored as a liquid or a solid mixed with soil. Spontaneous generation of heat that could destroy pathogens will not occur generally in liquid manure systems but can occur in solid handling systems if bedding is allowed to reach high temperatures. In low-humidity, high-temperature climates, solar sterilization and desiccation of manure occurs in open lots.

Self-disinfection can occur with time in liquid manure storages, especially in anaerobic lagoons, but laboratory and field experiments have shown that *Salmonella* or stable forms of parasites may remain alive in liquid cattle slurry manure in summer and in winter for several months (Table 2.1). *Salmonella cholera-suis* and total coliforms in swine lagoon wastewater held at 27°C died out in 33 days (d) or less (Krieger et al., 1975). Die-out of pathogens is more pronounced during the summer than during the winter. In dairy cattle manure (2.5% dry matter), *Salmonella typhimurium* died out in 44 d when the manure was held at 10°C and in 3 d when the manure was held at 35°C (McCaskey and Jaleel, 1975). Lagoons for storage of liquid manures are built to provide manure storage capacity for at least six months (mo) and longer in cold climates; thus, the elimination of enteric pathogens such as *Salmonella* and *Escherichia* from stored liquid manures is ensured. Viruses, especially those enclosed in tissue or in fecal segments, have a viability of several months and require a 3-mo storage time for self-disinfection.

The potential of disease transmission by recycled lagoon effluent in gutter flush systems remains a con-

cern. Variable results regarding pathogen survival have been observed when manure is stored in *anaerobic* lagoons, i.e., lagoons lacking oxygen. Pathogenic *Salmonella* and *Treponema hyodysenteriae* survived in anaerobic swine manure pits and in single-stage lagoons (Glock and Schwartz, 1975). *Salmonella typhimurium* seeded in swine and dairy lagoons existed in the lagoon effluent for 32 d after inoculation (Hill et al., 1981a; Hill et al., 1981b).

Variable rates of survival have been observed with parasitic organisms in manure storage systems. In a 22°C *aerobic* system, that is, in a system containing oxygen, *Ascaris suum* eggs larvated in 28 d but *Ascaris* eggs were unlarvated in other treatments (12°C anaerobic; 22°C anaerobic, and 12°C aerobic) (Marti et al., 1980). *Metastongylus spp.* eggs survived all treatment systems, but some larva hatched and died under aerobic conditions. *Oesophagostomum dentatum* and *Hyostongylus rubidu* larvae survived easily under 12°C aerobic conditions but were destroyed within 11 d at 22°C. *Strongyloides ransomi* eggs

Table 2.1. Viability of *Salmonella* serovars in cattle waste slurry in laboratory tests (Strauch, 1977b)

Slurry mixture	Organism	Days of survival	
		8°C	17°C
<b>Mixture I</b> (11% feces, 9% urine, 77.8% water, 2.2% straw)			
	<i>S. enteritidis</i>	320	200
	<i>S. gallinarum</i>	50	50
	<i>S. typhimurium</i>	125	60
	<i>S. paratyphi B</i>	175	50
	<i>S. cairo</i>	350	150
<b>Mixture II</b> (11% feces, 9% urine, 80% water)			
	<i>S. enteritidis</i>	280	140
	<i>S. gallinarum</i>	80	80
	<i>S. typhimurium</i>	50	50
	<i>S. paratyphi B</i>	50	20
	<i>S. cairo</i>	300	120
<b>Mixture III</b> (11% feces, 9% urine, 70% water, 10% sludge)			
	<i>S. enteritidis</i>	300	100
	<i>S. gallinarum</i>	120	80
	<i>S. typhimurium</i>	60	60
	<i>S. paratyphi</i>	60	40
	<i>S. cairo</i>	280	100
<b>Mixture IV</b> (11% feces, 9% urine, 79.8% water, 0.2% superphosphate)			
	<i>S. enteritidis</i>	300	160
	<i>S. gallinarum</i>	120	120
	<i>S. typhimurium</i>	130	60
	<i>S. paratyphi B</i>	120	50
	<i>S. cairo</i>	300	150

hatched rapidly under aerobic conditions but also survived at least 7 d under anaerobic conditions.

Fecal coliform bacteria in water are indicative of fecal contamination because these bacteria are present universally in the feces of every warm blooded animal. Their presence at elevated numbers suggests that enteric pathogens also could be present. Most waters, however, have a background level of coliform organisms resulting from wildlife and other such activity. Runoff and leaching from properly managed livestock grazing or properly managed manured cropland generally do not raise levels of coliform organisms in runoff significantly. Generally, if manure is incorporated into the soil during or immediately after application, nutrient concentration and coliform counts of runoff water from such fields are little, if any, greater than those from fields without manure. The primary source of microbial contamination of water is improper runoff control from animal confinement areas.

Nutrients may be added to water by runoff, leaching, or absorption from atmospheric sources, which include dry deposition (particulate matter), precipitation, or direct absorption of atmospheric ammonia ( $\text{NH}_3$ ). Frequently, in many open confined feeding operations, greater than half the N excreted by livestock is volatilized as  $\text{NH}_3$  gas (Arndt et al., 1979). Most is removed from the atmosphere through absorption by growing vegetation, absorption into water bodies, and fallout in precipitation. Consequently, much of the N escaping feedlots as  $\text{NH}_3$  returns to the soil-plant-water system within a few miles of its origin. It has been estimated that within a few miles of feedlots more than 100 lb N/a./yr can be returned to the soil and water as  $\text{NH}_3$ , with this quantity decreasing with distance from the livestock source. Thus, lakes and reservoirs near livestock confinement areas often are enriched by  $\text{NH}_3$  absorption and particulate fallout. The quantity of N that precipitation adds to water bodies (about 10 to 20 lb N/a./yr) far from livestock sources usually is somewhat less than that close to the sources and is less dependent on distance from  $\text{NH}_3$  source.

Surface water also can be contaminated by runoff from grazed pastures. Sediment load can be increased by overgrazing and by bank erosion resulting from livestock trampling. Best management practices (BMPs) to control these sources of pollutants seem to be using proper stocking rates and rotational grazing and controlling access to streams and watering ponds, usually by means of fences and water tanks. To date, there is limited scientific data verifying that these BMPs are effective.

Few BMPs to control  $\text{NH}_3$  volatilization from manure have been developed. Usually the problem is most serious in open lot operations in which manure is allowed to accumulate on the ground until annual or semi-annual removal. In many swine and dairy operations, manure is stored in either stacks or tanks from which much less  $\text{NH}_3$  escapes than from feedlot storage. Ammonia volatilization might be decreased by means of certain additives such as bedding, superphosphate or phosphoric acid, sulfur-containing compounds (including alum), or calcium chloride (Miner, 1995). Some of these materials have been used successfully in poultry houses, but their potential for use in livestock feedlots has not been evaluated thoroughly.

When  $\text{NH}_3$  enters a stream or lake directly, it exerts an oxygen demand and at concentrations greater than 2 milligrams/liter (mg/L) can be toxic to some fish species. The  $\text{NH}_3$  concentration in manure typically is 100–300 mg/L and can be as high as 10,000 mg/L (Ackerman, 1985). Wastewater treatment facilities located in regions with  $\text{NH}_3$  concentration regulations may not discharge effluent with  $\text{NH}_3$  levels above 4 mg/L in winter and 1.5 mg/L in summer. But field investigations in three Illinois counties showed average stream  $\text{NH}_3$  concentrations from 26 to 1,519 mg/L (Figure 2.3).

For land application of manure, losses of manure N and P in field runoff are related to rate, timing, and method of application; soil characteristics such as slope and texture; cropping management practices; and weather after application. Greatest enrichment of runoff occurs when manure is surface applied to frozen soil, especially when a major runoff event occurs shortly after application.

There is a high correlation between manure N and P loading rate and both concentration and total yield of N or P in runoff ( $r = 0.72\text{--}0.93$ ) (Khaleel et al., 1980). At high manure P loadings (223 lb P/a./yr), P losses were 1.8 lb P/a./yr with no snowmelt and 15.7 lb P/a./yr with snowmelt runoff. Manure P application rates of more than 50 lb P/a. seldom would be recommended, however. Results depend greatly on when runoff occurs relative to application time. A 1-d delay between application of liquid manure and a simulated rainfall has been shown to decrease pollution potential by at least 80% (Ross et al., 1979).

Manure application methods affect nutrient loss because (1) surface applied manures undergo less rapid decomposition and therefore may contain a higher concentration of contaminants and (2) manure incorporation will improve soil physical condition and thereby decrease runoff volume and erosion. Incorporation

ration frequently leads to less runoff of nutrients than on unmanured land. If manures are left on the soil surface, they may have a mulching effect (Mueller et al., 1984; Young and Mutchler, 1976) resulting in decreased particulate loss; but runoff of dissolved nutrients may increase. These elevated soluble nutrient levels are especially evident on cropland in which incorporation is impossible, such as in alfalfa fields (Wendt and Corey, 1980; Young and Mutchler, 1976) or on no-till areas (Mueller et al., 1984). Soluble P concentrations from manured plots may be several times greater than those from unmanured plots. Total loss of soluble P may increase little due to decreased runoff volume.

Loss of soluble P in runoff can be minimized by proper selection of the manure application rate and of the location and condition of fields on which manure is to be spread. An effective method of attenuating nutrient runoff is the use of vegetative buffer strips. A 25-foot (ft) forest buffer strip has been shown to decrease nutrient runoff from manured alfalfa plots to background levels (Doyle et al., 1975). Similarly, a 120-ft buffer planted to corn decreased feedlot runoff to background levels (Young et al., 1980). The effectiveness of 40- to 120-ft buffers in which 25 t/a. of manure was applied on top of snow still was evident inasmuch as 68% of P was trapped within 40 ft and 83% within 120 ft of the buffer (Thompson et al., 1978).

Plant nutrients in manure also can contribute to water eutrophication when the nutrients in runoff or tile drainage cause excessive growth of water plants

such as algal and aquatic weeds. Particulate matter in runoff settles out when it enters water bodies, but soluble manure components including plant nutrients remain in solution until precipitated or used by aquatic vegetation. Excessive growth and die-back of algae and weeds increase water BOD and deplete oxygen, which can cause fish kills.

Manures range from 40 to 135 lb BOD/t (Azevedo and Stout, 1974) and if deposited in water can change aquatic populations or cause fish kills. If there is insufficient dissolved oxygen for the desirable natural aerobic bacteria, anaerobic bacteria will dominate, and poor-quality water will result. Advanced stages can result in septic conditions under which the water has a disagreeable dark color and emits objectionable odors, sometimes liberating *marsh gas*, or methane ( $\text{CH}_4$ ). Normally, P absorbed on feedlot sediments exists in equilibrium with that in solution. As P is utilized by aquatic vegetation, more is solubilized from sediments. Although this equilibrium often keeps soluble P concentrations at a fraction of one part per million (ppm), algal growth can be maintained for some time.

## Ground Water

The primary ground water pollutant associated with livestock manure management is nitrate-N. Phosphorus and many other nutrients are absorbed readily by the soil through which percolating water moves; therefore, they seldom are major problems. Salts and pathogens seldom are problems, either. Sufficient nitrates can leach from some confined livestock areas to affect nitrate concentrations in ground water appreciably. And if excessive rates of livestock manures are applied to land, serious nitrate leaching can occur in the fields.

Soil in a beef cattle feedlot stocked at 200 head/a. will receive manure containing about 26,000 lb (13 t) of N/a./yr, and normally no nitrate leaching occurs. This balance is due to the compaction of manure by livestock hooves and to the salts excreted with manure, which form an impervious seal beneath the feedlot and thus allow very limited nitrification. If the feedlot is abandoned or grossly understocked, however, significant nitrate production and leaching may occur. Leaching of nitrates and other soluble nutrients frequently occurs beneath compost yards and dry storage piles. Generally, leaching beneath compost/storage piles is localized although nitrate concentrations may be intense.

To prevent potential leaching from lagoons and pits, many states now require that such structures be

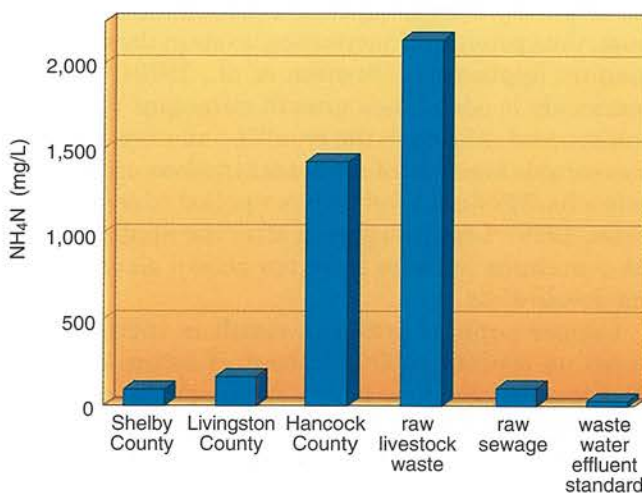


Figure 2.3. Ammonia (N) concentrations from three Illinois stream samples (1990) compared with typical levels in manure and waste water (Adapted from Illinois Environmental Protection Agency, 1991).

made impermeable by means of concrete, plastic liners, bentonite sealers, and clay. Soil types used in lagoon construction greatly affect potential nutrient leaching (Huffman et al., 1994). Most nutrient leaching from lagoons is by lateral flow. Few regulations exist for controlling leaching under compost or dry storage piles. Leaching could be controlled in such instances if piles were constructed on concrete pads or impermeable surfaces or if a roof was provided. Leaching also could be controlled by moving to a new solid manure storage area every 3 to 4 yr and subsequently seeding the abandoned area to alfalfa or to other deep rooted crops.

Probably the most important and extensive areas of concern related to nitrate leaching are the crop fields routinely receiving manure. Often because of a shortage of suitable land near the intensive livestock unit, or for the sake of convenience, fields near livestock confinement areas receive heavy manure applications. But typically only 10 to 30% of the organic N in manure (a figure possibly somewhat higher for poultry) mineralizes during the application year, and smaller amounts usually mineralize in each year afterwards. Thus, soil in a field receiving a modest 10 t of dry manure each year for several years builds up a potentially large mineralizable N pool, which eventually mineralizes more N than is used by the crop. When significant mineralization occurs late in the growing season, after the crop has been harvested, large pools of nitrate N accumulate during the winter noncrop period and may leach to ground water in the early spring or at any time when excess water is present.

Nitrate movement after manure application has been studied extensively, e.g., Bielby et al., 1973; Cooper et al., 1984; Liebhardt et al., 1979; Meek et al., 1974; Walter et al., 1975. In general, data have indicated that annual manure application rates should be limited to the amount needed to supply the available N required by the crop. Because of the complexity of manure/soil/crop/N interactions and the potential for great manure N losses from volatilization and denitrification, however, accurate estimates of acceptable rates are difficult to make. Several studies have measured after manure applications unexpectedly low percolation N losses, which have been attributed to high denitrification rates (Comfort et al., 1987; Cooper et al., 1984; Meek et al., 1974). More recent laboratory research has shown that with high P applications some soluble P also may move to lower depths in the soil profile (Provin et al., 1995). It is predicted, however, that long-term application of manure P is required before significantly affective ground water.

Monitoring soil levels by routine soil testing is recommended to control excess soil P accumulations.

## Soil Quality

The effects of manure on soil fertility are modified by changes in the soil environment that affect nutrient availability. Continual manure application changes soil organic matter content, soil pore volume and size (*soil aggregation*), and air/water relations within soil pores. Because soil microorganisms live in these pores, microbial activity is modified as well. Long-term application of manure, even at rates not exceeding the N needs of crops, results in soil buildup of P and K (Olsen and Barber, 1977; Pratt et al., 1956). Toxicity problems, however, have not been documented. Because this buildup increases the potential for P runoff, some states have recommended that manure applications cease if soil test P levels reach 150 ppm.

High rates of manure in semiarid and arid climates can result in accumulation of soluble salts in the soil profile (Mathers and Stewart, 1974; Vitosh et al., 1973). Because of the great amounts of sodium (Na) and K in some manures, soil physical condition, plant germination, and growth can be impaired. The effects of salt depend on soil texture, climate, and soil water-holding capacity. A ratio of average annual precipitation to percentage manure salt, in combination with soil texture, has been suggested as a method of establishing maximum manure loading rate (Powers et al., 1974; Stewart and Meek, 1977).

Arsenic (As), copper (Cu), zinc (Zn), and P sometimes are added to poultry or to swine rations at levels markedly increasing their concentrations in manure, thus potentially increasing levels in the soil after manure application (Brumm et al., 1979). Arsenic commonly is added as a growth stimulant to broiler chicken feed. Although the resulting manure contains measurable amounts of As, concentrations usually are below background levels when applied to soils (Morrison, 1969). Legumes grown after the application of As-containing manure have not shown elevated tissue levels of As.

Copper supplements can result in increases as great as tenfold in Cu content of swine manure (Brumm and Sutton, 1979). Although concern has been expressed over long-term Cu accumulations, even where 290 lb/a. of swine manure Cu was added over 11 yr, corn ear, leaf, or grain tissue concentrations did not exceed the normal range, and yields did not decrease (Anderson et al., 1991). These applications exceeded EPA Cu-loading limits by 40 lb/a.; soil pH at all sites was nearly neutral, however. Zinc sup-

plied by manure is more likely to be beneficial to crops than harmful, and many diets tend to be low in Zn. This is especially true if available soil P levels are excessively high. Inorganic P, Cu, and Zn are added to animal diets as essential nutrients for growth. But when manure is applied to land in order to meet the N requirements of crops, P and other elements also are applied in excess of crop nutrient needs and build up in the soil.

When fresh manure decomposes, it exerts a significant oxygen demand on the system. If manure is confined, as in an injection band, anaerobic conditions can develop and persist for several weeks (Comfort et al., 1988; Sawyer and Hoefft, 1990b). Such conditions can produce toxic  $\text{NH}_3$ , nitrite, and anoxia levels that are potentially toxic to root development and plant growth, especially in seedlings (Sawyer and Hoefft, 1990a, b). The addition of manure results in a slow accumulation of soil organic matter that may not be measurable during the first few years of applications (Unger and Stewart, 1974; Vitosh et al., 1973). With continual manuring, soil aggregation eventually is improved, soil water-holding capacity is increased, and air exchange is enhanced. Additionally, the soil often becomes a better medium of aerobic biological activity. Manure application, if not excessive, thus tends to improve soil quality over time.

## Air Quality

Animal manure stored inside enclosed buildings can affect the animal environment. Proper control of temperature, humidity, and air distribution is important in decreasing the adverse effects of manure gases, odors, parasites, and pathogens. Principal airborne components in such environments are  $\text{NH}_3$ , volatile amines, hydrogen sulfide, certain volatile fatty acids, indoles and phenols, mercaptans, alcohols, and carbonyls (Curtis, 1983). These materials may pose a significant threat to animal health and welfare if buildings are designed and managed incorrectly.

## Odor

For several reasons, odor in swine housing is a major concern to pork producers. First, certain principal components of odor, notably  $\text{NH}_3$ , increase respiratory disease susceptibility and decrease growth rates of growing/finishing pigs (Drummond et al., 1980; 1981a; 1981b) and of poultry (Nordstrum and McQuitty, 1976). Ammonia also has been implicated as a possible factor in respiratory problems in humans involved in intensive swine operations (Donham,

1990; Schiffman et al., 1995). Finally, odors from housing systems ultimately are vented to the atmosphere, causing air pollution, potential health reactions, and public complaints (Schiffman et al., 1995).

The obvious solution to all these problems is that of decreasing production of odorous compounds within the house. Although certain compounds have been studied extensively, the nature of many such components is understood poorly. Miner (1995) recently published a summary of research on noxious gases and odors related to swine production.

The gases formed from aerobic conditions are odorless and nontoxic and are primarily carbon dioxide ( $\text{CO}_2$ ). But anaerobic conditions can produce odorous and toxic gases. Thus for liquid manure, especially during mixing, safety precautions are necessary. In a well-ventilated confinement production unit, noxious gases usually reach harmful or lethal concentrations only in instances of ventilation failure or vigorous pit agitation (Skarp, 1975). The properties and physiological effects of major gases produced during anaerobic decomposition of manure appear in Table A-7. Some end-products of livestock and poultry manure decomposition are given in Table A-8.

Underfloor ventilation systems can help remove gases and odors generated by liquid manure pits in confinement buildings. Most gases liberated from anaerobic deep-pit storage are from sludge or from the lower portions of storage. New types of flooring such as expanded metal with open areas (40 to 60% porous), which are larger than those with concrete slats (15% porous), affect the ventilation systems needed to remove odors and gases.

Another approach to maintaining air quality in confinement buildings is periodic, rapid removal of manure from buildings in order to maintain a satisfactory level of animal health and insect control and to improve air quality. Removal of manure by recycled lagoon water flushes; gravity flow from shallow gutters; and mechanical scraper systems has succeeded. Other methods of improving air quality are scrubber systems (Koelliker et al., 1980; Licht and Miner, 1979), chemical treatments (Hill and Barth, 1976), and aeration systems.

