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CAST

The Science Source for Food, Agricultural, and Environmental Issues

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CAST

The Science Source for Food, Agricultural, and Environmental Issues

Mission and Policies

The mission of the Council for Agricultural Science and Technology (CAST) is to identify food and fiber, environmental, and other agricultural issues and to interpret related scientific research information for legislators, regulators, and the media involved in public policy decision making. CAST is a nonprofit organization composed of 30 scientific societies and many individual, student, company, nonprofit, and associate society members. CAST's Board of Directors is composed of 47 representatives of the scientific societies and individual members, and an Executive Committee. CAST was established in 1972 as a result of a meeting sponsored in 1970 by the National Academy of Sciences, National Research Council.

The primary mission of CAST is the publication of task force reports written by scientists from many disciplines. The CAST National Concerns Committee screens proposals from all sources and recommends to the board topics for approval as publication projects.

The CAST Board of Directors is responsible for the policies and procedures followed in developing, processing, and disseminating the documents produced. Depending on the nature of the publication, the society representatives may nominate qualified persons from their respective disciplines for participation on the task force. Aside from these involvements, the member societies have no responsibility for the content of any CAST publication.

Diverse writing groups and active participation by all task force members assures readers that a balanced statement on the topic will result.

The authors named in each publication are responsible for the contents. Task force members serve as independent scientists and not as representatives of their employers or their professional societies. They receive no honoraria, but are reimbursed for expenses. CAST publishes and distributes the documents.

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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 waste management and utilization in food production and processing.

Drs. L. L. Boersma, Department of Soil Science, Oregon State University, Corvallis, and Ishwar P. Murarka, Electric Power Research Institute, Palo Alto, California, 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 sciences, applied engineering, biological and agricultural engineering, food science, epidemiology and preventive medicine, fisheries, and soil and crop sciences.

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 Department of Agriculture, the Food Safety Inspection Service, 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, the Office of Technology Assessment, 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

Food production and processing is one of the most essential industries in the United States. Approximately 18% of private-sector employment derives from the food and fiber enterprise system, which employs farmers, herders, processors, transportation workers, wholesalers, retailers, and others. More than 22 million jobs are associated directly with food and fiber production.

The food production process begins with *photosynthesis*, or the biochemical reaction occurring in the leaves of plants or in photosynthesizing microorganisms living in freshwater lakes and streams or in oceans. This reaction combines carbon dioxide (CO_2) with water (H_2O) to form organic matter (CH_2O) and oxygen (O_2). The end results of this process include grasses, hay, fruits, vegetables, trees, and grains, e.g., wheat, barley, and corn. Products are harvested and processed and packaged for consumption by humans or as feed for animals producing, for example, milk, eggs, wool, and meat, which in turn are processed and packaged. This immense enterprise generates work on large land areas, in factories, and on the seas. Each step yields by-products, or wastes. These include production residues, e.g., the straw and stubble left on fields when crops are harvested; the waste generated in a milking parlor or in a slaughterhouse; and the excess of inputs, such as fertilizers and pest control chemicals, needed for sustained production.

This report by the Council for Agricultural Science and Technology identifies and describes the wastes and the wastestreams generated in the food production and processing industry. Total U.S. land area is 2,265 million acres (a.), of which 964 (42.6%) are used for agriculture. Of these, 443 million (46.0%) are in cropland cultivated on a regular basis and 410 million (42.5%) in pasture and rangeland cultivated infrequently or not at all. Cropland area occupies 19.6% of total land area and is equivalent to 1.77 a. per person, quite a large area compared with per capita cropland area in most other countries.

Production inputs required for crop production and utilization include fertilizer, pesticide, herbicide, fuel, and irrigation water. Waste and pollution occur when any of these are spilled or used excessively and escape into the environment. Soil erosion from cultivated lands is another aspect of waste generation in the food production system. Diffuse runoff from both cropland and rangeland contributes to suspended solids, dissolved solids, and biological oxygen demand in the nation's waterways.

A variety of processing wastes results from the processing of grains, vegetables, and fruits. To the extent that processing wastes occur at a central location and are identified quickly and that their use or disposal is regulated and controlled with relative ease, they differ from production wastes. Management of processing wastes, however, requires the passage of great quantities of water through treatment facilities.

Wastes produced in animal based agricultural enterprises include production wastes in cattle feedlots, pastures and rangelands, dairy farms, poultry farms, swine farms, and meat and poultry processing plants. Important waste components of the animal production facilities for cattle, dairy animals, poultry, and swine are manure and dead animals. Manure can be used successfully on land as a fertilizer, but waste management problems occur where the concentration of animals is quite high.