Odorous emissions from land application of manure can create a public nuisance. Hartung and Phillips (1994) reported that incidences of odor complaints occurred more frequently after the land application of manures than occurred normally as a result of livestock buildings or manure storage. Various chemicals such as hydrogen peroxide and potassium permanganate have been used to mask or to remove odors before land application but are expensive and danger-

ous. Direct incorporation of manure into the soil significantly decreases odor and  $\text{NH}_3$  emission.

### Dust

A great quantity of dust is produced when animals are confined, and increased animal respiratory problems can result. Dust is a potentially corrosive element in confined housing and contributes to the deterioration of buildings and equipment. Many odors in swine confinement buildings are dustborne. The total mass concentration of aerial dust in 11 swine finishing units averaged  $8.1 \text{ mg/meter (m)}^3$  during a 9-mo period and exceeded  $15 \text{ mg/m}^3$  in 13 of 88 farm visits (Day et al., 1965; Hammond et al., 1979). Peak dust concentrations in layer houses usually corresponded with feeding time and egg gathering (McQuitty et al., 1985). Studies have shown increased dust in buildings associated with increased animal activity and higher dust levels during winter seasons (Meyer and Bundy, 1991). Dust can be a major problem in open beef-cattle feedlots, especially in dry regions. Sprinklers and tank wagons often are used to control dust. Air filtering systems, ionically charged dust collectors, addition of 1 to 2% vegetable oils or animal fats in diets, and use of moist feeding systems have decreased dust in confinement building air significantly.

Dust acts as a substrate on which acids and gases can react. In the presence of acid-forming gas, dust is an important factor in the corrosion of metals. By placing acid or gases directly on and into the substrate, dust also acts as an abrasive with a gritty, grinding effect on metal. Deterioration of electrical systems in confined housing is a serious problem resulting from the corrosive action of dust and humidity.

### Aerial Microflora and Pests

Disease control is one of the major concerns of livestock producers, and a sanitation and health management program ensuring healthy livestock and efficient production is necessary. Animal manures can transmit and harbor disease organisms and parasites and can provide a medium for nuisances such as flies and mosquitoes. Removal of manure from the immediate area of animals therefore is desirable (Kinzer, 1981).

Aerial concentrations of bacteria often are high in beef cattle, dairy, or turkey confinement buildings. Certain manure systems, e.g., oxidation ditches, litter and gutter cleansers, however, do not contribute significantly to aerial bacteria levels (Goodrich et al., 1975). In fact, aeration systems decreased staphylo-

cocci, streptococci, salmonella, and coliforms in manure (Diesch et al., 1973; Robinson et al., 1971). Proper ventilation, dust control, and adequate sanitation are important in maintaining an optimal building environment.

Pest control, especially of flies and mosquitoes, is another concern attending manure management in livestock buildings. Mosquitoes can be both a nuisance to livestock and a disease vector. The high organic matter content of animal manure provides a favorable environment for the production of mosquitoes species that prefer polluted waters. The most common species in lagoons in the southern United States is *Culex pipiens quinquefasciatus*, or the southern house mosquito (Steelman et al., 1967a, 1967b). Other closely related forms of the *C. pipiens* mosquito species complex are common in polluted waters throughout the world (Barr, 1957; Laven, 1967; Mattingly et al., 1951).

Large populations of *C. p. pipiens* were found in swine manure lagoons sampled in central Indiana. Organic and nutrient concentrations of the lagoon effluent and presence of vegetation and floating debris around the edge of the lagoon surface were significant factors affecting their presence. The use of several insecticides and insect growth regulators to control mosquitoes in swine waste lagoons has been effective (Axtell et al., 1975.)

The breeding and development of flies depend greatly on the water content of manure (Azevedo and Stout, 1974). Flies are attracted to manure if water content ranges from about 35 to 85%; no oviposition or fly development occurs when manure water content is below 35% (Taiganides, 1977).

Manure solids from solid-liquid separators have been used as a bedding material in dairy free-stall units. Even though there generally is some natural heating of manure solids before use in free-stalls, concern has arisen about transmission of pathogens in milk or increased incidence of mastitis in dairy cows. Bacterial counts of *Escherichia coli*, *Enterobacter* spp., *Staphylococcus aureus*, *S. epidermis*, and *Streptococci* were lower in bedding, teat swabs, and milk when cows were bedded with limestone than in either freshly composted dairy manure solids or a 50:50 mixture of dairy manure solids and limestone (Janzen et al., 1982). Bacterial counts decreased in dairy manure solids by the process of composting for more than 14 d, and properly composted dairy manure solids seem a suitable choice for bedding in free stalls (Bishop et al., 1981).



## Other Environmental and Health Concerns

Animal excreta contains nutrients that can serve as fertilizer nutrients and as feedstuffs for animals. Animals such as rabbits routinely recycle a part of their excreta for its nutrients and microflora, which aid in the digestion of plant materials. Broiler litter is the animal excreta most commonly used as a feedstuff (McCaskey, 1995). The feed value of poultry litter was reported 41 yr ago (Noland et al., 1955), and such litter since has become an important feed source in areas where broilers and beef cattle are produced in proximity. The major incentive of feeding poultry litter is that it costs less than other feedstuffs. Much animal agriculture relies on the use of by-products such as feathermeal, bloodmeal, poultry by-product meal, and grain by-products as sources of low-cost nutrients in the form of feed ingredients. If not used as feedstuffs, many of these by-products would become an environmental liability (Fontenot, 1991). The use of poultry litter as a feedstuff has decreased the impact of this by-product on the environment because litter is recognized as a valuable resource rather than as a liability to society.

For poultry litter to become recognized as a feed ingredient, however, the practice of feeding litter to animals was challenged by the U.S. Food and Drug Administration (FDA) (Kirk, 1967). Although no harmful effects had been observed in animals fed excreta, scientists were challenged to demonstrate both the safety of the feeding practice to animals fed the excreta and the safety of the food products derived from these animals. Health issues raised by the FDA included pathogenic microorganisms, microbial toxins, mycotoxins, parasites, viruses, arsenicals, antibiotics and drugs, hormones, coccidiostats, pesticides, heavy metals, and trace minerals. The FDA (1980) revoked 21 CFR 500.4 on the use of poultry litter as an animal feed ingredient on December 30, 1980 (45 FR 86272) and is leaving the regulation of feeding animal wastes to the individual states. Thus, feeding of animal wastes is regulated by the individual states. The regulations usually are similar to the model regulation of the Association of American Feed Control Officials (AAFCO) (1982). The salient points of the AAFCO regulation are that (1) the waste must be processed so that it will be free of pathogenic organisms; (2) if the waste does not contain drug residues, no withdrawal period is required and the waste can be feed to any class of animals; and (3) if the waste contains drug residues a withdrawal of a minimum of 15 days is required prior to slaughtering animals or pri-

or to using milk or eggs for human consumption.

Before being utilized as feedstuffs, all by-products including animal excreta must be processed to ensure the elimination of pathogenic microorganisms. Heat and acid treatments have been practiced most widely as a means of ensuring that excreta-derived nutrients are safe for feeding. Mechanical heating by belt dryers, pelleting, or spontaneous heating that occurs in piles of animal excreta containing less than 25% water eliminates enteric pathogenic bacteria such as *Salmonella*, *Escherichia coli*, tubercle bacillus, and *Listeria monocytogenes* (McCaskey et al., 1985; McCaskey et al., 1992b). Temperatures in piles of dry-stacked poultry litter need not be as high as those achieved during pelleting, which usually exceed 160°C. The spontaneous heating in dry-stacked poultry litter occurs over a period of weeks, and temperatures are adequate because the combined effect of "low temperature and long time" are equivalent to that of "high temperature and short time."

Temperatures in excess of 130°F for 5 d eliminate bacterial pathogens (McCaskey et al., 1985). Furthermore, NH<sub>3</sub> released from the litter, when combined with the effect of spontaneous heating, is more inhibitory to pathogens than the effects of NH<sub>3</sub> or heat considered separately are.

Animal excreta intended for feeding also can be acidified, and the acid in combination with heat will eliminate bacterial pathogens (McCaskey and Martin, 1988). Various acids, both organic and inorganic, can be used to acidify litter. But because of the costs of acids and the potential hazards of handling, a common practice is to ensile the litter with fermentable materials such as corn grain, whole corn plant forage, or sorghum forage (McCaskey and Anthony, 1979). Lactic acid producing bacteria naturally found on forages and grain inhibit pathogenic bacteria. The acid-producing bacteria and the process itself have been accepted widely for centuries in the context of fermented vegetable preservation for human consumption.

Mycotoxin-producing fungi are not a health risk with most types of animal excreta intended for feeding (Bacon, 1986). In general, fungi are aerobic and require oxygen for growth and thus for the production of mycotoxins. Processing by spontaneous heating requires that excreta such as broiler litter be piled into a stack. Although the surface of the litter stack is exposed to air, its center is anaerobic. Ammonia emitted from the excreta during spontaneous heating, i.e., *deep stacking*, also is quite toxic to all types of microorganisms, including mycotoxin-producing fungi (Jones et al., 1994).

*Clostridium botulinum* is a pathogenic bacterium that produces a toxin deadly to humans and animals. Because the bacterium produces endospores that are very tolerant of heat and acid, this pathogen could create health hazards associated with the feeding of animal excreta (Cato et al., 1986). In addition to its tolerance of heat and acid, the bacterium is an anaerobe. It is spread widely throughout the environment but is a threat to animals and humans only when conditions support its growth. If the bacterium does not grow, it does not produce the deadly *botulinum* toxin. Poultry litter accumulated in poultry houses or litter recovered from poultry houses and stored in stacks is not conducive to the bacteria's growth. Moreover, water content of the litter generally is inadequate for it. Silage, because of its greater water content, is more likely than litter to provide conditions supportive of *C. botulinum*. A pH of 4.5 or less is required to retard growth of *C. botulinum* in silage (McCaskey and Anthony, 1978; McCaskey et al., 1985).

Botulism has been reported in cattle fed poultry litter that was acid fermented improperly. Where the disease has been reported, litter containing dead poultry usually has been implicated (Appleyard and Mollison, 1985). Acid fermentation of poultry litter by ensiling in the United States is very rare. Processing poultry litter generally involves high-temperature aerobic composting or high-temperature drying processes. Beef cattle—the animals most likely to receive such litter—will be free from *Clostridium botulinum* if these two processing methods are used. The feeding of litter to milk-producing dairy cattle is not permitted.

Parasites that on occasion might occur in animal excreta intended for feeding are a health hazard neither to the animal consuming the processed excreta nor to the human consuming the products of the animal. Parasites, which include trematodes, flukes, roundworms, tapeworms, protozoans, and related organisms, depend on a living host for survival. Because many parasites are host specific, feeding processed excreta across animal species—for example, from poultry to beef cattle—minimizes risk. Furthermore, only parasites reproducing by eggs, or ova, pose a threat, and studies have shown that processing excreta containing eggs eliminates the parasites (Cior dia and Anthony, 1969; Farquhar et al., 1979).

Antibiotics in feeds administered to animals are not a health risk when the excreta of these animals is processed into feed (Webb and Fontenot, 1975). Bacitracin and aureomycin are widely used antibiotics in animal production and are approved for use in poultry, swine, and beef cattle. If antibiotic residues oc-

cur in the excreta of one animal species considered for use as a feedstuff for another, the residue is of no consequence if the antibiotic is approved also for the recipient animal. Poultry litter is the most widely used excreta for feeding. Because built-up litter in broiler houses generally is removed twice annually, microorganisms in the litter have adequate time to attack the antibiotics, thus eliminating any residues in the litter before it is fed to beef cattle. Medicinal drug residues may be present in poultry litter. With a modest withdrawal period, however, no tissue residues were detected (Webb and Fontenot, 1975).

There is no evidence of pesticide accumulations in the excreta of animals. If diets do not contain prohibited levels of pesticides and if the premises of confined animals are not sprayed with unapproved pesticides, the hazards of pesticides in animal excreta intended for use as feedstuff are remote.

Heavy metals in animal excreta are due to metals in the diet. Arsenic, Cu, selenium, and chromium (Cr) are added to the diets of livestock and poultry to promote growth and animal performance. The concentrations added to feeds are controlled strictly at commercial and noncommercial feed mills. Cadmium, lead, and mercury are not added to feed but do occur naturally. All these heavy metals are excreted by animals and cannot be eliminated by excreta processing. Arsenic and Cu are added in the highest concentrations and thus create the most concern. Arsenic concentrations in the excreta of lactating cows decline to background concentrations within 5 d of dietary As withdrawal (Smith, 1973).

Copper is not fed to laying hens, so Cu levels in excreta usually reflect levels naturally present in commercial laying hen diets. But broiler diets are supplemented with Cu, and concentrations of 300 ppm in the excreta are common. Copper toxicity has been documented in sheep fed broiler litter with high Cu levels (Fontenot et al., 1972). Cattle are much less sensitive to excess dietary Cu than sheep are. Copper supplemented to achieve an equivalent of 500 ppm in litter when fed to cattle during the winter months for 7 consecutive yr showed no elevated Cu levels in tissues of these cattle during the following summer, when litter feeding ceased (Fontenot et al., 1983). Other minerals have not been detected in cattle excreta or poultry litter at concentrations high enough to present a problem (Westing et al., 1980).

To ensure that heavy metals, other minerals, and medicinals do not accumulate in the tissues of animals fed excreta, the recycled excreta should—depending on its source—be withdrawn from the animal's diet at least 15 d or more before the animal is slaughtered.

This withdrawal period allows the tissues of animals fed excreta to clear any potential excess residues. Residue accumulations, when they occur, usually are limited to the liver and kidneys whereas muscle tissues show little or no accumulation of medicinals administered in feed. The principal dietary nutrients in animal excreta are nitrogenous, much of which occur in the form of nonprotein N, and minerals. Animal excreta generally is a relatively poor source of energy, so grain or another source of carbohydrates is added to supplement the energy content when animal excreta is used as a feedstuff for rapidly growing animals. Because animal excreta dilutes the energy contents of finishing diets, it usually is not fed to feedlot animals. Because excreta is not fed during the finishing phase of animal production, any residues from excreta fed during the growth phase will be cleared from animal tissues.

In most instances, animal excreta is used as an alternative crude protein source for growing animals and for mature breeding animals. Because these classes of animals are not destined for immediate slaughter, residues pose no health threat to consumers. Because a withdrawal period is impractical for feeding animal excreta to lactating dairy cattle or to laying hens, use of excreta with drug residues in the diets of these classes of animals is prohibited. Sheep are sensitive to as little as 25 ppm of Cu in their diets, and

any feedstuffs, including animal excreta, that contain Cu in excess of 25 ppm should not be fed. The use of animal excreta as a low-cost feed ingredient has been practiced for more than 40 yr (Noland et al., 1955). In the United States, there have been no documented incidences of health hazards to animals fed processed excreta except in sheep. This long record often is cited as the major testament to the safety of feeding animal excreta.



Figure 2.4. Dairy cattle grazing on pasture. Photograph courtesy of Alan L. Sutton, Purdue University, West Lafayette, Indiana.

### 3 Integrated Manure Management System Components

The objective of manure management with pollution control is to collect, to store, and to utilize animal manures efficiently and to prevent contamination of the water, soil, and air, while producing within socio-economic constraints food products, e.g., meat, milk, eggs, and other livestock-based products, for human consumption. This objective requires integration of the manure management system components with the greatest potentials to maximize production efficiencies, to optimize animal and human health, and to decrease the likelihood of pollution within the current economic structure. Effects of manure management systems on environmental quality were discussed in the previous chapter.

Because of vastly different climatic conditions, animal species, manure characteristics, and engineering technologies and because of a wide range of other important parameters, a broad spectrum of integrat-

ed manure management systems exists (Figure 3.1). Their components can be arranged in many ways to meet specific needs and to address prevailing conditions.

This section will list and define common manure management components incorporated in livestock production units in the United States (Midwest Plan Service, 1985; U.S. Department of Agriculture, 1992). These components will be grouped into four subsections involving collection, storage, treatment, and utilization. Within each, outdoor lots and confinement housing will be discussed.

#### Collection

Runoff water from open livestock lots often is collected with earthen berms or dikes into earthen storage. In areas of high rainfall or runoff from large ar-

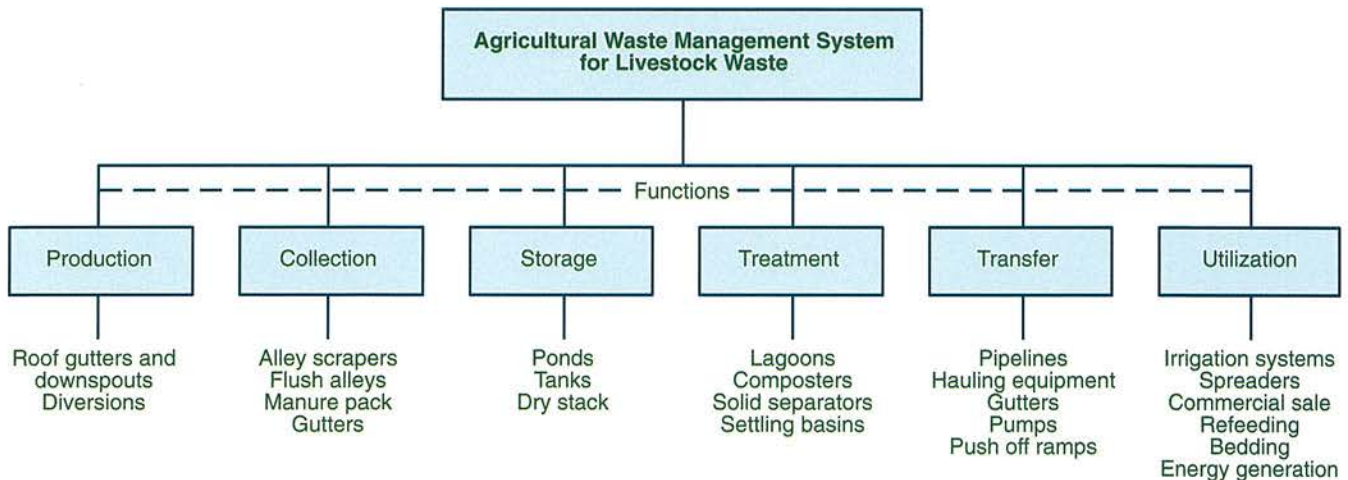


Figure 3.1. Analyzing resource data and formulating alternative solutions using the six functions of an agricultural waste management system. (Energy generation is included under the utilization function because utilization of waste material is the basic purpose of such operations. This is distinct from the treatment function, whose basic purpose is to change the characteristics of waste material. A substantial part of the original and strength of waste material still remains after it has been used for energy generation. Consequently, waste material discharged after energy generation must be managed similarly to that which has not been used for energy generation. In the instance of livestock manure, the management process could include transfer to storage and, from there, transfer to a second waste utilization function of land application.)

eas, concrete linings have been used successfully to maintain the function of channel areas. In large lot areas or in areas of steep terrain, collection points, which sometimes are concrete tanks, collect solids and funnel liquids into a network of pipes. This process decreases soil and manure erosion and movement and allows controlled management of collected liquids. These same earthen dikes can be used above the lot area to divert clean upland runoff from flowing across the lot and becoming contaminated.

Tractor-powered scrapers are perhaps the most common method of collecting manure solids in lots. These units can range from smaller 15 to 20-horsepower units to larger earth-moving equipment used on large beef-feedlots. Blades are mounted on the front and/or the back of power units. Most blades are steel, but half sections of large rubber tires are used successfully as scrapers and offer the advantage of not polishing a concrete floor to slickness. (Footing problems can be serious when dairy operation floors have been scraped daily for many years.) These units also offer a low collection cost because the tractor can be used with other activities in the livestock operation. As animal numbers have increased, tractor scraper collection has required significant labor input on large operations. Tractor scrapers seldom are used in swine and caged poultry layer operations. For open earthen feedlots, scrapers routinely are used to shape lots and to collect the excess manure hauled out to them. For beef cattle, pens usually are cleaned after each set of cattle is marketed.

A second type of mechanical scraper is fitted to a traverse channel and used in stanchion dairy barns, gutter cleaners in some swine farrowing units, and scrapers under cage layer (egg) or meat poultry operations. When manure deposition can be channeled to a smaller area or when, as in the case of swine farrowing, relatively small volumes of manure are generated, these units are a practical alternative. Scrapers can be controlled either manually or with timers. With automatic controls, frequent cleaning improves sanitation, decreases odors, and lightens scraper system load.

Gutter scrapers typically move manure with bedding or materials that are not excessively wet. Large volumes of bedding commonly are used to soak up urine and wastewater for more efficient removal of all manure. In cold climates, protection is required to keep scraper bars from freezing to the floor. Collection over large areas requires a long cable or chain system, which can fail structurally if loaded to excess. Caged, suspended poultry operations, however, also work efficiently with this system.

Approximately 25 yr ago, the hydraulic collection of manure by means of a flushing gutter was a technique new to swine buildings. The method now is used commonly in swine, dairy, and certain poultry operations. As animal numbers have grown per operation, this component system has become a more attractive, efficient, and economical alternative. Equipment to pump and to separate liquids from solids with a high fiber content predominates in some locations. Flush collection is very common on large dairy operations in the Southeast, the Southwest, and the Pacific Northwest. Cleaning twice or three times daily maintains the sanitary conditions required by milk inspectors. These systems are of limited value in colder upper Midwest and Northeast regions unless total confinement is being used so that indoor winter temperatures are elevated sufficiently to limit ice formation and freezing problems. In the arid Southwest, high evaporation rates and water shortages make other collection options more attractive.

Most operations recycle flush water, a practice that decreases system requirements for fresh water. Even with recycling, however, large manure-storage volumes are required. Climates with long, wet winters require large storage volumes so as to eliminate the need for land spreading of liquids on wet or saturated soils when runoff is likely. The hydraulic efficiency of flush water is improved when a large volume of water is released quickly; systems with several large valves, vertical gates, hinged drop gates, and rollover tanks are available commercially. The exact volume of flush water needed will depend on the volume of manure accumulation (animal numbers and time since last flush); the length, width, and slope of flush alley; and the volume and velocity of flush water. To satisfy hydraulic needs, operations have used high-volume pumps that can be controlled or automated with a timer.

The gravity system, also of the free-flowing hydraulic collection type, is used primarily for feces and urine and requires addition of little or no water. Although not used as widely as units with flush water, gravity collection systems are generally used in swine and dairy operations.

About 30 yr ago, floors were designed with openings allowing manure to be worked through and subsequently to fall into a storage unit located beneath the housing area. A wide variety of slats of reinforced concrete, wood, plastic, aluminum (Al), steel, and other materials have been used to construct such floors. Expanded metal slats, some plastic coated for warmth and smoothness, are common in the floors of lambing and swine farrowing crates. In some installations,

pipes carry hot water through slats to provide heat to animals. A key advantage of a slatted floor with pit storage below is that animals provide all the labor to collect the manure and to move it into storage or the gutter beneath, where it is collected by mechanical scraping or flushing. The major disadvantage of this system is the added cost of installing two floors. In the production of swine, a species that can select and utilize a dunging area, partly slatted floors are common and the best of both systems are available at an acceptable cost.

## Storage

*Storage components* are temporary holding containments for manure before it is spread on land (Figure 3.2). These units are designed to be emptied at frequencies of from every 7 d to 1 yr.

One of the oldest and simplest storage strategies is that of storing manure where it is deposited. Collection and removal can be accomplished on an annual or semiannual basis, when the land receiving manure is ready. For cattle operations, lot designs usually include mounds within the lot so that all cattle have a place to rest and to dry off above wet areas. Mounds are reshaped continually, as clay, sometimes mixed with lime, is scraped onto them and packed.

Earthen basins have been used for many years to contain manures from livestock operations. But many early structures were located relative to the building site only. Now, attention to soil type, water table level, construction material and technique, and design have greatly decreased the number of earthen storage systems leaking wastewater into surface and ground waters.

Recent research has defined the soil sealing capabilities of manure slurries. Whereas slurry storage tends to seal the soil eventually, there is a limit to how fast the sealing process will occur, and a certain particle size for the parent material is required—as is an imported soil liner. Some soils have an unacceptable infiltration rate, and alternatives such as plastic liners or other membranes placed in the bottom and side walls of an earthen structure may be required. Although liners are an alternative, they tend to be a high-cost item; and experience has shown a potential for failure causing leakage. Another option is to pack the pit with bentonite clay to control infiltration.

Tanks are placed above or below ground. Below-ground tanks are constructed almost entirely of reinforced concrete designed to handle additional support loads for equipment and external loads for soil and water pressure. They offer the elevation advantage of

easy filling and emptying.

Aboveground tanks, which must be designed to support internal filling, are built of wood and steel, in addition to concrete. Although they require additional filling expenses, they generally are cheaper to build because they require no excavation. Above-ground tanks also diminish the negative effects of high-water tables on foundation requirements.

Handling and storing manure solids often is a major systems task. In some systems, liquids have drained away or evaporated; in others, bedding is used to hold liquids, and all waste is handled as a solid. Many solids simply are stacked before land spreading. Other operations provide a concrete slab for the storage base, both to provide a stable working surface and to allow thorough cleaning. Some units may have one or more side walls. These storage designs serve as means of pushing the solids against the side wall, thereby facilitating unloading. In areas of high rainfall, some producers install a roof over the solid-manure storage area. This practice eliminates excess runoff, which can carry pollutants from the storage area.

## Additional Components

Various pumps, pipes, or open channel concrete conveyances have been used to transfer manures from livestock buildings to outside storage areas (Midwest Plan Service, 1985). Additionally, different pumps have been developed to agitate liquid manures for homogenous removal of solids and a relatively uniform application of nutrients to land. Pump design is



Figure 3.2. Two-stage lagoon with recycled water for swine manure collection, storage and treatment. Photograph courtesy of Don D. Jones, Purdue University, West Lafayette, Indiana.

determined according to manure solids content, conveyance distance, and conveyance height. Specific pumps are designed to agitate, to decrease solid particle size, to load storage structures and application tankers, and to irrigate liquids on land. Underground plastic pipe commonly is used to transport liquids and semisolids to storage structures. Pipe size depends on distance to storage, volume and fluidity characteristic of manure transferred, and slope. Open channels often are lined with concrete to decrease erosion and to control nutrient seepage. For solid manures, tractor loaders or elevated conveyor units commonly are used to load into application equipment. Mechanical scraper and elevating conveyor equipment is used to stack solid manure in storage facilities.

## Treatment

One of the first treatment components in many manure systems is liquid/solid separation. This generally consists of either a settling tank or a basin utilizing gravity or mechanical separation with screens, fine grates, or presses.

Liquid flush systems utilize a tank or a basin to slow manure stream velocity and to promote solids settling. Settling components can be designed and operated to provide either wet or dry manure sources. The septic tank is the most common example of a settling tank that always is full of wastewater. Settling basins treating outdoor lot runoff generally are operated dry. They collect runoff, slow velocity, settle out solids, and allow slow, continuous outflow of liquids so that units always drain completely (Figure 3.3).

Although settling is accomplished in both types of units, methods differ greatly. In septic tanks, solids must either be scraped from the bottom with some type of gutter cleaner unit or be pumped from the tank after the solids are resuspended. In the drain dry basins, tractor scrapers are used to remove solids to a nearby bank or staging area for additional drying and storage, or to go directly to the field for application. To have capacity for the next wastewater loading during rainfall events, these units require cleaning, which becomes a management or maintenance issue.

Mechanical screens are very common with the newer dairy and swine manure flush units. These screens usually are elevated to allow manure solids to fall to a temporary storage location. Flushed manure and wastewater are pumped to the separation screen in an elevated tower. Separated liquid then can flow by gravity to liquid storage and be recycled back through the facility.

Vegetative filter strips are an application of settling

applied most commonly to runoff from nonpoint sources but also can be adopted for use with point sources. When filter strips are used to treat water with a high solids content, they remove the solids and potentially choke the grass, making this system difficult to clean. Strips are most effective at removing sediment and the nutrients and organisms attached to it; soluble pollutants such as nitrate receive little treatment through a filter strip. In certain systems, however, solids are allowed to settle out in a basin, and the liquid is allowed to run across grass fields, thereby irrigating and nourishing the grass.

Biological treatment of waste can be divided into two groups based on whether the treatment takes place in the presence of air (aerobic) or its absence (anaerobic).

Because of the heavy loading of organic matter in animal manures, which requires large quantities of oxygen to degrade the manure, most biological treatment occurs anaerobically. The most common biological treatment component is some form of an anaerobic lagoon, which includes earthen structures that rarely are emptied completely and that undergo continuous anaerobic decomposition. Properly designed anaerobic lagoons significantly decrease the odor associated with anaerobic decomposition but require greater storage capacities than other units do. If lagoons are too small, they produce much more odor.

There is improved control of anaerobic decomposition in digesters. Biogas fermentation systems, although not used widely, generally are constructed to maximize  $\text{CH}_4$  production and to utilize  $\text{CH}_4$  through direct burning. The maximum amount of energy is derived through heat or through powering electrical



Figure 3.3. Concrete basin to settle solids during runoff from open swine lot. Photograph courtesy of Alan L. Sutton, Purdue University, West Lafayette, Indiana.

generators. Digesters can be in the form of an enclosed tank or a covered lagoon. Although considerable research has been devoted to anaerobic decomposition and a good understanding of the process exists, economics, equipment maintenance costs, erratic biogas production, and increased managerial skill requirements have limited the adoption of this technology for manure utilization.

Composting is another type of biological treatment that relies on microorganisms to degrade organic matter such as manures and farm animal mortalities to a relatively odorless, stable humus (Carr, 1994; Northeast Regional Agricultural Engineering Service, 1992). The C-to-N ratio of the composting mix needs to be adjusted to at least 15:1 by the addition of hay or straw, and the moisture should be adjusted to 40 to 50% to promote composting (McCaskey et al., 1996). During this process, microorganisms degrade complex organics such as proteinous and cellulosic compounds, and a variety of by-products such as  $\text{NH}_3$  and  $\text{CO}_2$  gases result. Volatilization of these gases and water accounts in part for a 20 to 30% decrease in weight and volume of composting material. Heat generated during composting is sufficient to kill enteric bacterial pathogens; the finished compost thus is safe to spread on land or to market as a soil amendment (Murphy, 1990).

Aerobic treatment of liquid wastewaters from livestock operations generally is limited to applications with dilute wastes and is used to decrease odors (Jones et al., 1971). Equipment such as floating aerators, which were developed to treat wastewaters from municipal and industrial sources, has been used in agricultural applications. Paddle wheels from oxidation ditches also have been used to pump/beat oxygen into liquid waste. Recirculating pumps powered by floating windmills sometimes are used on lagoons. All these units incorporate oxygen from the air into wastewater to support aerobic bacteria, which produce few odors in their breakdown of organic matter. Aerobic systems also operate at a more rapid rate and can handle shock loads of organic waste or changes of temperature more readily. Even though technology is available for this type of treatment process, it is used only when odor control is mandated, for cost of installation and operation can be very high.

Use of constructed wetlands is a relatively new technology currently being evaluated in the treatment of liquid wastewaters from livestock operations (Council for Agricultural Science and Technology, 1995; DuBowy and Reaves, 1994) (Figure 3.4). The process has been used successfully in Europe and in the United States for treatment of municipal wastewater from

small communities and from households in rural areas. Constructed wetlands are less costly to construct and to operate than municipal wastewater treatment plants and therefore are becoming popular in rural communities. Constructed wetland cells planted to aquatic vegetation typically are operated with 6 to 18-in. depths of wastewater in a long, narrow (length-to-width ratio of 4 to 6:1) earthen structure encouraging uniform effluent flow conditions (McCaskey et al., 1992a). Slow flow rates for wastewater in wetland cells are desired. The three types of vegetative systems used are (1) *submergent* (rooted on the bottom and growing up above water level), (2) *submerged* (rooted and growing in, but not above, water level) or (3) free-floating plants. Bulrushes and cattails are among the common wetland plants used for wastewater applications.

Plants serve several roles in the constructed wetland treatment system. First, they provide surface area on which bacteria grow and break down organic matter. Second, aquatic plants pump oxygen down to their roots. Some of this oxygen leaks into the surrounding water column and supports aerobic bacteria. Lastly, plants take up nutrients; unless they are harvested, however, this is not a pathway for nutrient removal from the wetland system. Plant uptake does shift the release of nutrients on a different time scale by moving them through the plant system. Because of the anaerobic environment, nitrates usually are denitrified. Detention times differ, but 2 to 8 d are perhaps the most common. Although only limited information is available, BOD removal rates are expected to range from 73 to 88% (McCaskey et al., 1994b, 1995). Rates of bacterial removal from wastewater can be even higher.



Figure 3.4. Aerial view of constructed wetlands treating swine lagoon effluent. Photograph courtesy of Thomas A. McCaskey, Auburn University, Auburn, Alabama.



Producers without a permit cannot discharge to a stream the outflow from constructed wetlands even though the water might have a lower pollutant load than the streams themselves. An alternative is to recycle treated wastewater for cleaning livestock facilities. Excess water can be irrigated onto land at relatively high rates because most nutrients have been removed and excess nutrient loading of land or nutrients in runoff are not a problem. Advantages of constructed wetlands for treatment of animal wastewaters include (1) low construction costs, (2) high wastewater-treatment efficiency, (3) limited land-area requirements, (4) low-energy requirements, (5) few or no mechanization requirements, (6) effective odor control, and (7) natural, biological processing (McCaskey et al., 1994b). Daily monitoring is necessary to avoid nutrient overloading of wetlands, which is capable of killing aquatic plants and contributing to noxious odors. Although constructed wetlands can function to some degree in cold weather, biological systems are more efficient in warm weather, a fact that might promote their use in warmer climates. Wastewater treated by constructed wetlands is odorless, and thus wetlands are an important wastewater treatment technology on farms near urban areas.

## Utilization

Manure utilization is the final component of the manure management system. The primary goal of this component is to control and to utilize nutrients effectively without affecting the environment adversely. There are four major uses of animal manure: (1) as a plant nutrient resource, (2) as a soil amendment, (3) as an energy source, and (4) as a feed ingredient. Land application of manure as a plant nutrient resource is the major use and has been a recommended practice

for centuries. The potential for replacement of fertilizer (N, P, K), addition of other micronutrients for plant growth, and addition of organic matter both to improve soil structure and to decrease erosion are key benefits of land application. Application methods include surface spreading with solid-manure box spreaders, liquid-tanker wagons or trucks, and various irrigation systems; or soil incorporation of both surface-spread solid manure by tillage systems and surface-spread liquid manure by tillage after spreading or direct injection. Irrigation systems include surface overland flow, spray irrigation, center pivot, and traveling guns. Utilization of nutrients from manures is discussed in detail in Chapter Four.

The feeding of manure nutrients involves manure processing to enhance safety and acceptability and to retain nutrients that can be incorporated usefully into animal diets. Successful implementation of this utilization component has been the feeding, in ruminant rations, of deep-stacked poultry litter, dried cage-layer manure, and ensiled swine-manure solids (Smith and Wheeler, 1979). Other processing practices researched have included chemical treatment and composting (Day, 1977). The feeding of manure requires additional managerial skills for balancing diets to meet animal nutrient and energy needs. Adoption of this component has been regional due to economics and to the supply of other conventional feed resources. Manure refeeding is discussed in Chapter Two.

Manures have been used in the production of single-cell proteins, but the technology has not been implemented to a great extent (Calvert, 1979). Manures have supplied nutrients to produce fly larvae, algae, and certain species of aquatic protein sources. Because this technology is site specific and market driven, it requires considerable specialized managerial skill to succeed.

## 4 Manure Nutrient Utilization through Land Application

### Manure Nutrient Content

Manure is an excellent nutrient source because it contains at least low concentrations of all the elements required to grow plants. Large volumes of manure often are available to producers, and although nutrient concentrations in manure tend to be low, manure's total potential value as a source of plant nutrients for crop production is quite high. For example, each year the P content of manures produced in Nebraska equals the quantity of fertilizer P purchased in that state.

Chemical composition of manure depends on species of animal, animal breed and age, and feed composition. Variations in the reported composition of manure before field application also are due to sampling errors (sometimes a sixfold variation in N and P content); by inclusion of bedding, soil, feathers, or spilled feed; and by losses from urine. Because the water content of manure is quite variable and is related to climate, animal species, and amount of feed and water consumed, results reported on a fresh weight basis are highly variable. Before manure reaches the field, changes in composition occur as a result of storage and handling technologies. Nitrogen, in particular, is lost as a result of volatilization, nitrification/denitrification, and concurrent biological transformation. Data given in Table 4.1 represent typical manure nutrient values for various handling systems (Bates and Gagon, 1981).

Figure 4.1 shows the average distribution of N, P, and K between feces and urine excreted by cattle, swine, and sheep. Fecal N is predominantly in the

form of unutilized organic N from feed and from microbial growth and metabolism. Generally, this N is unavailable to plants until mineralization has occurred. Most N in urine is in urea (or in uric acid excreted with the feces of poultry), which is hydrolyzed readily and made available to plants. Figure 4.1 illustrates that significant differences in the form and the distribution of N, P, and K exist among species. These differences stem in part from the composition of diets, the efficiency with which animals utilize nutrients, and the relative amounts of feces and urine produced.

In manure, most secondary nutrients and divalent

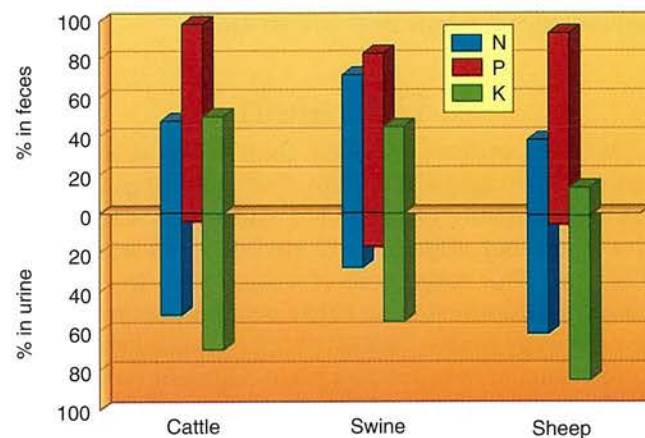


Figure 4.1. Distribution of nitrogen, phosphorus, and potassium between urine and feces for cattle, sheep, and swine (Adapted from Azevedo and Stout, 1974).

Table 4.1. Range in nutrient analysis of manure for various handling systems (Bates and Gagon, 1981)

Animal species	Nonliquid systems (lb/ton)			Liquid systems (lb/1,000 gal)		
	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O
Dairy	5-16	2-16	2-31	3-51	2-21	2-58
Beef	4-20	1-13	3-29	6-37	1-29	5-30
Swine	3-27	1-62	2-18	1-61	1-63	1-49
Poultry	4-111	1-96	2-55	35-75	13-91	13-39

micronutrients (calcium [Ca], magnesium [Mg], iron [Fe], manganese [Mn], Zn, and Cu) are associated predominantly with feces (Overcash and Humenik, 1976) whereas monovalent ions are excreted in urine. Mineral supplements in feed and geographical differences in soil and forage composition cause wide variations in concentrations of micronutrients in excreted manures.

## Effects of Handling, Storage, and Application Systems on Nutrient Content of Manure

Composition of manure applied to cropland usually is significantly different from that of freshly excreted manure. Variable amounts of decomposition occur during storage, and nutrients are transformed and lost in amounts dependent on system, climate, and other factors. Major losses are from volatilization of N and leaching of soluble nutrients. Bedding and litter will trap and conserve urinary nutrients but themselves contain low levels of mineral nutrients and usually dilute nutrient concentrations in stored manure. Similarly, addition of water in liquid-handling systems dilutes manure nutrient concentration.

Nutrient transformations also depend on storage period. With long-term treatment or storage, N loss generally is greatest through  $\text{NH}_3$  volatilization and/or denitrification. Phosphorus and K losses are less likely, except for runoff from open lots and/or settling in lagoons. So that maximum nutrient value from manure can be gained, losses in the collection and storage components of manure management systems need to be minimized.

Nitrogen, which is lost primarily through volatilization, is the primary nutrient lost from surface applied manure. For cattle and swine, about 50 to 70% of the N excreted is urea-N, found in the urine. Under many conditions, most or all urea-N is volatilized as  $\text{NH}_3$  within a few hours or days. Nitrogen loss ( $\text{NH}_3$  volatilization) from manures surface applied to fields is greatest when drying conditions dominate, e.g., dry, windy, sunny days (Brunke et al., 1988) and when dry matter content of manure is greatest (Sommer and Olesen, 1991). Field estimates of volatilization loss from surface-applied manure range from about 10 to 70% of ammonium-N applied (Ball and Ryden, 1984; Heck, 1931; Hoff et al., 1981; Lauer et al., 1976; Lockyer and Whitehead, 1990), depending on environmental conditions after application. It therefore is not uncommon for 50 to 70% of ammoniacal N excreted to be lost as  $\text{NH}_3$  before manure is incorporated into

the soil. In many instances, these losses have been linked directly to crop yield declines (Klausner and Guest, 1981; Sutton et al., 1982).