Seafood production is a large and diverse industry. Disposal of seafood waste depends on species, plant location, and processing method; use of waste products thus is complicated. Procedures designed to minimize disposal problems, e.g., ocean dumping and/or landfilling, are becoming increasingly difficult and costly as a result of environmental regulations. This trend has stimulated the development of utilization alternatives.

Economic considerations influence choice regarding the use of waste from activities associated with production and processing of food and fiber. Some wastes can be characterized as untapped resources. For example, nearly all waste products in agriculture are potentially feed ingredients for farm animals, foods for pets, or nutrient sources for crops. And increasing efforts are being made to convert wastes into marketable products so as to meet stricter environmental regulations pertaining to disposal options such as land utilization or land filling. Land filling and land utilization are two different and mutually exclusive processes. Land filling of sludges, biosolids, and other organics is discouraged and in some areas banned for certain of these wastes. Current regulations encourage land application of biosolids, which returns biosolids derived from municipal sources, biosolids from food processing plants, and manure from confinement livestock operations to the land where most of it originated. Technological developments, the pace of which can be accelerated both by institutional mechanisms and by scarcity of moderately priced raw materials for which food processing by-products substitute, can promote recycling efforts.

A large amount of organic material holds the promise of being available for conversion to useful products. A new emphasis should be placed on converting these wastes into marketable products. There is much potential to enhance the world food supplies through waste utilization. As the discussion about agriculture changes from production to sustainable production, waste products increasingly will be seen as valuable.

Organic matter produced on the land is a resource which, used properly, is inexhaustible. Outputs needed from agricultural research have changed because the scope of the problem has. Research on product development and use has been added to research on production. Increasing efforts are being made to convert waste into marketable products so as to meet increasingly strict environmental regulations.

Executive Summary

This report by the Council for Agricultural Science and Technology (CAST) describes the agricultural enterprise of the United States and identifies major streams of by-products and waste products associated with several sectors of the enterprise.

The food production process begins with the biochemical reaction occurring in the leaves of plants, or *photosynthesis*, whereby carbon dioxide is combined with water to form organic matter and oxygen. The resulting products include grasses, hay, fruits, vegetables, trees, and grains, e.g., wheat, barley, and corn. These products are harvested, processed, and packaged for consumption by humans or for feed to animals producing, for example, milk, eggs, wool, or meat, all of which in turn can be processed and packaged.

Food production and processing is a significant contributor to the U.S. economy. Approximately 18% of private-sector employment derives from the food and fiber enterprise system, which employs farmers, herders, processors, transportation workers, wholesalers, retailers, and others. This industry employs more than 22 million Americans and annually generates $902.5 billion, or 14.2%, of the Gross Domestic Product. A growing segment of the agricultural industry is directed to exports, which were projected to hit a record high of $45 billion in 1995.

Agricultural and food products are crucial to the well-being of society. The production of grains, fruits, vegetables, cattle, poultry, fish, and other crops; the storage and the distribution of farm products to processing plants; and the production of food in ready-to-use forms sustain and improve the quality of human life. But food production and processing sectors generate solid and liquid residues, or *wastes*.

As concerns about environmental pollution, and in some instances human health risks, mount, it becomes increasingly important to understand the nature and the extent of wastes generated from the production, processing, and consumption of food and the manner of their reuse or disposal.

The United States has both an ideal climate and superior soil resources for agricultural production. The world has just five large contiguous areas highly suitable for crop production, namely, in the United States, Asian Russia, India, China, and Western Europe. These areas have adequate rainfall so that nonirrigated agriculture is sustained, are primarily flat, and are served by large river systems. The area in the United States is located ideally with respect to latitude, i.e., between the 30th and the 50th parallels.

Total U.S. land area is 2,265 million acres (a.), and its population is 250 million; thus, the ratio of acreage to person is about 9:1. About 964 million a. are used for agriculture, of which 443 million a. (46%) are in cropland and 410 million a. (42.5%) in pasture and rangeland. Cropland therefore occupies 19.6% of total land area and amounts to 1.77 a./person. The number of cropland a./person in the United States is large compared with that in most other countries, and U.S. agriculture can produce sufficient food for the nation itself while producing export goods.

Of the 443 million cropland a. in the United States, 282 million a. (64%) are used for cultivated crops, 65 million a. for pasture, and approximately 95 million a. for diverse uses such as cover crops and summer fallow. Four crops—corn, hay, soybeans, and wheat—occupy 78% of all harvested cropland. The next most important crops in terms of acreage planted are cotton, sorghum, and barley, which account for 10% of all acres planted. In short, these seven major crops account for 88% of all U.S. cropland. Although economically very important, the acreage devoted to vegetables, fruits, and nuts is small, amounting to less than 2% of all cropland and substantially less than 1% of the nation's total land area.