Injection or incorporation of manure minimizes  $\text{NH}_3$  volatilization. Several studies have shown, however, that incorporation may increase denitrification losses (Comfort et al., 1988, 1990; Rice et al., 1988). Average  $\text{NH}_3$  volatilization and denitrification losses of 25.5 and 6.9%, respectively, based on the N content of manure delivered to the field, have been reported when manure was surface applied; compared to 0.9 and 14%, respectively, when injected (Thompson et al., 1987). Injection into a narrowly placed band has the potential disadvantage of causing uneven, stunted growth and chlorosis (Schmitt and Hoeft, 1986; Westerman et al., 1983) that may be due to toxic levels of  $\text{NH}_3$ ,  $\text{NO}_2$ , water, and anoxia (Sawyer et al., 1990). Such problems have been eliminated by use of sweep injectors or surface applications followed by incorporation through tillage.

The effectiveness of fall, winter, or spring manure applications depends on the differential nutrient losses that may occur and on the relative nutrient availability resulting from timing of microbial transformations in the soil (the immobilization/mineralization cycle). Early fall applications may result in significant conversion of ammonium-N, organic N, or nitrate-N followed by leaching or denitrifying of nitrate. Winter applications, especially on frozen soils, can increase runoff losses. Spring applications may cause temporary nutrient immobilization so that peak crop N demand may be unsatisfied even though adequate manure N has been applied. Mineralization is very weather dependent, but when losses of N are minimized, crop performance generally does not depend on application time (Talarczyk et al., 1995). Denitrification or leaching-N losses, especially with fall applications, can be decreased by the use of nitrification inhibitors (McCormick et al., 1984; Sutton et al., 1986).

Method and timing of manure application have little direct effect on P or K transformations but greatly influence the potential for loss of these nutrients in runoff from sloping terrain. Manure applications decrease sediment load in runoff either through mulching or through increasing infiltration rate and soil permeability (Mueller et al., 1984; Wendt and Corey, 1980; Young and Mutchler, 1976). When incorporated, manure decreases soil loss by improving soil physical characteristics including structure, infiltration rate, permeability, bulk density, and water-holding capacity.

Nutrients in dilute manure liquids, i.e., lagoon ef-

fluent or runoff water, applied by irrigation on growing crops can be utilized readily by plants and can provide a source of water during drought. Most nutrients in dry, surface applied manure will need to be solubilized and moved into the root zone before they become available for plant uptake. While decreasing volatilization losses of N, soil incorporation of surface applied manures facilitates both solubilization and nutrient placement in the root zone.

Given both the uncertainties in nutrient content of the original manure and the effect of the storage/handling system on losses and transformations, the importance of manure analysis for the individual farm is clear. Without such analysis, amounts of N, P, and K applied to the field must be estimated from the expected nutrient content of fresh manure, the level of dilution (plus any nutrients contributed by the diluent), and the percentage of loss anticipated by the system. Because each estimate has its uncertainties, this approach is very subject to error.

## Nutrient Availability

Estimates of nutrient availability in manure have been based on experience (Meisinger, 1984; Stanford, 1982) or on field research (Magdoff, 1978; Pratt et al., 1976; Safley et al., 1986; Tyler et al., 1964). Most studies have focused on N availability because it usually is the criterion by which annual manure application rates are established. A common approach to estimating N availability for a specific manure and a specific location is to credit all ammonium N plus some portion of organic N. Estimated organic-N availability depends on animal species (Pratt et al., 1973), climatic region (White and Safley, 1982), and handling and application method (Midwest Plan Service, 1985). Chang and Janzen (1995) showed that, over 20 yr, 56% of N in beef cattle manure was mineralized after application to barley.

Most manure K is in the soluble fraction and therefore readily available (Bartholomew, 1968; Motavalli et al., 1989; Watkin, 1957). Rather widely differing P availabilities have been reported, however. Some researchers have reported that the availability of manure P is equal or superior to that of inorganic fertilizers (During and Weeda, 1973; May and Martin, 1966); other researchers have shown lower responses from manure than from fertilizer P (Goss and Stewart, 1979; Motavalli et al., 1989; Rowarth and Tillman, 1990).

## Agronomic Effects of Manure

### Soil Physical Properties

Throughout the history of agriculture, the value of manure as a soil amendment to improve soil physical properties including wind and water erosion control and improved aggregation (Hafez, 1974; Sommerfeldt and Chang, 1985; Unger and Stewart, 1974) has been recognized. Large soil aggregates tend to decrease compaction, bulk density, and surface crusting and to increase large-pore space and permeability. Application of manure or other organic material to soils increases soil organic carbon (C) content and soil water-holding capacity, presumably by improving aggregation (Khaleel et al., 1981; Sommerfeldt and Chang, 1987). Increased water-holding capacity, decreased clay soil cracking, and increased water infiltration rate with manure application may benefit crops in dry years more than nutrients do (Holliday et al., 1965).

Organic matter additions improve soil physical characteristics by stimulating soil microbial activity and adding organic polymers. Complex polymers serve as a bridge between clay particles, binding together clay particles with associated microbes into soil aggregates (Boyle et al., 1989) or encapsulating and protecting organic molecules from additional microbial decomposition. Fungal hyphae also improve soil aggregation.

At high application rates, certain types of chicken or cattle manure have in some instances decreased the permeability and water-holding capacity of fine textured soil (Azevedo and Stout, 1974). This effect has been attributed to formation of a water-repellent, waxy material that decreases absorption. The potential effect of manure containing excessive monovalent cations such as Na or K on dispersal of soil aggregates is well documented, especially under arid conditions and in porous soils (Amoozegar-Fard et al., 1980; Mathers and Stewart, 1974). If soil aggregate dispersal occurs, infiltration rates decrease and runoff rates increase. The ratio of multivalent to monovalent ions, and especially to Na, is an important determinant of aggregate structure and stability. In humid regions of the United States, however, a harmful buildup of monovalent cations is unlikely, for they leach. Eliminating excessive feeding of salts and other nutrients in animal diets would significantly decrease the load of these nutrients to the soil.

## Soil Chemical Properties

Manure affects many chemical properties of soils, including organic matter content. This in turn affects BOD, chemical oxygen demand, ratio of C to N, and soil fertility. Manure also affects soil pH and both amounts and availabilities of major, secondary, and micronutrients. In addition, salinity, as indicated by the electrical conductivity of the soil, can be affected by manuring.

The organic constituents of manure, which make up from 80 to 90% of dry weight, except for composted poultry litter, which contains 60% organic matter, depend on feed, animal metabolism, storage, and handling method. Organic matter from cattle manure typically contains about half undigested cellulose and hemicelluloses, and 20 to 25% lignins and smaller amounts of fats, proteins, carbohydrates, and other substances, depending on diet. Poultry and swine manures contain relatively little lignin, cellulose, or hemicelluloses because the dietary concentrations of these organic compounds are very low.

After manure is applied to the soil, considerable aerobic microbial degradation usually results. Thus, large accumulations of organic matter seldom result even from heavy applications of manure, and several years may be required to demonstrate significant soil organic matter accumulation. In the short term, under certain soil type and climatic conditions, soil organic matter percentage may decrease after initial manure applications.

Normally, well-drained soils are aerobic. But manure can impose a tremendous oxygen demand on the system, and the soil environment sometimes becomes anaerobic, especially if water is excessive. Anaerobic conditions and certain metabolites formed anaerobically can inhibit plant growth.

### Nitrogen

Of all crop nutrients, N often is of greatest concern because (1) high concentrations can lead to environmental problems, (2) its availability is difficult to predict, and (3) additions usually are required for optimal crop growth. Manure contains ammonium N and organic N in widely different proportions, with traces of nitrite and nitrate. Ammonium N is available to plants immediately, but organic N first must be mineralized. Once formed, ammonium N may (1) remain in the soil, (2) be volatilized as  $\text{NH}_3$ , (3) be utilized directly by plants or microbes, or, as is usual, (4) may be oxidized to nitrate.

Microorganisms convert organic N to ammonium N under both aerobic and anaerobic conditions. Re-

action rate depends on temperature, just as carbon mineralization does, and generally proceeds rapidly over the soil water content range of 5 to 20% (Walter et al., 1975). Mineralization of N also depends on ratio of organic C to N. When ratios exceed 30:35, microorganisms draw on soil inorganic N to utilize excess C for growth. These very high ratios, which occur when large amounts of certain litter or bedding materials are included in manure, temporarily deplete available soil N. Net release of mineralized N begins when the C:N ratio is decreased to about 25, or when microorganisms no longer can assimilate all the N in the organic matter that they decompose.

Eventually, as energy sources become limiting and as cells die, the N immobilized in microbial cells is mineralized, but the release is gradual and never complete. If nitrate-N formed by mineralization is in an anaerobic zone and if other necessary conditions are satisfied, it may be denitrified by organisms and lost as nitrous oxide or as molecular  $\text{N}_2$  gas. Because of nonuniformity within a soil, environmental conditions such as aerobic and anaerobic zones may exist at different times or even simultaneously in a soil profile. This makes it impossible to state categorically how much N will be available to crops as the result of a certain application of manure. Rough estimates of mineralization, volatilization, denitrification, and leaching are possible, however, based on the characteristics of manure, soil, and expected climatic condition.

Many investigators have studied the effects of manure on levels of ammonium and nitrate in the soil profile (Olsen et al., 1970; Randall et al., 1975; Sutton et al., 1974; Sutton et al., 1979; Sutton et al., 1982). Under aerobic conditions, nitrification proceeds so rapidly that little buildup of ammonium occurs, even at the highest manure application rates. Anaerobic conditions, however, inhibit nitrification, and decreased ammonium concentrations during incubation suggest that major losses of N occur through  $\text{NH}_3$  volatilization. Where manure has been injected, concurrent nitrification/denitrification has been observed (Comfort et al., 1988; Rice et al., 1988). Nitrogen application rate and climatic condition have important effects on the amount of nitrate present and available for leaching.

Accumulation and movement of nitrate in the soil after a 3-yr cumulative application of 1,780 t of dairy manure/a. were related to rainfall from May through September. During an unusually wet season, considerable denitrification was observed in a poorly drained clay loam at depths of from 1 to 4 ft. Soil type, crop grown in the manure treated field, and application

method also affected nitrate leaching (Sutton et al., 1979).

After 3 yr of liquid swine-manure injection at an average rate of 60 t/a./yr (which supplied about 575 lb N/a./yr), significant movement of nitrate to at least a depth of 4 ft was detected (Sutton et al. 1982). Nitrate from manure that was surface spread and incorporated by disking tended to remain more concentrated in the top foot of soil although significant leaching to the 4-ft depth also occurred.

### Phosphorus

It is a simple matter to accumulate manurial P in the soil because application at rates meeting crop N requirements will lead to overapplication of P relative to crop need. Low solubility and high sorption rates in the soil result in low P levels in the soil solution but potentially high levels of particulate P, only a part of which is extractable and available as a plant nutrient. Two factors may increase P solubility in soil. Under anaerobic conditions in acid soils, ferric iron ( $\text{Fe}^{+3}$ ) is reduced to ferrous iron ( $\text{Fe}^{+2}$ ), which tends to raise pH and to promote  $\text{Fe}^{+3}$  reduction. Ferrous phosphates are more soluble than ferric phosphates. Additionally, organic matter may increase dissolved P levels through mechanisms that are understood incompletely (Olsen and Barber, 1977). Even so, soil P remains sparingly soluble and tends to accumulate in the top part of the soil profile.

If more P is added to a soil than can be sorbed onto available surfaces, the concentration of dissolved P is increased temporarily, and two reactions can occur: the dissolved phosphate can react with exchangeable Ca in alkaline soils or can react with Fe or Al in acid soils, thereby forming precipitates of phosphate minerals. Simultaneously, dissolved P may leach through the soil until it reaches a region in which potential sorption sites are not saturated. Sorption takes place rapidly, and the boundary between P saturated and unsaturated zones generally is distinct (Walsh et al., 1976). There also is evidence that manure P can leach several feet into soils through movement in soluble organic forms. The nature of these compounds is understood poorly.

A number of authors have studied P movement in soils that has resulted from manure treatments. In Rothamsted studies, added P had penetrated to a depth of only 1.5 ft after more than a century of manure applications at a rate of 16 t/a./yr (Cooke, 1967). Although more recent research showed that repeated manure applications increased P level in the soil, the P was retained in the upper portion (predominantly in the plow layer) of the soil profile.

Considerable research has shown that most soils have a great capacity to assimilate P additions from manure, without detrimental environmental effects. Only a few instances of ground water contamination by phosphate have been reported (Walsh et al., 1976). Runoff from manured areas or erosion of manured soils with high P levels remains a major concern (Sharpley, 1995). High levels of available P can lead to soil fertility problems. For example, P-induced Zn deficiencies have been studied widely (Adams, 1980). Affected crops include citrus, field beans, and potatoes. These cases of Zn deficiency, which generally occur when Zn supplies are marginal to inadequate in calcareous or coarse soil, have been corrected easily with Zn applications. Because manure contains P as well as Zn, however, it is unlikely that P buildup from manure application will create a P-Zn imbalance.

### Potassium and Other Nutrients

Unlike N and P, K is leached rapidly from applied manure, and its release requires neither mineralization nor decomposition of organic matter. Potassium binds to negative exchange sites on soil particles and thus tends not to move through the soil. There is a dynamic equilibrium of K ions between the soil solution, cation exchange sites, and nonexchangeable sites on and in soil particles. The amount of K held by the soil and the relative strength with which it is held depend on the nature of the soil and on the presence of other cations.

When K applications from manure exceed K requirements of crops grown on the specific soil, K accumulation in surface horizons has been demonstrated (Randall et al., 1975; Sutton et al., 1978; Sutton et al., 1979). Addition of K, especially on low exchange-capacity soils, has affected cation balance and/or caused K movement below the application zone (Evans et al., 1977; Sutton et al., 1979; Vitosh et al., 1973). In drier regions, excess K and other salts in manure can accumulate and create salinity problems.

Most micronutrient elements also resist leaching and tend to accumulate in upper levels of the soil. Manures usually contain nutrient quantities sufficient to prevent or to delay micronutrient deficiencies in crops. Micronutrient availability is controlled primarily by such soil properties as soil acidity level (pH), organic matter content, and nutrient holding capacity. Micronutrients typically are present at levels too low to allow competition with the bases for major cation exchange sites. It is believed that, instead, micronutrients usually are bound by specific sites or are complexed with organic constituents in the soil (Keeney and Wildung, 1977).

Animal manures were used to correct Zn deficiency symptoms of plants even before the cause of these symptoms was known. Manures also have been documented to correct Cu and Fe deficiencies (Chaney and Giordano, 1977). Organic matter in manure provides readily available chelated Fe, which is superior to inorganic soil Fe (Miller et al., 1969). Other potential manure micronutrient interactions include P-induced Zn or Mn deficiency and Zn- or Cu-induced deficiency. These relations tend to be quite complex and poorly understood.

Early research with cumulative bimonthly applications of manure equivalent to 240 t/a. increased contents of total Cu, Zn, molybdenum (Mo), and water-soluble boron (B) in six soil types (Atkinson et al., 1958). Nutrient availability to clover subsequently was variable. Manure treatments significantly increased the pH of all six soils, and the increases in sand, sandy loam, and silt loam soils were greater than 1 pH unit. Uptake of B and Mn were depressed on manured soils as a consequence of increased pH whereas Mo uptake was enhanced in all soils except the loam, which initially was alkaline.

Short-term soil pH increases, even in neutral soils, often result from rapid production of  $\text{NH}_3$  and ammonium N. Furthermore, the addition of barn lime to some manures can increase soil pH substantially. As nitrification and mineralization of organic C proceed, pH may drop.

### Soil Biological Properties

Several studies and reviews (Doran et al., 1977; Ellis and McCalla, 1976; Strauch, 1977a) have reported the fate of bacterial, viral, and parasitic pathogens in soils receiving animal and municipal waste applications. Several factors such as temperature, water content, pH, sunlight, nutrient levels, toxic substances in manure, soil, and antibiotics or antagonistic organisms were implicated in pathogen survival in the soil (Doran et al., 1977).

*Salmonella typhimurium* died within 1 week (wk) in dry soil incubated at 39°C; in some instances, however, *Salmonella* survived 42 d (Zibilske and Weaver, 1978). Survival rates at 5°C and at 22°C were not comparable, and usually both were greater than at 39°C. In some samples, *Salmonella* numbers increased up to 3 d before declining. Some have suggested that, to prevent disease outbreaks, animals should not be allowed to graze for 2 to 3 wk after manure application (Elliot and Ellis, 1977). Die-off of fecal coliforms from municipal sewage lagoon effluent-application on soil occurs in two phases: a rapid phase,

in which 90% of bacteria die within 48 hours (hr) of irrigation; and a subsequent, slower decline over about 2 wk, in which the remaining 10% is eliminated.

Fecal coliforms in sewage sludge were destroyed completely in 10 hr of bright sunlight, but there was very little decrease in microbial numbers in the absence of bright sunlight under cool, damp, overcast conditions (Bell, 1976; Bell and Bole, 1978). From this research, it was concluded that livestock would be protected adequately from possible *Salmonella* and *Escherichia coli* infection if at least 2 sunny days had elapsed between the cessation of waste irrigation and the consumption of alfalfa forage.

In other research, coliphage in liquid digested sewage sludge decreased rapidly with drying time. Within 48 hr of sludge application on grass, coliphage was not detected (Brown et al., 1980). Fecal coliforms, however, could survive on pasture grasses for 2 to 3 wk after sludge application. Rainfall did not affect survival. Several other studies reported by Ellis and McCalla (1976) illustrated a much wider range of pathogen survival. A review of Reddy et al. (1981) models die-off rates and pathogen transport in the soil. More information on pathogens in manures is provided in Chapter Two of this publication.

### Manure Effects on Crops

Many experiments have demonstrated that land application of manure will produce crop yields equivalent or superior to those attainable with commercial fertilizer (Huber et al., 1993; Midgley and Dunklee, 1945; Motavalli et al., 1989). Similarly, crop quality improvements have been associated with manure applications (Eck et al., 1990; Pimpini et al., 1992). When crop improvements with manure were greater than those attained with commercial fertilizer, response usually was attributed to a manure supplied nutrient or to improved soil condition not provided by commercial fertilizer (Kelling and Schmitt, 1992; Mathers and Stewart, 1982; Miller et al., 1969). Although the most frequently measured benefit associated with manure applications is from the nutrients contained, physical properties of the soil, i.e., water-holding capacity, infiltration rate, structure, and other properties, often are improved greatly. These improvements may decrease crop water stress.

## Application Strategies

Because the livestock and poultry producer has an available manure source that serves as a nutrient resource, an application strategy for utilizing nutrients is important (Figure 4.2). If maximum recycling of manure nutrients is a goal, then manure must be applied at a rate dictated by the manure nutrient present at the highest concentrations relative to crop need. In most instances, this nutrient is P. If a strategy based on P availability is used, manure is applied at a rate meeting crop P requirement, which often results in the need for additional N and K from commercial fertilizer. This is the most conservative application strategy because it dictates the lowest application rates, is the least likely to have undesirable side effects, and makes the most efficient use of all manure nutrients. It has the disadvantages of being more expensive than other strategies in terms of labor, energy, and time and sometimes is impractical because some producers must have much more land available in relation to the amount of manure produced. A more practical alternative might be to apply enough manure to meet crop P needs for several years and to use N fertilizer in the intervening years.

Historically, manure has been applied at a rate to fulfill crop N requirement without causing environmental problems such as nitrate leaching to ground water. This strategy maximizes application rate but makes relatively inefficient use of manure P and K unless the field subsequently is rotated to other crops—such as legumes—without further nutrient additions. It is the strategy of choice when the amount of land available for manure application is limited.



Figure 4.2. Incorporation of liquid manure into the soil. Photograph courtesy of Alan L. Sutton, Purdue University, West Lafayette, Indiana.

Whereas other environmental considerations may restrict timing and application, location, or method, the amount of N available is the most common rationale for determining manure application rate.

Quite often, manure can be applied to meet all crop nutrient needs even though crops differ in kind and amount of applied nutrient required for optimal yield. Many legume crops, for example, utilize large amounts of N but generally are in a symbiotic relationship with an “N-fixing” soil bacteria root nodule such as *Rhizobium* or *Bradyrhizobium*. Consequently, little N fertilizer generally is required once a crop is established. Legumes, however, utilize inorganic N preferentially to biologically-fixed N and readily utilize N from manure (Kelling and Schmitt, 1992). Thus, photosynthetically generated carbohydrates, which would have been used to feed bacteria in the root nodules for fixing elemental N, are available for other growth processes. When alfalfa effectively scrubs the soil of available N (Mathers et al., 1975; Sutton et al., 1979), little “credit” is given manure N because available N could have been generated symbiotically. The relatively high requirements of legumes for P, K, and micronutrients still may make manure a preferred source of nutrients for legumes.

A major disadvantage of relying on manure as a supplemental source of available N for crop production is the fact that the producer has little control over the time at which manure N becomes available. This may occur during the last half of summer and is too late for most small-grain crops except corn, which requires considerable N during grain development. Mineralized N produced in the fall is largely unused and subject to leaching unless a cover crop or a nitrification inhibitor is used.