Each step in the production and processing of agricultural commodities generates by-products that are considered wastes because they are not needed by and are without market value to producers and processors of food. These wastes include production residues, e.g., the straw and stubble left on fields when crops are harvested; the waste generated in a milking parlor or in a slaughterhouse; and the excess of inputs, e.g., fertilizers and pest control chemicals, needed for sustained production. Waste materials or by-products generated on farms or at processing plants are almost exclusively organic. An excess of these materials improperly managed can—like an excess of inorganic material—cause environmental pollution. Such pollution can be defined as (1) *point source*, e.g., pollution discharge through a pipe, for instance, from factories, food processing and manufacturing plants, or municipal-wastewater treatment plants, or (2) *nonpoint source*, or diffuse, e.g., pollution from agricultural, silvicultural, urban, and construction runoff (U.S. Environmental Protection Agency, 1987a).

Production inputs required for crop production and utilization include fertilizer, pesticide, herbicide, fuel, and irrigation water. Waste occurs when any of these are spilled or used excessively; pollution can occur when they escape into the environment. Soil erosion from cultivated lands is another aspect of waste generation in the food production system. Diffuse runoff from both cropland and rangeland contributes to suspended solids, dissolved solids, and biological oxygen demand in the nation's waterways.

A variety of processing wastes results from the processing of grains, vegetables, and fruits. To the extent that processing wastes occur at a central location and are identified quickly and that their use or disposal is regulated and controlled with relative ease, they differ from production wastes. But management of processing wastes requires the passage of great quantities of water through treatment facilities.

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Seafood production is a large and diverse industry. Because disposal of seafood waste depends on species, plant location, and processing method, use of waste products is complicated. Procedures, e.g., ocean dumping and/or landfilling, that are designed to minimize disposal problems are becoming increasingly difficult and costly as a result of environmental regulations.

Most agricultural production waste when measured in terms of total mass is organic and consists of straw, leaves, partly digested materials in the form of manure, and residues left after the processing of harvested grains, fruits, or vegetables. One can obtain an approximate idea of total mass by assuming that each acre (0.4247 hectare) of land used for agriculture produces about 11,000 pounds (lb) (500 kilograms [kg]) of dry matter consisting of cellulose, starch, sugars, and proteins, all biodegradable materials. The 964 million a. used for agriculture thus yield 10.6 trillion lb (4.82×10^{12} kg), which, packed to the density of hay—or 50 kg/meter $(m)^3$, would need to be stacked 0.66 m high if it were distributed evenly over the land area of the state of Illinois. This amount of organic material must be disposed of each year. Much of this material is left on the land, but a large part is consumed by animals and then appears in the form of manure, which must be used or disposed of. Other material appears in concentrated form as process waste at canneries. The problems encountered in handling these organic materials are discussed in chapters on waste management and utilization on land, cattle feedlots, dairy farms, poultry farms, and swine farms. Additional chapters discuss processing wastes such as processing grain into oil, processing fruits and vegetables, and processing milk into dairy products. Harvesting and processing seafood is discussed in a separate chapter.

Agricultural production requires two major inputs—fertilizers and pesticides, which give rise to waste materials. Fertilizers are used to make crops grow larger. The major fertilizer nutrients are nitrogen, phosphorus, and potassium. Of these, nitrogen and phosphorus present the most serious management problems. The chemical formulations in which nitrogen is applied are highly soluble in water so that the nitrogen not used by plants can be leached from the root zone through the subsoil and into ground water. Management strategies are being designed and used to minimize this movement. Although not moving with the drainage water as nitrogen does, phosphorus reaches streams because it is attached to soil particles suspended in water running over the surface of the land to these streams. Where soil erosion is serious, excessive levels of phosphorus can occur in streams.

Pesticides are substances used to prevent, destroy, repel, or mitigate the damage of any insect, rodent, nematode, fungi, or weed, or any other form of life declared a pest; and any substance or mixture of substances intended for use as a plant regulator, defoliant, or desiccant. Pesticides can be either natural or synthetic: modern pesticide materials include synthetically produced organic chemicals, naturally occurring organic and inorganic chemicals, microbial agents (both naturally occurring organic and genetically engineered agents), and miscellaneous chemicals not commonly thought of as pest control agents, e.g., chlorine (Cl) added to swimming pools for algae control or to household disinfectants. The issues pertaining to use of pesticides were discussed in detail in CAST Issue Paper No. 2, *Pesticides in Surface and Ground Water* (Council for Agricultural Science and Technology, 1994).

A large amount of organic material holds the promise of being available for conversion to useful products. A new emphasis should be placed on converting these wastes into marketable products. There is much potential to enhance the world food supplies through waste utilization. As the discussion about agriculture changes from production to sustainable production, waste products increasingly will be seen as valuable.

Organic matter produced on the land is a resource which, used properly, is inexhaustible. Outputs needed from agricultural research have changed because the scope of the problem has. Research on product development and use has been added to research on production. Increasing efforts are being made to convert waste into marketable products so as to meet increasingly strict environmental regulations.

In the last two decades, food processing firms, like most other U.S. manufacturers, have decreased their outputs of pollutants. At the same time, they have placed a new emphasis on converting wastes into marketable by-products. Indeed, there remains a considerable quantity of waste with the potential to enhance world food supplies. But uneconomic recycling should be avoided in that it wastes resources potentially more beneficial elsewhere.

Improved waste recycling is possible through continued technological development. Improvement also can be induced by scarcity or by high-priced raw materials for which food processing by-products can substitute. Additionally, a number of institutional mechanisms can encourage recycling and environmental enhancement.

This CAST report was prepared for the purpose of identifying by-products and waste streams of the U.S. agricultural enterprise. The data provided in this report must be evaluated as part of the larger issue of land use. Land is the nation's most valuable resource, and its sustainable use is necessary to ensure the future of society. Other issues relevant to land use are wetlands, soil erosion, urban sprawl, highway construction, industrial parks, and airports.

Land use and land development occur at the confluence of many usually diverse interests. Information was assembled in this report so that the ongoing discussion about how best to use land can be advanced with factual information about the agricultural enterprise.

1 Introduction

Agricultural and food products are crucial to the well-being of society. The growing of grain crops on farms; the production of fruits, vegetables, cattle, poultry, and other crops; the storage and the distribution of farm products to processing plants; and the production of food in ready-to-use forms sustain and improve the quality of human life. Food production and processing sectors, however, generate solid and liquid residues, or *wastes*.

As concerns about environmental pollution, and in some instances human health risks, mount, it becomes increasingly important to understand the nature and the extent of wastes generated from the production, processing, and consumption of food and the manner of their disposal or use. This Council for Agricultural Science and Technology (CAST) report depicts in detail the generation, management, and utilization of waste associated with food production and processing.

Production and processing of agricultural commodities generate by-products that usually are discarded. Most of these materials are considered wastes because they are not needed and without value to producers and processors of food. Many waste materials or by-products generated on farms or at processing plants are organic, an excess of which, if improperly managed, can—like an excess of inorganic material—cause environmental pollution. This pollution may be defined as (1) *point source,* pollution discharged through a pipe, e.g., from factories, farms, food processing and manufacturing plants, industrial sources, and municipal-wastewater treatment plants or from active mine runoff; or (2) *nonpoint source,* diffuse pollution, e.g., from agricultural, silvicultural, urban, and construction runoff (U.S. Environmental Protection Agency, 1987a).

The report describes the agricultural enterprise in the United States and attempts to identify major streams of by-products and waste products associated with several sectors of this enterprise.

The agricultural industry employs more than 22 million Americans and generates $902.5 billion, or 14.2%, of the Gross Domestic Product. A growing segment of the agricultural industry is directed to exports, which are projected to hit a record high of $45 billion in 1995.

2 Landbase and Agriculture

Evaluation of land resources for agriculture begins with the realization that the United States has both an ideal climate and superior soil resources for agricultural production. Figure 2.1 illustrates the world's cropland area, which is comprised of just six contiguous areas for crop production, namely those in the United States, Asian Russia, India, China, Western Europe, and Brazil. These areas have adequate rainfall so that nonirrigated agriculture is sustained, are primarily quite flat, and are served by large river systems. The area in the United States is located ideally with respect to latitude, i.e., between the 30th and the 50th parallels. The land in Asian Russia is much farther north, between the 50th and the 60th. The variety of crops that can be grown on that landbase therefore is more limited than that which can be grown on the U.S. landbase, which has a longer growing season and a higher mean temperature.

Total U.S. land area is 2,265,000 acres (a.), on which 250 million people live: the ratio of acreage to person is 9.06:1. United States land area in agricultural production and its use for specific production types appear in Figure 2.2. Of the 964 million a. of agricultural land, 46.0% is in cropland and 42.5% in pasture and rangeland. Cropland area is 19.6% of total land area and amounts to 1.77 a. per person. Most agricultural waste is generated by cropland agriculture although several environmental concerns are associated with pasture and rangeland grazing as well.