## Economic Value as a Nutrient Source

The fertilizer value of manure depends on its nutrient content, availability, and usability within the farming operation. Most frequently, this value is based on the manure’s N, P, and K contents. Because nutrient content and availability depend on animal type and age, feeding program, and manure handling system, estimates range from \$3.65/t for dairy manure without bedding to \$36.01/t for deep-pit poultry manure (Sutton et al., 1985). When secondary or micronutrients are required, the value associated with these elements contained in the manure also should be included. On many soils, however, native supplies of many nutrients are adequate, and therefore addition of these elements with manure has little or no value. Similarly, when long-term manure or fertiliz-



er use has built soil test P or K well beyond the responsive range, the full value of manure P and/or K may not be warranted.

A dollar value based solely on chemical analysis is not a true measure of the value of manure. Other benefits associated with land application, e.g., increased soil organic matter, improved soil structure and tilth, increased water-holding capacity, decreased runoff and soil erosion potential, and improved aeration and growth of beneficial soil organisms, also should be included. Because these benefits are quite difficult to quantify, they usually are omitted from economic evaluations.

Appendix Tables A-3 and A-4 present a regional analysis of the potential fertilizer value of manure for the 48 contiguous states. This analysis is based on estimated nutrient availabilities and recoverabilities after storage of manure from livestock and poultry production in the United States. An average of 15% of the nation's N used as commercial fertilizer is equivalent to manure nutrients available if the distribution was compatible with crop needs. On a nationwide basis, about 42% of the crop need for P could be supplied by manure.

Little fertilizer is purchased in certain regions (South Atlantic, West South Central, and Mountain) due to less cropland production demand, thus, the relative amounts of manure nutrients available for crops are much higher than other regions in the United States. If properly distributed and utilized on productive cropland, manures could significantly reduce commercial fertilizer costs and allow industry growth in many regions of the United States. West South Central and South Atlantic states have more P for cropped soils in relation to commercial fertilizers, whereas high levels of K from manure are shown in West South Central and Mountain state regions. If this manure could be distributed appropriately, and even if more than 100% of crop need was determined to be of no value, then the total potential manure fertilizer replacement value from all livestock and poultry production still would approach \$3.4 billion dollars/yr. This does not, however, include costs for transportation, processing, and management. On the other hand, the aforementioned manure value does not reflect the economic value of improved soil quality, decreased runoff and soil erosion potential, and increased crop yield potential under water stress.

## 5 Recycling and Utilizing Manure for Purposes Other Than Plant Nutrition

Several alternative processes and methods have been developed for the utilization of animal manures other than as plant nutrients. The use of manures as energy resources, processed feed ingredients, composted soil amendments, and processed oils will be discussed.

### Recycling Nutrients for Feed

Animal health issues associated with refeeding manure were discussed in Chapter Two. The feeding of animals with animal manures as a source of low-cost nutrients is not a new practice. Early reports demonstrated the presence of “growth promotants” in dried animal feces fed to rats (McCullum, 1922). The observed benefit to rat growth was associated with growth factors such as vitamins in the feces. Some animals such as rabbits and rats routinely recycle a portion of their voided excreta to obtain required nutrients. Early husbandry practices for feeding swine commonly provided swine access to cattle yards, where undigested feed grains voided by cattle became available for recycling by swine. Poultry and swine have little reluctance to scavenge for nutrients, and where these species have access to their own manure or to the manure of other animals, they readily explore it for nutrients.

The benefit of feeding manures or other byproducts

derived from agriculture and industry is principally economic (McCaskey et al., 1992b; McCaskey et al., 1994a). Crop residues, animal manures, and a variety of byproducts from food and feed processing plants contain protein, fiber, minerals, lipids, and carbohydrates that can serve as dietary nutrients for animals (Figure 5.1). By-products with feed value generally are low-cost sources of feed nutrients. A variety of “exotic” feed resources have emerged over the years such



Figure 5.1. Commercial processing of poultry litter into cattle feed. Photograph courtesy of Thomas A. McCaskey, Auburn University, Auburn, Alabama.

Table 5.1. Relative values of animal wastes utilized for different purposes

Kinds of wastes	Dollars per metric ton			Dollars (x 1,000) for collectable wastes <sup>a</sup>		
	Fertilizer <sup>b</sup>	Feed <sup>c</sup>	Methane <sup>d</sup>	Fertilizer <sup>b</sup>	Feed <sup>c</sup>	Methane <sup>d</sup>
Beef cattle waste	25.06	118.14	13.73	416,800	1,890,200	219,680
Dairy cattle waste	17.00	118.14	12.74	348,086	2,405,094	259,360
Swine waste	18.61	136.57	17.17	103,062	756,325	95,087
Caged layer waste	36.45	155.14	17.93	118,791	505,601	58,401
Broiler litter	26.54	159.57	16.29	64,598	388,393	39,650

<sup>a</sup>Based on values from Van Dyne and Gilbertson (1978).

<sup>b</sup>Values adapted from Wilkinson (1979).

<sup>c</sup>Values from Smith and Wheeler (1979).

<sup>d</sup>Values calculated from data presented by Smith and Wheeler (1979).

as blood meal, meat and bone meal, feather meal, citrus pulp, and tankage from rendering plants (Wiseman and Cole, 1983).

Early studies with animal manures explored the use of swine, cattle, and poultry manures as potential feedstuffs (Anthony, 1966; Noland et al., 1955). The relative values of animal manures as a source of energy, feed, or fertilizer appear in Table 5.1 (Fontenot et al., 1983). Because both poultry excreta from laying hens and poultry litter from broiler chickens have higher concentrations of nutrients than manures from other animal species do, poultry manures are most valuable as feed resources. And because poultry are reared in intensive management systems and practically all manure is collectible, it has been used widely for refeeding. Poultry litter from broiler chicken production is especially valued as a feedstuff because it is relatively dry and easily managed with conventional equipment. Layer poultry manures have not been used widely as a feed source because, unless dried, they have a higher water-content, which limits their use as a concentrated feed. The ash content of layer poultry manure is about twice that of poultry litter because litter dilutes concentrated manure (Kinzell et al., 1983) and layers require a high Ca level for egg shell development. The feeding of broiler poultry litter is limited principally to ruminant animals because of its high content of nonprotein N—primarily of uric acid, and its high fiber content. When litter is available readily at low cost and beef cattle are produced in proximity to broiler poultry operations, the use of litter as a feed generally is viable.

Although low cost is the major reason that producers feed manures, and especially poultry litter, to animals, other factors contributing to this practice are the value of litter during drought, when feed grains, pastures, and hay crops are in short supply. In the Southeastern region, feeding poultry litter as a supplement to cattle during winter decreases the need for other feed ingredients.

As discussed, the microbial safety of animal manure intended as a feed source depends on the proper processing of the manure to ensure elimination of enteric bacterial pathogens. Processes demonstrated effective in eliminating enteric bacteria from animal manure are mechanical drying or pelleting (McCaskey and Harris, 1982), spontaneous heating (McCaskey et al., 1992b), and acidification accomplished by direct acid addition or by its production through lactic fermentation (McCaskey and Anthony, 1979; McCaskey and Martin, 1988; McCaskey and Shehane, 1980).

Swine and cattle manures should be collected and

processed daily because they have a high water-content and tend to degrade rapidly (Adriano et al., 1971; Arndt et al., 1979). Thus, their use as a feed ingredient is limited. Various methods could be used to process these manures into feed, but because of high water-content and high drying cost, the method most often used is ensiling.

The ensiling process provides a low-cost alternative for processing and storing wet manure sources (> 25% water). Wet animal manures include cattle, swine, and caged layer manures. These should be processed within one day of being voided. If wet manures are stored longer, they degrade and thus are more difficult to ferment; they also lose nutrients, and their palatability can suffer. Dry manures (< 25% water) such as broiler litter, turkey litter, and air-dried, caged layer poultry manure can be fermented successfully if certain conditions are achieved: water content must be adjusted to approximately 40%; a soluble carbohydrate source such as ground shelled corn must be added; and the waste percentage must be limited to an amount not impeding a drop in pH to 4.5 or lower in the fermented product (McCaskey and Anthony, 1979).

Manure preparation is especially important for poultry manures because they are both highly alkaline (pH of 8.2 to 8.4), and highly buffered (Goering and Smith, 1977); they therefore require more lactic acid to drop the pH below 4.5 (McCaskey and Wang, 1985; McCaskey and Harris, 1982). Generally, the proportion of poultry litter added to chopped whole-corn plant forage should not exceed 30% of the dry matter of the total mixture (McCaskey, 1986). On a wet weight basis, this proportion is approximately 15 to 20% poultry litter to 80 to 85% corn forage.

Poultry litter alone does not ferment and achieve pH values of 4.5 or below, because it lacks adequate fermentable carbohydrate and water content for microbial growth (McCaskey and Anthony, 1979; McCaskey et al., 1992b). Swine manure and cattle manure also may lack sufficient carbohydrate reserves, and their water content usually is too high. Animal manures therefore must be blended with other feed ingredients to adjust carbohydrate and water content. Various proportions of animal manures and feed ingredients have been evaluated, and if water is adjusted to 40% and at least 6% of carbohydrate (dry basis) is available for fermentation, most mixtures of feed ingredients and animal manures will ferment. Cattle manure comprising 40% wet weight of an ensiled feed mixture with 45% corn grain and 15% fermented corn silage achieved a pH of 4.1 after 4 d of ensiling at 35°C (McCaskey and Anthony, 1975). Although cattle ma-

nure is itself a source of coliform bacteria, the addition of manure to a mixture of feed grains helped the mixture eliminate coliforms during fermentation (Knight et al., 1977).

Manure from feedlot cattle fed highly concentrated diets results in optimal fermentation because undigested grain in the diet serves as a carbohydrate source for conversion to silage acids. Manures from cattle fed high roughage diets lack adequate carbohydrates to ferment properly.

## Conversion to Fuel and Energy

As energy costs increased in the 1970s and the 1980s, livestock producers explored the potential of anaerobic digestion of animal manure to produce *biogas*, i.e.,  $\text{CH}_4$  and  $\text{CO}_2$  (Figure 5.2). *Anaerobic digestion* is the natural process whereby bacteria existing in oxygen-free environments decompose organic matter. As a result of such digestion, organic material is stabilized and gaseous by-products—primarily  $\text{CH}_4$  and  $\text{CO}_2$ —are released. Typically, anaerobic digesters are designed to operate in either *mesophilic* (20°C to 45°C) or *thermophilic* (45°C to 60°C) temperature ranges. Methanogenesis can occur at temperatures as low as 4°C (Stevens and Schulte, 1979).

Anaerobic digesters were constructed on 85 to 100 farm sites in the United States (Ashworth et al., 1984), but only a few on-farm digesters were operated for more than 2 yr. Most used designs developed by civil engineers for the treatment of municipal wastewater, but the nonhomogeneity of animal manures presented major materials problems, e.g., solids settling, scum

formation, and grit removal. Most early digesters produced biogas at design rates. High capital costs and significant managerial inputs also were characteristic of many early agricultural digesters. Additionally, most could not be used with hydraulic flush manure removal systems because the size of the reactor needed to achieve desired hydraulic retention time was large and the energy to maintain temperatures was costly.

Most livestock manures and many other agricultural by-products can be processed in anaerobic digesters to produce biogas. Quantity and quality ( $\text{CH}_4$  concentration) of biogas produced depend on reactor design and operating temperature and on type and



Figure 5.2. Biogas collection from anaerobic livestock methane digesters. Photograph courtesy of Don D. Jones, Purdue University, West Lafayette, Indiana.

Table 5.2. Reported values for methane production from animal manures

Animal type	Ration	Ultimate methane yield ( $B_0$ ) ( $\text{m}^3\text{CH}_4/\text{kg}$ volatile solids added)	Reference
Swine	Corn based, high-energy ration	0.52	Kroeker et al. (1979)
Swine	Corn based, high-energy ration	0.48	Stevens and Schulte (1979)
Swine	Corn based, high-energy ration	0.48	Hashimoto (1984)
Swine	Corn based, high-energy ration	0.47	Chen (1983)
Swine	Corn based, high-energy ration	0.45	Fischer et al. (1975)
Swine	Corn based, high-energy ration	0.44	Iannotti et al. (1979)
Swine	Barley based ration	0.36	Summers and Bousfield (1980)
Beef cattle	Corn based, high-energy ration, manure collected from concrete	0.33	Hashimoto et al. (1981b)
Beef cattle	Ration was 7% corn silage, 87.6% corn; manure collected from dirt lot	0.29	Hashimoto et al. (1981a)
Beef cattle	Ration was 91.5% corn silage, 0% corn; manure collected from dirt lot	0.17	Hashimoto et al. (1981a)
Caged layers	Grain based ration	0.39	Hill (1982a)
Dairy	58–68% silage	0.24	Morris (1976)
Dairy	72% roughage	0.17	Bryant et al. (1976)

quality of manure placed in the digester. Freshly excreted manure is preferable to older, more decomposed manure. Manure from nonruminant livestock fed diets composed primarily of grain tends to produce more biogas per unit than manure does from ruminants fed a high roughage diet (Hashimoto et al., 1981b). Methane generation rates differ widely because rations vary (Table 5.2).

Ultimate  $\text{CH}_4$  yield from animal manure does not depend on digestion temperature. If retention time is sufficient, biogas production from a given amount of manure will be the same, regardless of digester temperature, over the range  $10^\circ\text{C}$  to  $50^\circ\text{C}$  (Heukelekian, 1933; Maly and Fadrus, 1971).

Mesophilic anaerobic fermentation of animal manures in full-scale, pilot-scale digesters has been reported by numerous researchers (Converse et al., 1981; Hashimoto, 1983; Hills, 1983; Pain et al., 1984; Pos et al., 1985; Safley et al., 1987). Anaerobic decomposition of organic matter at low temperatures ( $< 20^\circ\text{C}$ ) is referred to as *psychrophilic digestion*. Over the past several years, psychrophilic anaerobic digestion has been studied extensively by Swiss researchers (Sutter and Wellinger, 1988; Wellinger, 1989; Wellinger and Kaufmann, 1982; Wellinger and Sutter, 1988). Satisfactory biogas production from beneath swine facilities has been observed at temperatures ranging from  $15^\circ\text{C}$  to  $20^\circ\text{C}$ . Gross biogas production for a digester operated at  $20^\circ\text{C}$  and at a retention time of 40 to 50 d was comparable to that for a digester operated at mesophilic temperatures at half the retention time (Sutter and Wellinger, 1988; Wellinger and Kaufmann, 1982).

Because less heat is required to raise waste temperature, the net energy release from a psychrophilic digester was 30 to 40% greater than that of a comparable mesophilic digester. To achieve the same volatile solids reduction, low-temperature digestion required, however, a solids retention time approximately double that for mesophilic digestion (Stevens and Schulte, 1979).

Biogas production is possible from anaerobic manure lagoons (Hart and Turner, 1965; Oleszkiewicz and Koziarski, 1986). Floating covers for harvesting biogas have been installed on lagoons in several locations throughout the world (Balsari and Bozza, 1988; Cadwallander, 1987; Chandler et al., 1983; Melvin and Crammond, 1981). The basic concept is to use a floating cover to harvest  $\text{CH}_4$  as it escapes from the lagoon surface. A collection system is used to concentrate biogas flow. Compared with conventional anaerobic digesters, anaerobic lagoons are designed for relatively low loading rates of 0.056 to 0.104 kg volatile sol-

ids (VS)/ $\text{m}^3/\text{d}$  compared with 2.7 to 17.7 kg VS/ $\text{m}^3/\text{d}$  for anaerobic digesters (American Society of Agricultural Engineers, 1985; Hill, 1984). Recommended loading rates increase with mean ambient temperature.

A biogas production rate of  $0.21 \text{ m}^3/\text{m}^2/\text{d}$  from the surface of a pilot-scale anaerobic swine lagoon with a loading rate of  $3.36 \text{ kg VS}/\text{m}^3/\text{d}$  was determined to be the equivalent loading rate of  $0.113 \text{ m}^3/\text{m}^3/\text{d}$  for 1.86 m-deep lagoons (Humenik and Overcash, 1976). Gas composition was 70%  $\text{CH}_4$  and 25%  $\text{CO}_2$ . Gas production from a full-scale anaerobic swine lagoon and from pilot-scale dairy and poultry lagoons ranged from 70.4 to 83.9%  $\text{CH}_4$  (Allen and Lowery, 1976). Researchers suggested that these deep lagoons could increase anaerobic digestion.

Table 5.3 presents operational data for anaerobic digesters used for a variety of animal types, diets, temperatures, and loading rates. Volatile solids reduction and  $\text{CH}_4$  yield depend heavily on substrates and operating conditions.

Several types of anaerobic digesters have been used to process livestock manure. These include completely stirred tank reactors, plug flow digesters, and low-temperature lagoon digesters. Each reactor type is unique and can be used in specific situations. Several publications deal with digester design and management and with biogas utilization (Koelsch et al., 1989; Parsons, 1984; Walsh et al., 1988).

Biogas also can contain high concentrations of water and hydrogen sulfide ( $\text{H}_2\text{S}$ ). Combined, these materials form sulfuric acid, which when used in internal combustion engines contributes to engine wear. Some engine manufacturers recommend that biogas with  $\text{H}_2\text{S}$  concentrations exceeding 1,000 ppm not be used. Hydrogen sulfide can be removed from biogas by means of one of several techniques including the passing of biogas through special aqueous solutions and the activation of C beds, molecular sieves, and iron sponge beds. Suppliers of this type of technology should be consulted to determine the appropriateness of  $\text{H}_2\text{S}$  removal for a given situation (Koelsch et al., 1989; Parsons, 1984; Walsh et al., 1988).

## Other Processes

Animal manures can be subjected to various pyrolytic procedures producing chars and industrial petrochemicals (Overcash et al., 1983). These oils and chars can be used for fuel or can be processed for production of carbon black, synthetic rubber, printing ink, and other products. Processes such as hydrogenation, hydrogasification, and coal liquidification produce

CH<sub>4</sub>, heating oils, and synthetic gas. Using manure for the production of any of these products, however, is generally not economical, and consequently the quantity of manure subjected to pyrolytic procedures is quite limited.

Other uses for animal manures include their feeding to various organisms other than livestock. For example, manures can be used to culture yeasts and algae which, in turn, can be used as animal feeds. Algae production of 240 megagrams/hectare is possible, and algae contain up to 2.5 times more N than corn does. Problems with algae harvesting and low nutrient digestibility increase cost and limit the potential use of this process. Thus, quantities utilized are small. In certain areas, however, and especially in China (Wohlfarth and Schroeder, 1979), animal manures are used extensively for fish production. For highest efficiency, several fish species are produced simultaneously. Fish production rates in excess of 45 lb/a./d are possible.

In parts of Pennsylvania and elsewhere, substantial quantities of manures (especially horse and poultry) are used for commercial mushroom production. About 45% of mushroom production in the United States occurs in Pennsylvania, where approximately 52,000 t of poultry manure and 240,000 t of horse manure are used annually. Although pig and cattle manures can be used, horse and poultry manures are preferred because of their physical properties. Typically, the manure is mixed in a 1:1 ratio with straw or hay and composted 2 wk outdoors and then several weeks in controlled temperature rooms to promote development of a favorable fungal population. The compost, subsequently inoculated with mushroom hyphae, serves as a slow-release N source for growing mushrooms. Because about 75 d is required for a complete cycle, several mushroom crops can be produced annually. Residue remaining after mushroom production must be disposed of, creating problems

where land for disposal is limited.

Manures frequently are composted for various reasons (Rynk, 1992) (Figure 5.3). Through the action of thermophilic microorganisms involved in composting, approximately 30 to 40% of C in manure usually escapes as CO<sub>2</sub>, thereby decreasing the bulk of animal manures. During composting, water content decreases and handling characteristics improve. Nitrogen in compost generally is stabilized in organic compounds. When manures are composted to kill weed seeds and pathogens, they decrease the potential of soluble nutrient leaching or runoff. Surface applied composts are less likely to contaminate surface water than raw manure is. Potential for compost to be eroded remains, however, and the composting process usually causes loss of one-third to one-half of manure N. The heat generated (55°C to 60°C) usually kills weed seeds and pathogenic organisms. The resulting compost is used for gardening and horticulture and also is valuable for field crops. Recycled litter and manure compost also have been used as bedding or litter.



Figure 5.3. Mechanical mixing of composting cattle manure. Photograph courtesy of Don D. Jones, Purdue University, West Lafayette, Indiana.