The number of cropland acres per person in the United States is great compared with that in most other countries. Examples of comparable numbers for several geographic regions are shown in Figure 2.1. The land area available for crop production is expected to decrease in the future. Water also is a factor limiting food production (Figure 2.3). Not surprisingly, U.S. agriculture can produce sufficient food for the nation itself while producing export goods. Inasmuch as the value of agricultural exports during the past

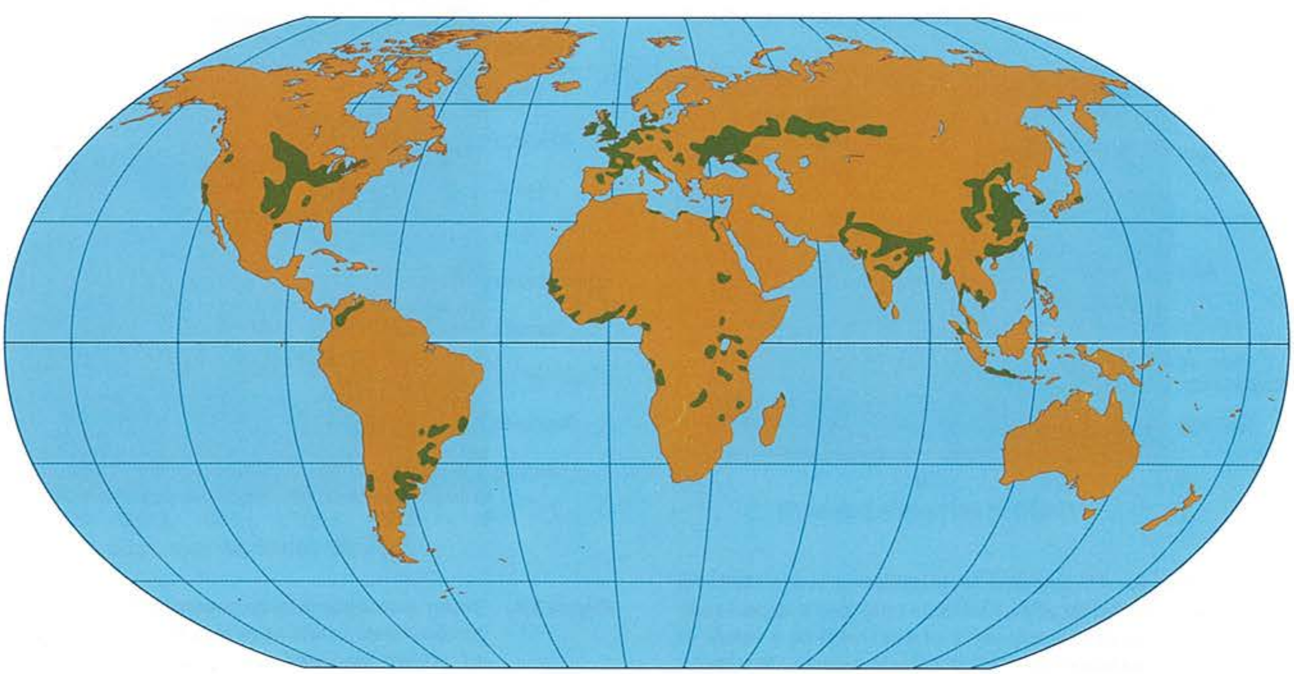

Figure 2.1. Illustration of world's major cropland areas (*Rand McNally Cosmopolitan World Atlas*, 1978).

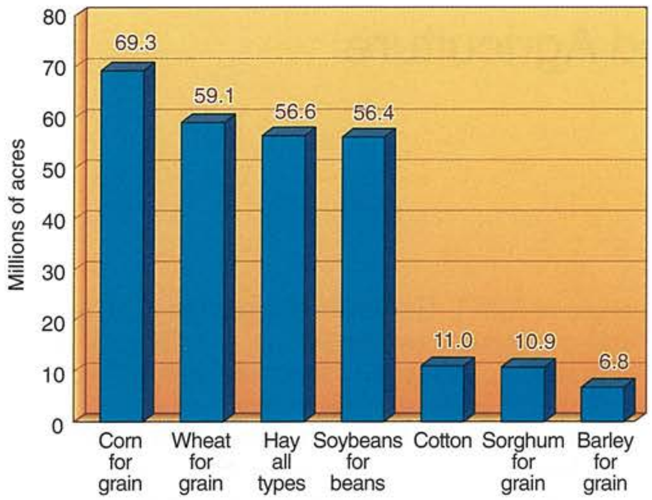

Figure 2.2. Schematic representation of approximate relative areas of harvested U.S. land devoted to various crops (U.S. Department of Commerce, 1994).

several decades has been about equal to that of imported oil, the agricultural industries are a vital part of the U.S. economy, and land is a resource to be husbanded and managed for long-term productivity and sustainability. Improvement and conservation of the land resource are necessary and require both designation of very erosive, fragile, and shallow cropland for soil-improving crops and practices and use of land as reserves for wildlife and recreation. Soils with problems such as those due to salinity and alkalinity or due to specific chemicals, e.g., aluminum toxicity, require treatment before they can be used for agriculture. To the extent that waste generated by agricultural practices can result in these conditions, they are discussed in this report.

Of the 443 million cropland a. in the United States, 282 million (64%) are used for harvested crops, 65 million for pasture, and approximately 95 million for diverse uses such as for cover crops, summer fallow, or failed crops. Four crops, viz., corn, hay, soybeans, and wheat, occupy 78% of all harvested cropland (Figure 2.4). The next most important crops in terms of acreage planted are cotton, sorghum, and barley, which account for 10% of all acres planted. In short, these seven major crops account for 88% of all U.S. cropland. Although economically consequential, the

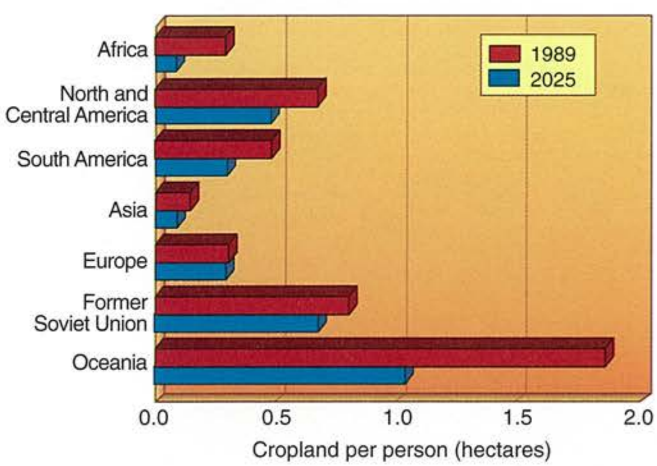

Figure 2.3. Cropland in selected geographic regions in 1989 and estimated for 2025. Available cropland is expected to decrease in many parts of the world as a result of degradation of fertile lands due to misuse, population growth, and natural forces (Homer-Dixon et al., 1993; World Resources Institute, Washington, D.C., 1993).

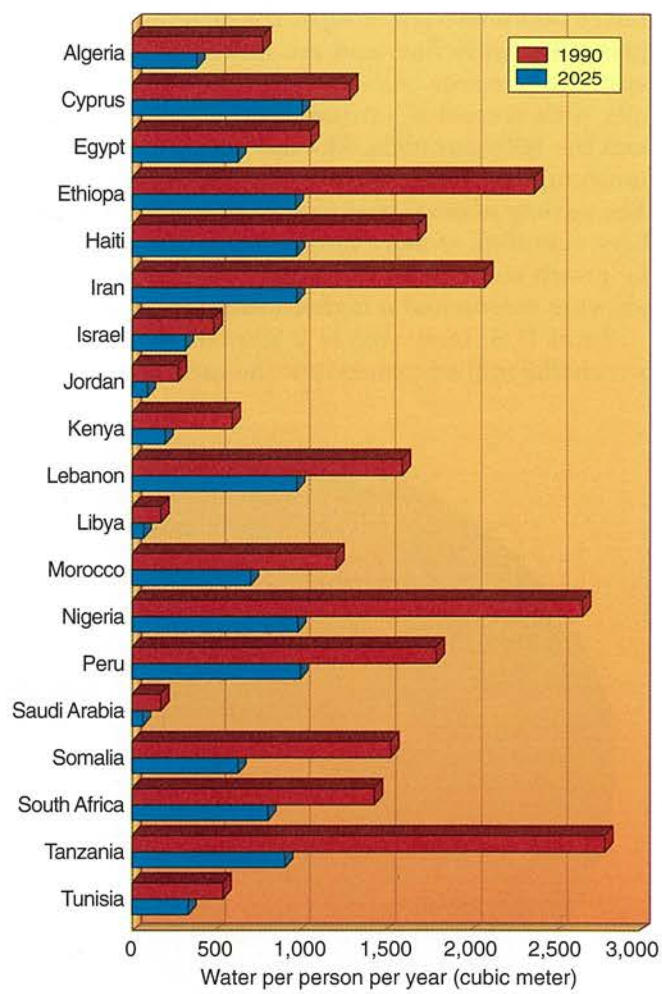

Figure 2.4. Water shortages may be severe in the future. In 2025, several nations will have less than 1,000 meters (m)³ of water per person—the minimum amount considered necessary for an industrialized nation (Homer-Dixon et al., 1993).

acreage devoted to vegetables, fruits, and nuts is small, amounting to less than 2% of all cropland and substantially less than 1% of total land area.