Table 5.3. Reported operational characteristics of animal manure anaerobic digesters

Animal Type	Conditions	Methane-yield ( $m^3 CH_4/kg$ volatile solids fed)	Loading rate volatile solids ( $kg/m^3/day$ )	Temp. ( $^{\circ}C$ )	Retention time (days)	Volatile solids destruction (%)	References
Caged layer	Grain based diet whole manure	0.23-0.27	1.7-2.0	35	22-40	53-58	Safley et al. (1987), Converse et al. (1981)
Dairy	Whole manure	0.13-0.19	1.8-3.4	35	10-30	31	Hills and Kayhanian (1988), Jewell (1979)
Dairy	Filtrate after screening through 10 mesh	0.14-0.20	1.0-3.1	35	10	26-38	Hills and Kayhanian (1988), Lo et al. (1984)
Dairy	Separated slurry	0.15	1.8	34	20	37	Pain et al. (1984)
Dairy	Corn silage based ration	0.22	3.2	35	30	—	Jewell (1979)
Dairy	Corn silage ration separated manure	0.39	0.12	8-31	67	69	Safley (1991)
Swine	Whole manure confinement	0.38-0.45	2.1-3.0	35	15	—	Fischer et al. (1978), Kroeker et al. (1979)
Swine	High grain ration	0.30-0.42	3.5-4.0	35	10-25	63	Hashimoto (1983), Fischer et al. (1978), Summers and Bousfield (1980)
Swine	Manure from finishing animals	0.22-0.38	0.8-3.0	20-30	14-30	36-43	Pos et al. (1985)
Swine	Flushed whole manure	0.28	0.11	11-22	50-63	—	Chandler et al. (1983)
Swine	Fresh feedlot manure	0.21	3.4	35	18	39	Hills (1983)
Beef	High grain ration	0.31	4.3	35	10	—	Hashimoto (1982)

## 6 Animal Mortality Management

### Problem Magnitude

As large livestock and poultry production facilities concentrate and expand, the task of farm animal mortality disposal becomes increasingly critical. With the declining number of rendering firms and the public concern about ground water degradation resulting from contamination from animal burial, new alternatives for animal mortality disposal clearly are needed. Alternatives include a coordinated collection system using a refrigerated trailer at a common drop-off site, on-farm incineration, on-farm refrigerated or frozen storage with subsequent transportation to a renderer, and composting.

Because of their relatively small size, livestock and poultry enterprises of the past could deal with animal mortalities in various ways that would be unobtrusive by today's standards. Larger operations, however, produce more animals on a smaller land area. Thus, on-farm mortality animal disposal is an unsightly, unpleasant, and unsound practice for many modern livestock producers who are trying to maintain a disease-free herd while protecting the environment. Rendering firms that transform dead animals into useful commodities such as meat and bone meal or fertilizer have been a common disposal resource. This method of disposal is becoming increasingly impractical, however. The number of rendering firms has declined dramatically in recent years, and this decrease is likely to continue because the cost is high for collecting an economically feasible quantity and quality of carcasses.

Most rendering firms collect, for a fee, animals from a broad geographic base. This causes two problems. First, the cost of collecting a large quantity of animals on a regular basis is high and the supply of mortalities is inconsistent because rendering firms must be contacted by producers. Second, animals are in various states of decay when they reach the rendering facility, and carcass condition influences quality and dollar value of rendered end-products. Therefore, the task of managing farm animal mortalities has become an on-farm disposal problem, and the methods that have been used successfully on farms include compost-

ing, incineration, centralized collection, on-farm refrigeration, and contained burial.

### Mortality Management Methods

#### Composting

Composting was evaluated at the University of Maryland (Murphy and Handwerker, 1988) and since has been accepted widely by poultry producers and by environmental agencies as a feasible, environmentally acceptable method for disposal of poultry mortalities (Blake and Hulet, 1990; Blake et al., 1992; Patterson and Blake, 1994). Composting also is being investigated by some in the swine industry, who are using simply built and easily maintained composting facilities and equipment (Fulhage, 1994) (Figures 6.1 and 6.2). Composting is a complex degradative process by which organic wastes are converted into safe, stable humus by microorganisms.

There are four requirements for efficient composting. (1) The material to be composted must be organ-



Figure 6.1. Roofed composter for dead animals, with concrete floor, wood bin walls and roof overhang to protect the work area. Photograph courtesy of Alan L. Sutton, Purdue University, West Lafayette, Indiana.



ic, e.g., mortalities and animal manures. (2) The C to N (C:N) ratio of the material should be at least 15:1. Mortalities are primarily proteinous materials and require a C supplement such as hay or straw to adjust this ratio. (3) Moisture of the material to be composted should be adjusted to about 45%, and (4) a bulking agent that is a component of the C:N ratio must be used in the composting recipe to decrease bulk density of the compost mixture, a practice that allows air to penetrate (Carr, 1994). Air is required in the composting process so that microbes can decay the mortalities with a minimal production of odors. During composting, heat is generated sufficient to kill microbial pathogens such as *Salmonella* and *Escherichia coli* O157:H7 (Murphy, 1990).

Composting of poultry mortalities is conducted in wooden bins by respective layering—at a weight ratio of 3:1:0.3:0.5—bulking agent, mortalities, C supplement, and water in the bins. After 30 d of composting, the compost is transferred to another bin to undergo a second 30-d composting process. The period can be shortened if the C:N ratio is increased. After two-stage composting, compost weight and volume each typically are decreased 20 to 25% (Britt and McCaskey, 1992). Approximately 80% of the compost generated in one bin can be recycled as a bulking agent to build another compost pile. The finished compost has no noxious odors and on a wet-ton basis (35% moisture) contains about 50 lb N, 100 lb superphosphate, and 61 lb of potash. The fertilizer value of a wet ton of mortality compost is approximately \$47 (McCaskey et al., 1996).

### Incineration

Another method of disposing of dead animals is incineration. Despite its increasing popularity, there is discontent regarding its performance and efficiency. Incinerators have been used as a means of dispos-

ing of dead animals, particularly by producers not serviced by a renderer. Many producers using incinerators still encounter problems due to low efficiency and high fuel cost. The life of an incinerator has been estimated at approximately 10 yr.

United States Environmental Protection Agency emission standards allow for only 0.225 grains of particulate matter/hr. Even though incinerators producing much less particulate matter are available, the law still requires an afterburner. Ashes may be disposed of on the farm. Incineration probably is the most labor intensive method of disposal and is limited to smaller carcasses.

### Centralized Collection

An alternative to on-farm refrigeration units is the coordinated collection of dead animals at a local site and the subsequent transport of accumulated carcasses to a rendering facility. Using this method, producers deliver dead animals to a local self-service collection point, where carcasses are placed in a refrigerated semitrailer. Individual producers disinfect trucks before returning to their farms. Periodically, the refrigerated trailer containing accumulated carcasses is transported to a rendering firm. This method allows for the collection of a higher quantity and quality of dead animals on a regular basis and provides a value-added product.

### On-Farm Refrigeration

The use of an on-farm refrigeration unit both inhibits decomposition when a renderer is unable to pick up carcasses immediately and decreases the need for frequent pickups. The renderer may be more accommodating in making a pickup because the refrigeration unit guarantees a greater quantity of higher-quality carcasses.

An on-farm refrigeration unit is practical for producers serviced by a renderer, for if deterioration is to be prevented, unrefrigerated carcasses should be stored for no more than 6 to 10 d. In that period, however, most producers not serviced by a renderer would not accumulate enough carcasses to warrant pickup.

Because costs differ greatly, the cost of rendering services with a refrigeration unit is difficult to estimate. If, however, the producer pays per pickup and does so more than once a week, then obviously the total annual service fee paid a renderer could decrease substantially.

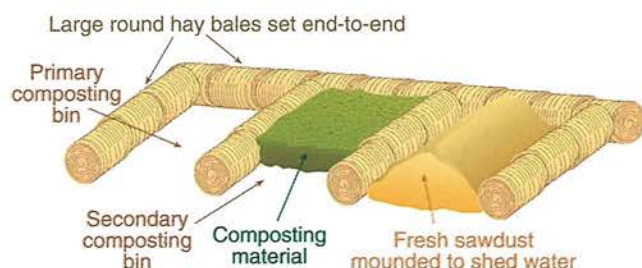


Figure 6.2. Schematic of a simple dead-animal compostor (Fulhage, 1994).

### On-Farm Freezer Unit

There are essentially two types of freezer units that could be purchased for on-farm storage of dead animals. Smaller household freezers or commercially sized walk-in freezers are available. Regardless of the type chosen for a certain operation, a freezer unit has the ability to prevent carcasses from deteriorating for as long as 1 mo. Even if producers are not serviced regularly by a renderer, the renderer may be willing to pick up a large quantity of dead animals.

### Contained Burial

Burial of dead animals has been a common method of disposal permitted in some states. Because of potential water quality degradation from leaching and predator concerns, however, many states reject burial as a disposal method. When enclosed containment tanks are placed underground for dead animal dispos-

al, similar design requirements, management, and utilization procedures are necessary so that no leaching occurs. Covering the storage container and injecting wastes are necessary practices if odors and flies are to be controlled.

### Summary

Although several dead-animal disposal methods have been described and implemented for livestock and poultry operations, very little research has been conducted to compare the potential value, safety, and environmental threat of these methods. State laws for dead-animal disposal have been enacted based on practical experiences or theoretical assumptions. Guideline development and management parameters based on research and technical studies are needed. A thorough economic analysis of each method has yet to be conducted, and new technology to develop value-added products should be encouraged.

## 7 Future Research, Educational Needs, and Regulatory Policy

This document has focused on the accomplishments of animal manure management research and educational programs in the United States addressing environmental issues and concerns. Much research and technology has been aimed at utilizing rather than disposing of manure. More information is needed about how to control nutrients and odorous compounds and how to develop practical technologies that the production sector can use in integrated systems compatible with a sustainable environment.

Educational programs to inform and to encourage adoption of current conservation technologies and BMPs by farmers are an area of immediate focus. If implemented adequately, available management, storage, and nutrient utilization technologies can solve many current water and air pollution problems. Regulatory policies often change as a result of environmental concerns, but regulations need to be based on reliable, scientific information and on their previous success as practices known to improve and to sustain the environment. Frequently, the "one size fits all" syndrome can be avoided. A brief discussion of specific areas in research, education, and regulatory policy needing attention follows.

### Research

Water-quality research, especially that focusing on nonpoint pollution effects on watersheds, has evidenced a resurgence. This research is critical because manure management research funding from all sectors decreased significantly after an initial support base in the early 1970s. Virtually no extramural support was provided researchers in this area from the late 1970s through the 1980s. Inadequate research funding has been dedicated strictly to animal manure management systems even though animal manures are being identified as the major contributors to nonpoint pollution.

Research areas that would yield positive environmental benefits include (1) modification of animal diets, (2) development or improvement of manure treatment processes, (3) nutrient control and utilization of manures in soil-cropping systems, (4) odor reduction

and control, (5) economic analysis of manure system alternatives, and (6) new technologies for value-added products and processes for manures. Development of new technologies requires realistic management, consistent and dependable operation, and economic feasibility.

### Diet Modification

Investigators (Adeola et al., 1995; Cromwell and Coffey, 1994; Cromwell et al., 1995; Jongbloed and Lenis, 1994; Mroz et al., 1994) recently have reported the potential to decrease nutrient outputs in manure through dietary manipulation, including use of phytase to decrease P and other mineral excretions; decreased protein levels in diets and supplementation with synthetic amino acids to decrease N excretion; change in dietary carbohydrate content; and use of growth promotants to increase protein accretion, to decrease fat accumulation, and to enhance nutrient digestibility. A decrease in nutrient excretion also can decrease odors (Sutton et al., 1995). Processing the diet by grinding, pelleting, steam flaking, fermenting, and chemically treating increases dietary nutrient digestibility, enhances absorption efficiency, and decreases excretion products. Excess nutrient excretion can be decreased by phase feeding to meet animal nutrient needs more accurately without excess nutrients; by split-sex feeding to meet nutrient needs of each sex more accurately; by individual feeding of animals, e.g., lactating dairy cows or gestating sows; by minimizing feed wastage; and by limiting feeding.

Because many of these investigative areas are fairly new, continued research is needed to develop technologies that can be implemented by production agriculture. Additionally, biotechnological genetic research and management technologies enhancing the digestibility and nutrient balance of feed resources to meet animal nutrient needs is vital to decreasing nutrient outputs significantly. Significant genetic changes in animals require changes in dietary nutrient levels (Schinckel et al., 1988; Stahly et al., 1989). Research must continue to define nutrient requirements for optimal economic production potential of the

animal without excess nutrient excretion. The greatest benefits from this type of research are increased food-production efficiency resulting in a reliably low-cost food supply for the consumer, increased profitability for the producer, and lowered requirements for a sustainable landbase for manure application.

### Manure Treatment

For at least 30 yr, research has been conducted on various biological treatments of animal manures. Goals were either to conserve nutrients or to remove and to stabilize them for improved handling, preservation, or utilization. Odor control also has been a focus of treatment systems. Most processes tested have required additional labor, equipment, and energy inputs and have generated little economic return. Economic incentives or other benefits related to the well-being of the business must be available before treatment systems will be used. Additional treatment systems need to be developed and tested so that limits or standards for nutrient flow and odor control can be set.

Methods of extracting nutrients from manure and of producing value-added products that may be marketable seem a worthy area of research. Examples of treatment are flocculation, precipitation, electrolysis, ozonation, filtration, and chemical digestion. The use of constructed wetlands to treat dilute livestock wastewater systems needs further research. If constructed wetlands can treat wastewaters sufficiently to meet water-quality standards for discharge, this technology will be adopted rapidly by many livestock producers. Management and design guidelines are needed, however; and the long-term use of constructed wetlands for manure treatment still is questionable. Composting technology needs to be improved so that the potential of recycling several biowastes together to produce a stable product utilizable as a resource can be investigated. For example, recycled newsprint, cardboard, leaves, chopped shrubs, and other such waste materials could be combined with manures and other residues.

### Soil Amendment

Because of environmental pressures, considerable research must be conducted on runoff control and loading rates, site analysis, and pollution potential of P and possibly K from manures. Some state regulations are imposing P limits on manure applications. The landbase required for manure application when P limits are specified is 2.5 to 4 times that required

when N is the limiting nutrient. Debate continues about the solubility of P from organic sources such as manures, the loading limits for different soil types before leaching, the form in which P moves during runoff from soils, and the methods of chemically or physically controlling P movement. Increased research toward resolving these issues is needed before regulatory policies are adopted.

Because of the organic nature of manure, microbial metabolism is enhanced in the soil after manuring. Currently, however, the rate or timing of nutrient mineralization is controlled poorly, which complicates the synchronizing of crop nutrient demands with crop mineralization and manure release. To clarify the availability of nutrients for plant use and to determine the proper management guidelines for efficient nutrient usage without pollution creation, research must continue in soil microbiology, soil physical and chemical interactions, and materials development to control the fate of certain nutrients—especially that of N. Nitrogen has been controlled by nitrification inhibitors, and P may be controllable by aluminum sulfate.

Because tens of millions of acres of U.S. land receive animal manures annually, the overloading of these soils with manure and thereby the opportunity for nitrate leaching are major concerns. To solve problems associated with manure management effects on surface and on ground water quality, much additional research is needed to determine and to predict mineralization rates and N availability under a myriad of soil, climate, and cropping conditions. Excessive manure rates, often coupled with additional fertilizer N, have created a large pool of residual nitrate-N in many soils after harvest. Given an appropriate soil and climate, much residual nitrate-N may be leached during these noncrop periods.

Because manures, crops, soils, and climates are very diverse, leaching potentials are difficult to quantify. To apply the proper rate of manure to the soil, one needs to determine residual nitrate-N content of the soil, mineralization rate of soil organic N, total N content of manure to be applied, manure N-percentages that will be mineralized in the year of application and for several years afterwards, N requirement of the crop, potential for nitrate leaching and denitrification, and efficiency with which soil mineral-N is taken up by the crop. Additionally, the nutrient contents of manure differ greatly—even from load to load, and there is a need for useful analytical techniques for measuring nutrient content in the field. To identify the best practices to use in a given situation, all these variables need to be integrated into user-friendly computer models to guide decision making.

Because the N/P ratio of most manures is narrower than that required for production of most crops, after several years of manure applications, available soil P levels often increase substantially and only the quantity of P removed by the crop needs to be added annually. In these instances, manure rates should be decreased to levels meeting P requirements, with additional N, if needed, being provided by fertilizers or other resources. It is possible that sufficient P could be applied in manure to meet crop needs for several years, with crop N needs' being met with fertilizer N during intervening years. Considerably more research is needed to evaluate this approach, which research indicates would greatly increase the efficiency with which fertilizer N is used. The ammoniating of manure to yield a more favorable N/P ratio also needs investigating.

Additional work is needed to develop (1) accurate risk assessment associated with high P loading rates and (2) a means of evaluating manure chemistry and soil chemistry changes taking place when P at high rates or over extended periods is applied on soils. No reliable method for predicting mineralization rates of either soil N or manure N exists to help calculate optimal manure application rate. Because of variability in the composition of manure even from load to load, it is, practically speaking, quite difficult to determine accurately and rapidly the N and P content of manure. Accurate methods of predicting mineralized N percentage that can be utilized by the growing crop are lacking, as is equipment able to apply manure within 25% or even 50% of the desired rate. Because basic knowledge, techniques, and equipment are lacking, only highly empirical guides are available to follow for calculating suitable manure application rate. These methods need improvement. If, however, manure application rate is controlled according to crop P requirement, crop N requirement is much less likely to be exceeded and an unacceptable buildup of available soil P may be prevented. Again, user-friendly computer models and similar decision aides need to be developed.

A major problem arising from the land application of manure in many locations is the lack of sufficient and suitable land nearby. Consequently, application rates on available land often greatly exceed crop requirements, and nitrate leaching can occur. In such instances, manure needs to be transported a greater distance for land utilization, and manure processing or compaction by composting or pelleting may be necessary. Transportation distances dictate that researchers develop technology to enhance manure nutrient content and availability, for example, by partial

digestion of manure with concentrated sulfuric acid, ammonification, and/or drying and pelletizing by reaction heat. Rock phosphate or other plant nutrients also could be added, enriching a final product with a higher analysis fertilizer value. Refeeding, CH<sub>4</sub> generation, and other uses of manure may prove more profitable than land utilization. An approved manure management plan often is required now before a livestock or poultry confinement permit is granted by the state or the local governing body.

The problem of inadequate area for land utilization is especially critical for many poultry operations and for some swine and dairy operations. Economic studies have indicated that nutrients in beef feedlot manures as a fertilizer resource would pay for the cost of transportation up to 9 miles from the source. Economically acceptable transportation distances for liquid or slurry manures are considerably shorter.

Improving the genetic capacity of specific crops to increase nutrient utilization from manure amended soil has promise. Specific plant species and cropping rotations may be developed that increase nutrient use, especially where the landbase for manure application may be limited. New on-farm methods of rapidly estimating the nutrient levels in manures and soils are needed to assist producers in management decisions, manure application rate adjustments, and "prescription techniques" to control and to improve efficiency of use of available nutrients for crop production. Additional research is needed to develop equipment for optimal, uniform, and accurate application and incorporation of manures into the soil.

Conservation compliance requirements of the Food Security Act of 1985 and the Food, Agriculture, Conservation and Trade Act of 1990 often prohibit tillage on erodible soils. Yet such soils often respond dramatically and positively to manure application. Whether manure can be applied to these soils without disturbing the crop residue cover needed to prevent soil erosion and without diminishing environmental quality, is an open question that needs research.

## Odor Control

Odors from livestock and poultry industries have been the most recent public environmental concern regarding large-scale animal production. The number of lawsuits involving odor has increased significantly in recent years, and the viability of some livestock operations hinges on resolution of odor control. Similarly, many large operators have moved to or expanded facilities in remote areas of the United States, actions that may decrease revenue and employment in

states where livestock and poultry traditionally have been produced and constitute an important component of the economy. During the last 30 yr of animal manure management, very little funding has been dedicated to odor research. Some commodity organizations and a few states have begun to dedicate pilot research studies on odor control from livestock operations. Increased research is needed immediately to facilitate rapid solution of the problem.

Odor studies should include the effects of animal diet; manure treatment; handling (management) systems; chemical, physical, and microbiological methods; weather components; facility design; and factors related to the quality and quantity of odor causing compounds (Miner, 1995). Work is needed to identify and to measure accurately major odor compounds and to correlate identifiable compounds with *olfactometry*, or human nose, methods. Storage-system or animal-diet additives to control odors should continue to be developed. Several types of filter systems have been investigated, but additional research is warranted.

### Economics

As the industry embraces increasingly integrated approaches to food and fiber production, producers need clear, concise, and accurate economic analyses of manure management alternatives including realistic monetary returns to operations. Lending agencies and governmental regulations are requiring environmental impact statements and an economic analysis of agribusiness. Incorporated into this analysis should be descriptions of alternative manure management systems and of their potential integration into operations. Decision making can be fruitful only when data are valid and information is available through research.