Wastes generated by agriculture and their dispersal into the environment are the thrusts of this report. The authors evaluate the stream of agricultural waste products in its context, as part of the total U.S. economic system.

Cropland Uses

Cropland acres harvested are shown in Tables 2.1 through 2.4. Each table indicates the number of acres devoted to specific crops or crop groups. The first table shows all cropland acres, with vegetable crops and orchards shown as groups. The subdivisions within each group appear in Tables 2.2, 2.3, and 2.4 for orchards, vegetables, and hay, respectively. Table 2.5 shows the area occupied by nursery and greenhouse crops, bedding plants, cut flowers, and ornamentals. The values of fruit and nut and of vegetable crops are great relative to their respective cropland areas (Table 2.6). Some insight into the value of a crop in terms of $/a. can be obtained by comparing Tables 2.1 and 2.6 while recalling that yields per acre differ greatly from region to region. Average net profit per year (yr) is $27,910,463 divided by 288 million a., or $96.91/a.

Table 2.1. Number of acres of all major crops harvested in 1992 (U.S. Department of Commerce, 1994)

Crop	Acres
Corn for grain	69,339,869
Hay (alfalfa, other tame, small grain, wild grass, silage, and others)	56,596,466
Wheat for grain	59,089,470
Soybeans	56,351,304
Cotton	10,961,720
Sorghum for grain	10,887,147
Barley for grain	6,818,065
Corn for silage	6,069,124
Orchards	4,770,778
Oats for grain	4,187,873
Vegetables	3,782,358
Rice	3,117,718
Sunflower seed	1,905,088
Field seed and grass seed	1,725,743
Peanuts	1,594,611
Dry edible beans	1,548,766
Sugar beet	1,441,815
Irish potato	1,351,084
Sugar cane	883,927
Tobacco	831,231
Sorghum for silage	493,589
Berries	171,999
Flax seed	156,630
Total	304,076,375

Table 2.2. Number of acres of orchard crops harvested in 1992 (U.S. Department of Commerce, 1994)

Crop	Acres
Citrus	1,241,320
Oranges	915,947
Grapefruits	206,230
Lemons	67,329
Grapes	867,161
Apples	583,624
Pecans	473,426
Almonds	441,700
Peaches	226,029
English walnuts	214,159
Plums	142,118
Cherries	126,395
Pears	83,183
Avocados	74,344
Pistachios	69,344
Total orchard crops	4,542,793
Total orchards	4,770,778

Table 2.3. Number of acres of vegetables harvested in 1992 (U.S. Department of Commerce, 1993a)

Crop	Acres
Sweet corn	762,132
Tomatoes	397,368
Green peas (excluding cowpeas)	328,287
Lettuce and romaine	287,468
Snap beans	272,698
Watermelons	220,244
Cucumbers and pickles	138,639
Dry onions	138,060
Broccoli	122,429
Carrots	108,250
Cantaloupes	106,938
Asparagus	85,929
Sweet peppers	73,966
Squash	69,029
Cauliflower	62,465
Total	3,173,902
Total vegetables (from Table 2.1)	3,782,358

Table 2.4. Number of acres of hay harvested in 1992 (U.S. Department of Commerce, 1994)

Hay	Acres
Alfalfa hay	22,792,626
Tame hay (other than above)	19,727,365
Wild hay	6,773,734
Grass silage, haylage, green chop	4,257,569
Small grain hay	3,045,172
Total	56,596,466

Table 2.5. Nursery and greenhouse crops, mushrooms, and sod grown for sale in 1992 (U.S. Department of Commerce, 1994)

Crop category	Under glass (sq ft)	In the open (acres)
Floriculture crops	655,853,141	61,106
Bedding plants	228,235,819	13,816
Cut flowers	137,462,732	32,258
Foliage plants	150,996,176	10,418
Potted flowering plants	139,158,144	4,614
Mushrooms	63,631,031	—
Woody nursery crops	127,742,863	331,462
Sod harvested	—	218,161
Vegetable and flower seeds	3,552,729	78,296
Greenhouse vegetables	28,486,757	—
Total	883,935,463	699,579