Rarely have manure management systems been documented economically. The most thorough evaluation of several manure management alternatives for all farm species was in 1978 (White and Forster, 1978); this work needs to be updated, expanded, and made available to producers, policy makers, consultants, and educators. With the evaluation of different waste management systems, there needs to be a critical assessment of cost/benefit ratio and of effects on water, air, and soil quality. Adoption of realistic policy decisions also is necessary.

In recent decades, and especially in the last few years, concentration of livestock feeding operations has increased—operations housing more than 50,000 feeder cattle, 100,000 sows, or 1,000,000 broilers and layers exemplify this trend. Operations this size pro-

duce as much manure as a city of several million people does. Not only associated technological problems but also social and economic problems need to be addressed. Generally, very large enterprises ultimately decrease profitability for small and dispersed family operations even though they enhance point source cash flow. The ultimate social and economic impacts on producers, consumers, and the environment are unknown.

### New Technologies

Investigation of highly technical opportunities, by means of new research tools, should be supported financially. The genetic engineering of microorganisms and the processes of bioremediation are examples of such new tools. Development of value-added manure derived products may be helpful. Attempts to derive and to concentrate nutrients by processing manures for refeeding, conversion to energy, and amending soil need to be continued so that increasingly economical solutions to manure management problems can be identified.

For feeding animal manure, the minimum amount of processing usually is most economical. Most animal manure feeding has been in close proximity to the location of manure, mainly because manures have a high water-content and are bulky. Manure that is fairly dry, such as poultry litter, has higher value. Processing and packaging of manure would facilitate its use as animal feed. Technically, at least some manures can be processed for transport over long distances. In fact, trade of manure occurs. A survey in 1989 indicated that 21 states had regulations permitting the sale of animal waste as a feed ingredient (McCasky et al., 1990). Generally, however, the use of nutrients from manure is limited by economics because their cost exceeds that from other feedstuffs. Nevertheless, commercial trade of manure, especially of poultry litter, is continuing. Financial incentives to processors would increase the quantity of product processed and marketed.

Because computer capabilities double every few years and because animal manure management involves so many variables and is so complex, interactions between variables can be clarified through the development and use of user-friendly computer simulation models. Renewed efforts are needed to develop models that provide realistic simulations of the consequences of alternative management practices.

## Education

One of the greatest needs in the implementation of new manure-management technology is the broadened and deepened education of producers, consultants, policy makers, regulators, others assisting producers, regulatory agency personnel, and the urban public. Information needs to be communicated about environmental concerns and solutions in animal agriculture to the general public (the consumer) and to young people. These individuals are dissociated from agriculture and seldom recognize the link between a sustainable agriculture and environmental quality. Methods of delivering information and technology, i.e., multimedia methods, are needed, as is increased funding for education at all levels and for staffing of qualified personnel. Again, realistic computer simulation models would be an excellent educational tool. Demonstration of current and new technology on production units can convince producers to adapt technology and BMPs. Partnerships between Land Grant universities, the Natural Resources Conservation Service (NRCS), commodity organizations, commercial industries, and regulatory agencies can deliver the same educational information to producer and consumer.

### Training Experts

Through the Land Grant university and college system, additional support for curriculum and staffing to train well-qualified, degree holding individuals to fill key responsibilities in regulatory policy, design, and management decisions is critical. Several academic curricula, outreach extension programs, and graduate research programs very productive in the early 1960s have been dismantled. Supply of qualified individuals is insufficient to fill positions as regulators, NRCS personnel, engineers, soil science and environmental science consultants, extension educators, and industry personnel.

### Producers

Although considerable effort has been expended in educating the livestock producer, the need for an increased effort is greater today than ever because of regulatory pressure, public concern, and rapidly changing industrial structure. Producers, often confused by conflicting information from various sources, need to be aware of the potential consequences of animal manures in the environment. Similarly, risk assessment tools need to be provided to allow accu-

rate operational analyses and corrective measures for problem areas. Best management practices, conservation practices, current technology adoption, expert systems development, and computer aided decision making programs need to be developed, demonstrated, and implemented. Educational materials need to target specific clientele levels, and a variety of resource materials and sources of assistance need to be identified.

Education programs for livestock producers and consumers would facilitate the use of animal manure as feed. In states such as Alabama and Virginia, where organized educational programs concerning the feeding of poultry litter have been conducted, the use of manure as feed has increased. Consumers should be made aware of the safety aspects of this practice.

## Regulatory Policy

The National Pollution Discharge Elimination System (NPDES) program of the EPA, the U.S. Clean Water Act of 1987, and the Coastal Zone Management Act have provided regulatory policies that affect livestock industries and their relations to water quality. As a result of such legislation, states have adopted or are adopting regulations involving permits or approvals of manure management systems or nutrient management plans for livestock operations. Some states require the adoption of specific BMPs; others require minimal design criteria. Certain county governments have tightened zoning requirements.

Even though regulations are enforced to control water pollution, some BMPs, because they are expensive, or labor intensive, are not implemented by producers. Examples of different types of BMPs appear in Appendix B. Some states are requiring development of manure management plans that utilize BMPs for approval of manure management systems. Members of the livestock industry would prefer a voluntary approach to meeting pollution requirements when implementing BMPs. For example, the National Pork Producers Council has implemented an Environmental Assurance Program to train and to ensure that certified producers understand and use approved practices. A risk assessment identifying the payoff for a high level of environmental management for certain practices is included, and a complete manure nutrient management plan integrated for the entire operation is developed. In addition to the need for an educational thrust, incentives encouraging the initial adoption of BMPs would be helpful. Demonstration grants, cost-sharing facilities, "right to farm" protection, and tax incentives for proper BMPs are poten-

tial options.

In contrast, mandatory regulations of BMPs and other management restrictions may be enforced on the production sector. Such regulations often lead both to rigid procedures failing to account for variability between enterprises and to poor control. It would be more effective to establish and to enforce regulations only in cases of purposeful mismanagement. Regulatory policies should be based on scientific evidence and on the latest technologies. Water quality standards should be grounded in baseline water parameters for a watershed, and standards should be performance based. If BMPs are implemented, their effectiveness in promoting water quality in a specific watershed should be evaluated. Strict environmental regulations could affect smaller producers adversely because of costs to operation and need for management skills—which may be limited—to implement environmental restrictions.

Watersheds need to be evaluated and environmental controls implemented according to an assessment for each location. For the most effective improvement in water quality, currently polluted watersheds or those perceived as polluted need to be analyzed carefully, and site-specific practical solutions need to be identified and prioritized. With the advancements in science and monitoring technology, combined with the effects of implemented practices, methodological adjustments to improve or to sustain water quality will be identified and implemented.

The FDA established a policy (21 CFR 500.4) not sanctioning the use of poultry litter as animal feed

(Kirk, 1967). Broad interpretation subsequently extended this policy to include all animal wastes used as ingredients in animal feeds. The FDA took this position because agency personnel considered the amount of information available at the time was inadequate to conclude that animal manure was safe when used as a feed ingredient. On December 30, 1980, after data became available from a research project involving several scientists (McCaskey and Anthony, 1979), the FDA (1980) revoked 21 CFR 500.4 on the use of poultry litter as an animal feed ingredient (45 FR 86272). The FDA now is leaving the regulation of animal-manure feeding to the states. In many states, regulation follows American Association of Feed Control Officials (AAFCO) (1982) model for processed animal manure.

The salient points of this regulatory model are (1) waste must be processed so that it will be free of pathogens; (2) if waste is derived from animals certified to have not been fed drugs, no withdrawal period is required, and the waste can be fed to any class of animals; and (3) if waste is derived from animals that cannot be so certified, a 15-d withdrawal is required before slaughter or use of milk or eggs for consumption by humans. Some individual states have more specific regulations. State regulations generally follow the AAFCO regulation, which is not unduly restrictive. The quantity of animal manure used for animal feeds has increased gradually in the past 10 to 20 yr. The commercialization of manure into feed has been slow, however, because costs associated with processing and marketing increase feed cost to about that of conventional feedstuffs.



## Appendix A: Tables

Table A-1. U.S. farmland in 1992 by region<sup>a</sup> that could benefit from manure fertilizer (x 1,000 acres) (U.S. Department of Commerce, 1992)

Land classification	New England	Mid-Atlantic	South Atlantic	W. North Central		E. South Central		W. South Central		Mountain	Pacific	E. North Central		U.S. totals
				Central	Central	Central	Central	Central	Other			Other		
Total cropland	1,806,077	13,974,605	21,795,773	168,385,393	26,723,213	66,519,591	44,103,123	23,970,667	68,164,220	377,432	435,820,094			
All pasture and grazing	727,310	5,071,611	12,474,229	96,828,984	16,717,496	130,478,607	197,554,917	38,127,118	9,070,704	1,817,420	510,868,396			
Total woodland	1,630,723	4,861,037	11,893,728	9,390,665	11,001,988	10,251,212	11,266,673	4,960,925	34,376,580	152,270	99,765,801			
Land in federal programs	22,445	219,516	835,326	13,203,899	1,336,657	4,528,142	5,287,317	1,612,548	2,530,506	19,512	29,595,878			
Totals	4,186,555	24,126,769	46,999,056	289,808,941	55,779,354	211,777,552	258,212,030	68,671,258	114,142,010	2,366,634	1,076,070,169			

<sup>a</sup>Regions include the following states:

New England	Mid-Atlantic	South Atlantic	W. N. Central	E. S. Central	W. S. Central	Mountain	Pacific	E. N. Central	Other
Maine	New York	Virginia	Minnesota	Kentucky	Arkansas	Montana	Washington	Illinois	Alaska
New Hampshire	New Jersey	N. Carolina	Iowa	Tennessee	Louisiana	Idaho	Oregon	Indiana	Hawaii
Vermont	Pennsylvania	S. Carolina	Missouri	Alabama	Oklahoma	Wyoming	California	Michigan	
Massachusetts	Delaware	Georgia	N. Dakota	Mississippi	Texas	Colorado		Ohio	
Rhode Island	Maryland	Florida	S. Dakota			New Mexico		Wisconsin	
Connecticut	W. Virginia		Nebraska			Arizona			
			Kansas			Utah			
						Nevada			

Table A-2. Livestock and poultry by region<sup>a</sup> of the United States (U.S. Department of Agriculture, National Agricultural Statistics Service, 1995-1996)

Livestock (x 1,000)	New England	Mid-Atlantic	South Atlantic	W. North Central		E. South Central		W. South Central		Mountain	Pacific	E. North Central		U.S. totals
				Central	Central	Central	Central	Central	Other			Other		
Total cattle and calves (1996)	609	4,159	7,060	30,170	8,540	23,530	12,800	7,360	9,410	181	103,819			
Total hogs and pigs (1995)	37	1,272	10,045	30,180	1,835	2,365	1,105	336	12,980	36	60,190			
Sheep (1996)	42	229	78	1,063	33	1,379	2,217	783	361	38	6,224			
Stock sheep	7	42	19	430	9	372	618	630	96	12	2,234			
Sheep on feed														
Poultry														
Laying (1995)	12,172	40,274	68,487	59,651	31,858	53,915	9,435	39,811	66,575	1,263	384,241			
Broilers (1994)	0	753,200	2,181,100	218,700	1,693,400	1,635,400	0	288,600	51,250	195,890	7,017,540			
Turkeys (1994)	175	16,825	89,210	76,000	0	25,000	4,900	2,100	11,200	32,115	289,025			

<sup>a</sup>See Table A-1 for detail of the region.

Table A-3. Tons of plant available nutrients in manure produced by region<sup>a</sup> of the United States, 1995<sup>b</sup>.

Livestock (∞ 1,000)	New England	Mid-Atlantic	South Atlantic	W. North Central		E. South Central		W. South Central		Mountain	Pacific	E. North Central		Other	U.S. totals
				Central	Central	Central	Central	Central	Central			Central	Central		
<b>Cattle</b>															
Nitrogen	12,485	85,260	144,730	618,485	175,070	482,365	262,400	150,880	192,905	3,715	2,128,294				
Phosphorus (P <sub>2</sub> O <sub>5</sub> )	8,831	60,306	102,370	437,465	123,830	341,185	185,600	106,720	136,445	2,627	1,505,378				
Potassium (K <sub>2</sub> O)	14,616	99,816	169,440	724,080	204,960	564,720	307,200	176,640	225,840	4,349	2,491,661				
<b>Hogs</b>															
Nitrogen	221	7,632	60,207	181,080	11,010	14,190	6,627	2,016	77,880	216	361,142				
Phosphorus (P <sub>2</sub> O <sub>5</sub> )	185	6,360	50,225	150,900	9,175	11,825	5,523	1,680	64,900	180	300,952				
Potassium (K <sub>2</sub> O)	166	5,724	45,203	135,810	8,258	10,643	4,970	1,512	58,410	162	270,857				
<b>Sheep</b>															
Nitrogen	221	1,217	437	6,719	187	7,880	12,758	6,359	2,057	226	38,057				
Phosphorus (P <sub>2</sub> O <sub>5</sub> )	196	1,082	338	5,972	166	7,004	11,340	5,652	1,828	200	33,828				
Potassium (K <sub>2</sub> O)	539	2,976	1,067	16,423	457	19,261	31,185	15,543	5,027	551	93,028				
<b>Poultry</b>															
Nitrogen	2,474	105,990	306,407	56,368	218,047	220,833	2,990	48,762	25,236	31,965	1,019,071				
Phosphorus (P <sub>2</sub> O <sub>5</sub> )	3,087	127,255	366,589	66,718	261,975	265,039	3,584	58,493	30,481	37,728	1,229,948				
Potassium (K <sub>2</sub> O)	1,865	85,147	28,455	47,918	174,119	177,252	2,518	39,557	20,586	27,004	824,421				
<b>Totals</b>															
Nitrogen	15,400	200,099	511,844	862,651	404,313	725,268	284,774	208,017	298,078	36,121	3,546,564				
Phosphorus (P <sub>2</sub> O <sub>5</sub> )	12,298	195,002	519,572	661,055	395,146	625,053	206,046	172,545	233,654	40,736	3,061,106				
Potassium (K <sub>2</sub> O)	17,186	193,662	464,165	924,231	387,793	771,876	345,873	233,252	309,863	32,066	3,679,967				

<sup>a</sup> See Table A-1 for detail of the region.

<sup>b</sup> Calculated from Midwest Plan Service (1985) and Sutton et al. (1985). Based on annual inventory, volume of manure production, and nutrient content at time of land application.

Table A-4. Potential commercial fertilizer replacement with manure nutrients by region<sup>a</sup>, 1995

Nutrient (tons)	New England	Mid-Atlantic	South Atlantic	W. North Central		E. South Central		W. South Central		Mountain	Pacific	E. North Central		Other	U.S. totals
				Central	Central	Central	Central	Central	Central			Central	Central		
Commercial fertilizer used <sup>b</sup>															
Nitrogen	38,518	650,671	1,557,506	7,705,832	1,476,760	3,274,404	1,705,200	2,360,211	5,059,407	48,921	23,877,503	5,059,407	48,921	23,877,503	
Phosphorus (P <sub>2</sub> O <sub>5</sub> )	12,425	214,602	249,616	2,776,361	501,500	443,987	645,471	524,854	1,955,384	8,159	7,332,358	1,955,384	8,159	7,332,358	
Potassium (K <sub>2</sub> O)	14,399	263,965	278,345	1,690,384	555,207	170,712	111,186	356,453	2,746,028	19,134	6,205,812	2,746,028	19,134	6,205,812	
Manure nutrients produced <sup>c</sup>															
Nitrogen	15,400	200,099	511,844	862,651	404,313	725,268	284,774	208,017	298,078	36,121	3,546,564	298,078	36,121	3,546,564	
Phosphorus (P <sub>2</sub> O <sub>5</sub> )	12,298	195,002	519,572	661,055	395,146	625,053	206,046	172,545	233,654	40,736	3,061,106	233,654	40,736	3,061,106	
Potassium (K <sub>2</sub> O)	17,186	193,662	464,165	924,231	387,793	771,876	345,873	233,252	309,863	32,066	3,679,967	309,863	32,066	3,679,967	
Potential % replacement <sup>d</sup>															
Nitrogen	40	31	33	11	27	22	17	9	6	74	15	6	74	15	
Phosphorus (P <sub>2</sub> O <sub>5</sub> )	99	91	208	24	79	141	32	33	12	499	42	12	499	42	
Potassium (K <sub>2</sub> O)	119	73	167	55	70	452	311	65	11	168	59	11	168	59	

<sup>a</sup>See Table A-1 for detail of the regions.<sup>b</sup>Source: 1995 Commercial Fertilizers, TVA Environmental Research Center, Tennessee Valley Authority, Muscle Shoals, Alabama.<sup>c</sup>See Table A-3.<sup>d</sup>Numbers are rounded.

Table A-5. Crops produced by region of the United States (U.S. Department of Agriculture, U.S. National Agricultural Statistics Service, 1994)

Crop Acres (∞ 1,000)	New England	Mid-Atlantic	South Atlantic	W. North Central		E. South Central		W. South Central		Mountain	E. North Pacific		Central	U.S. totals
				Central	Central	Central	Central	Central	Central		Central	Central		
Forage														
Alfalfa	191	1,699	170	9,700	430	530	5,605	1,955			1,010	5,845	25,585	
Other hay	650	3,010	2,580	12,200	5,020	7,070	3,050	1,580				1,830	36,990	
Grain crops														
Barley	0	211	155	4,360	25	45	3,015	1,010				120	8,941	
Corn	227	3,540	2,540	36,080	2,470	2,185	1,404	505				27,000	75,951	
Oats	32	406	248	4,015	55	1,230	473	545				1,650	8,654	
Rice	0	0	0	97	225	2,205	0	330				0	2,857	
Sorghum	0	0	167	5,900	222	4,045	500	0				180	11,014	
Wheat	0	618	1,680	31,435	1,600	15,000	10,121	5,083				4,369	69,906	
Protein crops														
Dry beans	0	36	0	894	0	16	398	204				361	1,909	
Peanuts	0	0	1,299	0	280	440	23	0				0	2,042	
Soybeans	0	1,200	3,175	26,035	4,510	4,720	0	0				19,420	59,060	
Sunflowers	0	0	0	2,605	0	25	63	0				0	2,743	
Vegetables														
Potatoes	85	64	74	270	11	16	515	242				132	1,409	
Sweet potatoes	0	2	39	0	9	23	0	8				0	81	
Sugar														
Beets	0	0	0	646	0	42	361	179				191	1,421	
Cane	0	0	443	0	0	382	0	0				0	899	
Miscellaneous														
Cotton	0	0	1,169	334	2,280	8,775	555	1,030				0	14,143	
Hops	0	0	0	0	0	0	7,190	28,245				0	39,553	
Mint oil	0	0	0	0	0	0	18	83				50	151	
Tobacco	2	20	426	3	28.5	0	0	0				25	761	

Table A-6. Nutrient requirements per acre for the various crops<sup>a</sup> (Adapted from Bennett, 1993)

Crop	Yield/acre	Nitrogen (lb)	Phosphorous (lb)	Potassium (lb)	Magnesium (lb)	Sulfur (lb)
Forage						
Alfalfa	10 tons	600	120	600	53	51
Other hay	22 tons	1,100	330	1,155	105	115
Corn for silage	32 tons	266	114	266	65	33
Grain crops						
Barley	100 bu	150	55	150	17	20
Corn	200 bu	266	114	266	65	33
Oats	100 bu	115	40	145	20	19
Rice	14,000 lb	112	60	148	14	12
Sorghum	16,000 lb	250	90	200	44	38
Wheat	80 bu	134	54	162	24	20
Proteins						
Peanuts	9,000 lb	240	39	185	25	21
Soybeans	60 bu	324	61	142	27	25
Vegetables						
Potatoes	800 cwt	269	90	345	50	22
Sweet potatoes	300 cwt	156	64	313	18	0
Tomatoes	30 ton	180	48	336	28	41
Sugar						
Sugar beets	46 tons	255	40	550	80	45
Sugar cane	100 tons	360	156	610	100	86
Miscellaneous						
Cotton	1,500 lb	180	63	126	35	30
Tobacco	4,200 lb	414	62	577	56	64

<sup>a</sup>Based on the amount of manure nutrients produced relative to the amount of fertilizer (especially nitrogen) used and potential for using the manure nutrients in crop production, expanded animal production should be considered (based on potential use of nutrients), especially in the East North Central, Pacific, Mountain, W. South Central and E. South Central regions.

Table A-7. Properties and physiological effects of noxious gases (Adapted from Taiganides and White, 1969)

Gas	Density <sup>a</sup> g/L	Specific gravity <sup>b</sup>	Odor	Color	Explosive range <sup>c</sup> (min.) (max.)	Odor threshold <sup>d</sup> ppm	Maximum allowable concentrations <sup>e</sup> /ppm	Concentrations, <sup>f</sup> ppm	Exposure period <sup>g</sup>	Physiological effects
Carbon dioxide (CO <sub>2</sub> )	1.98	1.53	None	None	— —	—	5,000	20,000 30,000 40,000 60,000 300,000	— — — 30 min 30 min	Asphyxiant Safe Increased breathing Drowsiness, headaches Heavy, asphyxiating breathing Could be fatal
Ammonia (NH <sub>3</sub> )	0.77	0.58	Sharp, pungent	None	16 —	5	50	400 700 1,700 3,000 5,000	— — — 30 min 40 min	Irritant of throat Irritant of eyes Coughing and frothing Asphyxiating Could be fatal
Hydrogen sulfide (H <sub>2</sub> S)	1.54	1.19	Rotten eggs smell, nauseating	None	4 46	0.7	10	100 200 200 500 1,000	Several hours 60 min 30 min —	Poison Irritation of eyes and nose Headaches, dizziness Nausea, excitement, insomnia Unconsciousness, death
Methane (CH <sub>4</sub> )	0.72	0.58	None	None	5 —	15	1,000	500,000	—	Asphyxiant Headache, nontoxic
Carbon monoxide (CO)	1.25	0.97	None	None	— —	—	50	500 1,000 2,000 4,000	60 min 60 min 60 min 60 + min	Poison No effect Unpleasant, but not dangerous Dangerous Fatal

<sup>a</sup>Density of the gases in (g)/liter(L) at 32° F. Density of air is 2.29 g/L.

<sup>b</sup>Specific gravity is the ratio of the weight of the gas to that of atmospheric air. If the number is less than one, the gas is lighter than air; if greater than 1, it is heavier than air.

<sup>c</sup>Explosive range is the range within which a mixture of gas and atmospheric air can explode with a spark (Δ by volume).

<sup>d</sup>Odor threshold is the lowest concentration at which the odor is detected. This figure can only be approximate.

<sup>e</sup>Maximum allowable concentration is the concentration set by health agencies as the maximum allowed in a atmosphere where humans work over an 8 to 10 hour period. Possibly the levels should be lower for animals since they must be in the environment continuously.

<sup>f</sup>Concentrations are in parts of pure gas per million parts of atmospheric air. To change to concentration by volume, divide by 10,000.

<sup>g</sup>Exposure period is the time during which the effects of the noxious gas are felt by an adult human or a 150 pound pig.

<sup>h</sup>Physiological effects are those found to occur in adult humans. Similar effect would be felt by a 150 pound pig. Lighter pigs would be affected sooner at lower level.

Table A-8. Compounds identified in the air exposed to the products of the anaerobic decomposition of livestock and poultry manures

Alcohols <sup>ab</sup>	Amines <sup>acd</sup>	Mercaptans <sup>ce</sup>
Methanol <sup>ab</sup>	Methylamine <sup>d</sup>	Methylmercaptan <sup>c</sup>
Ethanol <sup>ab</sup>	Ethylamine <sup>cd</sup>	Sulfides <sup>ce</sup>
2-Propanol <sup>ab</sup>	Trimethylamine <sup>c</sup>	Dimethyl sulfide <sup>c</sup>
Butanol <sup>b</sup>	Triethylamine <sup>d</sup>	Diethyl sulfide <sup>c</sup>
Propanol <sup>b</sup>	Carbonis <sup>abfg</sup>	Esters <sup>ay</sup>
iso-Butanol <sup>a</sup>	Formaldehyde <sup>b</sup>	Ethyl formate <sup>a</sup>
iso-Pentanol <sup>b</sup>	Acetaldehyde <sup>abg</sup>	Methyl acetate <sup>a</sup>
Acids <sup>edf</sup>	Propionaldehyde <sup>abg</sup>	Propyl acetate <sup>c</sup>
Acetic <sup>e</sup>	Butyraldehyde <sup>b</sup>	Butyl acetate <sup>c</sup>
Propionic <sup>e</sup>	Valeraldehyde <sup>b</sup>	iso-Propyl acetate <sup>a</sup>
Butyric <sup>edf</sup>	Heptaldehyde <sup>b</sup>	iso-Butyl acetate <sup>a</sup>
iso-Butyric <sup>e</sup>	Octaldehyde <sup>b</sup>	iso-Propyl propionate <sup>a</sup>
iso-Valeric <sup>e</sup>	Decaldehyde <sup>b</sup>	Fixed gases <sup>h</sup>
Aromatics <sup>f</sup>	iso-Butyraldehyde <sup>b</sup>	Carbon dioxide <sup>h</sup>
p-Cresol <sup>f</sup>	Di acetyl (2, 3-Diketo-butane) <sup>f</sup>	Methane <sup>h</sup>
Nitrogen heterocycles <sup>aef</sup>	Hexanal <sup>f</sup>	Ammonia <sup>h</sup>
Indole <sup>ae</sup>	Acetone <sup>g</sup>	
Skatole <sup>ae</sup>	3-Pentanone <sup>g</sup>	
Pyrazines <sup>f</sup>		

<sup>a</sup>Bethea and Narayall, 1972.

<sup>b</sup>Merkel et al., 1969.

<sup>c</sup>White et al., 1971.

<sup>d</sup>Miner and Hazen, 1969.

<sup>e</sup>Burnett, 1969.

<sup>f</sup>Hammond et al., 1974.

<sup>g</sup>Hartung et al., 1971.

<sup>h</sup>Day et al., 1965.



# Appendix B: Examples of Best Management Practices

## Nutrient Management

1. Decrease commercial fertilizer applied to the field by the corresponding amount of manure nutrients applied.
2. On each field, keep a record of manure and chemical fertilizer applications, crop information, and soil and manure test results.
3. Test the soil in each field for P, K, and other nutrient levels, pH, and cation exchange capacity. Follow a soil testing routine recommended by the Cooperative Extension Service or by a crop consultant or fertilizer dealer.
4. Test manure for total N,  $\text{NH}_4\text{-N}$ , P, K, possibly Mn and Ca, and dry matter.
5. Apply manure uniformly with calibrated equipment. Check calibration routinely.
6. Use the nutrients carried in runoff as manure from feedlots, animal exercise or handling areas, etc. Provide a settling basin to greatly decrease the solids suspended in water. Maintain grassed buffer areas to filter out solids and to absorb nutrients where field runoff may occur.
7. Nitrification inhibitors in liquid-manure injection systems can decrease N losses in coarse-textured soils all year long, in all soils during fall and summer, and in fine or medium textured soils with high water-tables during winter and spring.
8. To benefit crops in terms of economics and efficiency, apply a nitrification inhibitor and manure at a rate meeting crop N-requirement.
9. In general, it takes 18 lb  $\text{P}_2\text{O}_5$  to increase soil P test by 1 ppm and 6 to 7 lb  $\text{K}_2\text{O}$  to increase soil K test by 1 ppm. Soils low in these nutrients can be built up to recommended levels by means of extra manure nutrients.
10. To prevent excessive P and K buildup, rotate manure applications to other fields, or decrease applications to meet the most limiting nutrient requirement (generally P) and then supplement with commercial fertilizer.
11. Incorporate manure in the soil to decrease nutrient losses from runoff and  $\text{NH}_3$  volatilization.

## Crop Factors

1. Base crop fertilizer needs on realistic yield goals. Deduct N credits of last year's legumes from this year's fertilizer requirement. For the current crop year, before deciding on fertilizer, estimate N contributions from manure, legumes, organic matter and plant residues, and irrigation water.
2. Consider using N-enriched manure to balance crop N, P, and K needs.
3. Use commercial fertilizer only when manure does not meet crop needs.
4. Apply N so that it is available during peak plant demand.
5. Apply fertilizer with proper timing and placement for maximum plant utilization.
6. Add a nitrification inhibitor, e.g., NServe, to stabilize N before injecting manure on poorly drained, fine textured soils or injecting high-N manure in the summer or fall.
7. Incorporate manure to decrease N loss and manure runoff.
8. Apply manure on nonlegume crops as a first priority.
9. When necessary to minimize erosion, surface apply manure over fall cover crops or surface residues rather than on tilled soils.
10. During the summer, broadcast manure on pastures where nutrients can be used immediately or inject manure with an inhibitor on harvested or fallow fields.

## Soil Factors

1. Apply manure to fields with the lowest soil test for nutrients.
2. To decrease compaction, runoff, denitrification, and leaching, avoid applying manures to wet soils.
3. Apply manure (possibly with an inhibitor) in the fall if compaction is a prevalent soil problem.
4. To minimize nitrate leaching, apply manure to sandy soil shortly before planting time and apply small amounts of N frequently instead of a large amount at one time. Do not fall-apply on sandy

soil.

5. Add N (anhydrous ammonia or urea) to manure when injecting manure at lower application rates to balance nutrients and to meet crop needs.
6. Apply manure in the fall after the soil has cooled to 50°F or less, or add a nitrification inhibitor.
7. Give manure application preference to highly eroded soils with low nutrient and organic matter levels.

## Manure

1. In the spring or fall, apply manure with the greatest N content; in the summer, apply that with the least N content.
2. Haul the highest nutrient content manure to the farthest fields.
3. Apply the lowest nutrient content manure to the closest fields. Irrigate with runoff water and lagoon water.
4. Apply the highest nutrient manure to corn silage, vegetable root crops, or other crops with high nutrient demands.
5. Apply the highest nutrient manure to legumes only if you have no better use for the N, for legumes can produce their own N if none is provided.
6. To avoid N leaching to ground water, limit N applications on sandy soils, and avoid soils with high water-tables.
7. Do not apply more N than the crop needs.
8. Apply high-P manure to fields with the lowest P soil-test levels.
9. If manure is applied to the same fields every year, alternate each year between high-nutrient and low-nutrient manures.
10. Apply most concentrated manures to crops with the highest nutrient demands.

## Site and Environment Factors

1. To minimize N loss, odor, and runoff potential, inject manure or incorporate solid manure on the same day as surface spreading.
2. Apply manure on erosive soils; delay application and tillage until spring.
3. To retain nutrients, incorporate manure on non-erosive soils in the fall.
4. Incorporate manure in *karst* areas, or areas of limestone characterized by sinks, underground streams, and caverns.
5. Apply manure on frozen or snow covered soil only if it is necessary to empty storage, the land is not

subject to flooding, land slope is less than 2%, or erosion control practices, e.g., terrace conservation tillage, cover crops, and contour farming, are in place.

(Note: Increase manure spreading separation distance by 100% where runoff may occur.)

6. Surface apply manures in highly erodible land (HEL) to cover crops or residue cover or consistently with erosion control practices.

## Livestock on Pasture or Range

1. Prevent excessive manure accumulations by keeping adequate land-to-livestock ratios.
2. Maintain highly productive forage to slow runoff, trap manure, and use nutrients.
3. Rotate grazing to protect forage and soil.
4. Rotate feeders and waterers to prevent paths, manure concentrations, mud holes, and overgrazing.
5. Locate feed and water away from water courses. Provide shade to discourage animals from standing in water courses.
6. Drain feed, water, and shelter areas away from surface water, and provide grass filters to receive runoff.

## Additional Recommendations

1. Check with local city and county officials for applicable regulations on zoning, health, building codes, setback distances, etc.
2. Unless manure is incorporated by the end of the working day (and before rainfall occurs), do not apply manure within 50 ft of road ditches or within 100 ft of a surface tile inlet, sinkhole, intermittent stream, drainage ditch, or other body of water.  
(Note: Increase manure spreading separation distances 100% where runoff may occur.)
3. Do not apply manure within 200 ft of a water well.
4. Do not apply manure on a floodplain during high-water periods nor at other times unless manure is incorporated by the end of the working day or unless there is sufficient residue or crop coverage to protect soil from erosion.
5. Because of the risk of runoff, do not surface-spread liquid manure on slopes steeper than 6% (unless there is sufficient residue or crop coverage to prevent runoff) or on frozen or snow covered slopes steeper than 2% (unless the manure is incorporated into soil by the end of the working day).

## Appendix C: Symbols and Abbreviations

a.	acre	L	liter
Al	aluminum	lb	pound
B	boron	m	meter
BMP	best management practice	mg	milligram
BOD	biological oxygen demand	Mn	manganese
C	carbon	mo	month
Ca	calcium	Mo	molybdenum
CH <sub>4</sub>	methane	N	nitrogen
CO <sub>2</sub>	carbon dioxide	N <sub>2</sub>	dinitrogen
Cu	copper	Na	sodium
d	day	NH <sub>3</sub>	ammonia
EPA	U.S. Environmental Protection Agency	P	phosphorus
FDA	U.S. Food and Drug Administration	ppm	part per million
ft	foot	t	ton
g	gram	VS	volatile solids
hr	hour	wk	week
K	potassium	yr	year
kg	kilogram	Zn	zinc

## Appendix D: Glossary

**Aerobic.** Presence of dissolved oxygen.

**Anaerobic.** Absence of oxygen.

**Anaerobic digestion.** The natural process whereby bacteria existing in oxygen-free environments decompose organic matter.

**Biogas.** Methane and CO<sub>2</sub>.

**Deep stacking.** Process of stacking manure-bedding mixtures such that spontaneous heating takes place.

**Dilute manure liquids.** Lagoon effluent or contaminated runoff water from open lots.

**Industry structure.** Size distribution of the industry's production operations.

**Karst areas.** Areas of limestone characterized by sinks, underground streams, and caverns.

**Marsh gas.** Methane.

**Mesophilic temperature range.** 20°C to 45°C.

**Net cost.** Fixed and variable costs less nutrient benefits.

**Olfactometry.** Methods of odor evaluation using human panels.

**Psychrophilic digestion.** Anaerobic decomposition of organic matter at low temperatures (< 20°C).

**Storage.** Temporary holding location for manure before it is spread on land.

**Soil aggregation.** Soil pore volume and size.

**Submerged vegetative system.** Plants rooted and growing in, but not above, water level in constructed wetlands.

**Submergent vegetative system.** Plants rooted on the bottom and growing up above water level in constructed wetlands.

**Subsidization.** Cost-sharing.

**Thermophilic temperature range.** 45°C to 60°C.

**True costs.** Economic and socioeconomic costs associated with pollution.

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soil.

5. Add N (anhydrous ammonia or urea) to manure when injecting manure at lower application rates to balance nutrients and to meet crop needs.
6. Apply manure in the fall after the soil has cooled to 50°F or less, or add a nitrification inhibitor.
7. Give manure application preference to highly eroded soils with low nutrient and organic matter levels.

## Manure

1. In the spring or fall, apply manure with the greatest N content; in the summer, apply that with the least N content.
2. Haul the highest nutrient content manure to the farthest fields.
3. Apply the lowest nutrient content manure to the closest fields. Irrigate with runoff water and lagoon water.
4. Apply the highest nutrient manure to corn silage, vegetable root crops, or other crops with high nutrient demands.
5. Apply the highest nutrient manure to legumes only if you have no better use for the N, for legumes can produce their own N if none is provided.
6. To avoid N leaching to ground water, limit N applications on sandy soils, and avoid soils with high water-tables.
7. Do not apply more N than the crop needs.
8. Apply high-P manure to fields with the lowest P soil-test levels.
9. If manure is applied to the same fields every year, alternate each year between high-nutrient and low-nutrient manures.
10. Apply most concentrated manures to crops with the highest nutrient demands.

## Site and Environment Factors

1. To minimize N loss, odor, and runoff potential, inject manure or incorporate solid manure on the same day as surface spreading.
2. Apply manure on erosive soils; delay application and tillage until spring.
3. To retain nutrients, incorporate manure on non-erosive soils in the fall.
4. Incorporate manure in *karst* areas, or areas of limestone characterized by sinks, underground streams, and caverns.
5. Apply manure on frozen or snow covered soil only if it is necessary to empty storage, the land is not

subject to flooding, land slope is less than 2%, or erosion control practices, e.g., terrace conservation tillage, cover crops, and contour farming, are in place.

(Note: Increase manure spreading separation distance by 100% where runoff may occur.)

6. Surface apply manures in highly erodible land (HEL) to cover crops or residue cover or consistently with erosion control practices.

## Livestock on Pasture or Range

1. Prevent excessive manure accumulations by keeping adequate land-to-livestock ratios.
2. Maintain highly productive forage to slow runoff, trap manure, and use nutrients.
3. Rotate grazing to protect forage and soil.
4. Rotate feeders and waterers to prevent paths, manure concentrations, mud holes, and overgrazing.
5. Locate feed and water away from water courses. Provide shade to discourage animals from standing in water courses.
6. Drain feed, water, and shelter areas away from surface water, and provide grass filters to receive runoff.

## Additional Recommendations

1. Check with local city and county officials for applicable regulations on zoning, health, building codes, setback distances, etc.
2. Unless manure is incorporated by the end of the working day (and before rainfall occurs), do not apply manure within 50 ft of road ditches or within 100 ft of a surface tile inlet, sinkhole, intermittent stream, drainage ditch, or other body of water.  
(Note: Increase manure spreading separation distances 100% where runoff may occur.)
3. Do not apply manure within 200 ft of a water well.
4. Do not apply manure on a floodplain during high-water periods nor at other times unless manure is incorporated by the end of the working day or unless there is sufficient residue or crop coverage to protect soil from erosion.
5. Because of the risk of runoff, do not surface-spread liquid manure on slopes steeper than 6% (unless there is sufficient residue or crop coverage to prevent runoff) or on frozen or snow covered slopes steeper than 2% (unless the manure is incorporated into soil by the end of the working day).

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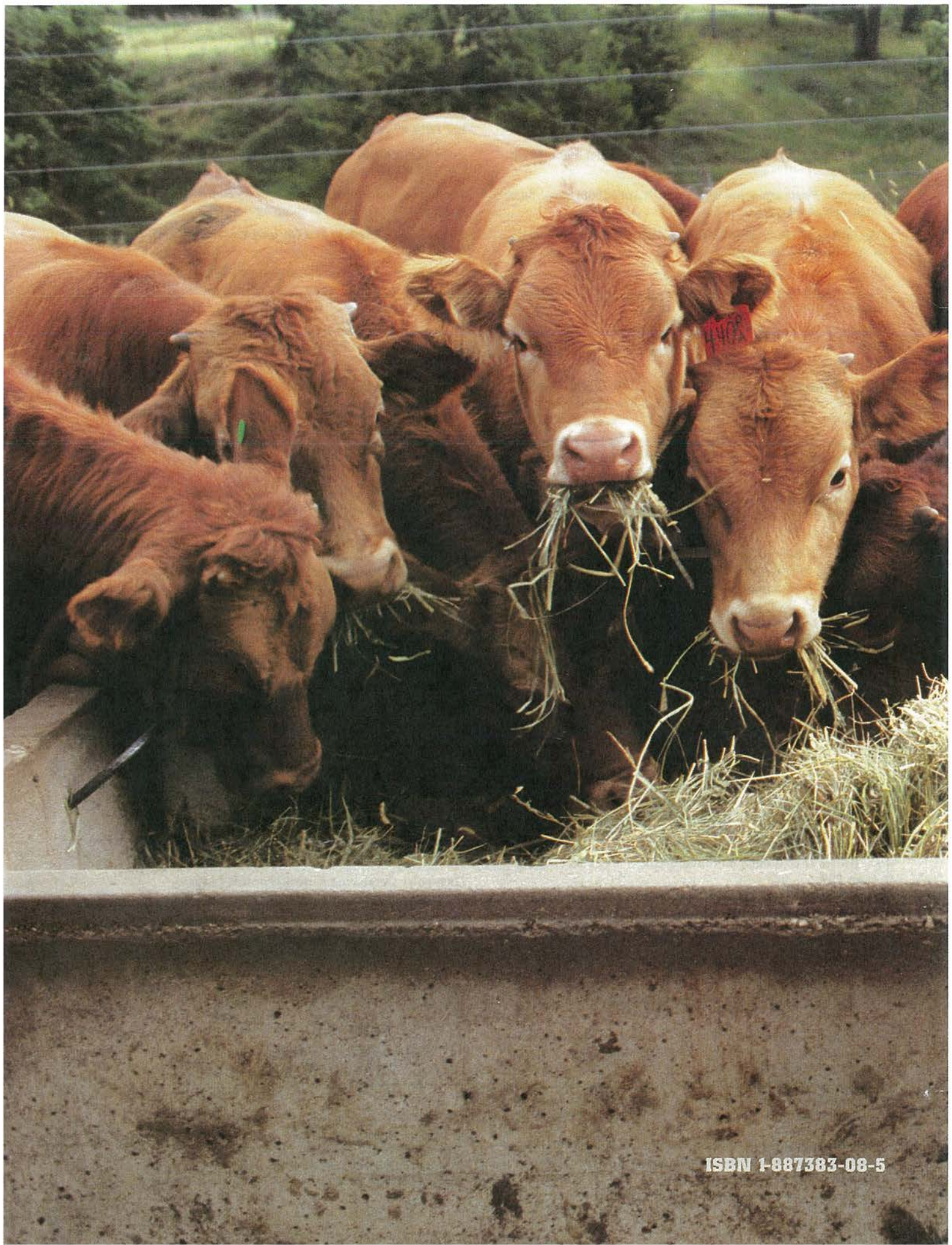
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