Table 2.6. Market value of agricultural products sold in 1992 (U.S. Department of Commerce, 1994)

Product	Value (thousand $)
Cattle, calves	41,676,243
Grains	35,972,166
Dairy products	17,765,439
Poultry	15,425,176
Hogs, pigs	10,047,423
Fruits, nuts	9,200,069
Nursery, greenhouse	7,634,924
Vegetables	6,404,618
Other crops	5,584,661
Cotton, cotton seed	4,579,868
Hay	3,172,780
Other livestock	1,787,894
Tobacco	2,679,170
Sheep, lambs, wool	677,904
Total sales	162,608,334
Expenses	130,779,261
Net profit	31,829,073

3 Crop Production-Waste Management and Utilization

Summary

Fertilizer recommendations are designed to prevent undue buildup of nutrients in soil to the level that ground water can be affected adversely through leaching; surface water, through runoff; or growing plants, through nutrient imbalance, induced deficiency, or toxicity. Fertilizer production inputs become wastes only when the best management practices for given crops and soils are ignored. Nitrogen is a fertilizer of concern with respect to ground water: when rainfall exceeds evapotranspiration, some nitrate eventually reaches ground water and can cause problems when drinking water is obtained by pumping from ground water. Nitrate also reaches surface waters, where they support growth of undesirable plants such as algae. Efforts are being made to develop increasingly precise tests to determine N need. Neither P nor K is mobile in most soils or in ground water. Likewise, neither is considered a direct hazard to human or to livestock health. Agricultural limestone contains no harmful residues. Sludges, increasingly used to provide P and K, may contain potentially hazardous elements such as cadmium, which must be monitored. Sludges should be managed as organic fertilizers.

Pesticide usage rates increased steadily from 1964 to 1993. The Pesticide Use/Risk Reduction initiative announced in June 1993 is a joint effort by the U.S. Department of Agriculture, the U.S. Food and Drug Administration, and the U.S. Environmental Protection Agency to limit the use of pesticides posing unreasonable risks to humans and the environment. The plan is designed to decrease pesticide risks while permitting cost-effective pest control methods.

Crop residues help recycle nutrients back to the soil, thereby diminishing the need for applied nutrients. Quantity and quality of residue from a crop depend on species, environment—especially moisture and N availability, and soil productive capacity. Retention of crop residues on the land where grown usually is the most practical and sound waste management practice. Forage production leaves little waste material for additional management; and because residues are returned to the soil, few wastes are associated with fruit and vegetable production.

The use of crop residues for fuel should, in the foreseeable future, occur on-farm or at most within a few miles of it. Evolving technological innovations and economic conditions well may lead to increased and more effective use of crop resides as animal feed.

Introduction

Inputs necessary for sustained production of plant products may include fertilizer, pesticide, fuel, and irrigation water. When any of these inputs are spilled or used in excess, waste occurs. And if they enter surface or ground waters, pollution may occur. The potential for environmental harm depends on several factors, including waste quantity and chemical content, and application timing.

Other waste product sources include production residues and wastes generated when agricultural products are processed into food, feed, and fiber. This chapter discusses waste generation and describes measures to minimize and/or to use these wastes in an environmentally sustainable manner.

Production Inputs

The only crop production inputs analyzed in this report are fertilizers and pesticides. Fuel, although essential to crop production, is omitted because it should not be wasted on the farm if appropriate containment precautions and regulations are adhered to and if contaminated soils are cleaned properly. Irrigation water management is a subject beyond the scope of this report and indeed has been covered in a previous CAST task force report, *Effective Use of Water in U.S. Agriculture* (Council for Agricultural Science and Technology, 1988; see also National Research Council, 1989).

Fertilizer

Plants require certain macro and micronutrients for growth (Table 3.1). The macronutrients required are nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca), and magnesium (Mg). Additionally, plants require small quantities of the essential micronutrients. With the exception of legumes, which, in symbiosis with bacteria in root nodules, obtain N from the atmosphere, growing plants obtain most essential nutrients from the soil.

Soil colloids and clay minerals store nutrients and retain them against leaching. Soil organic matter, part of the colloidal system in soils, contains N, P, and S, which are made available to plants through mineralization carried out by microorganisms.

Ongoing use of crop production systems that remove products from the land depletes the soil's supply of nutrients. Moreover, many soils are naturally deficient in nutrients. As a result, fertilizers are required to restore depleted nutrients and to correct nutrient deficiencies.

The most efficient strategy for the application of fertilizers is to provide them at the time of and in the amount needed for plant growth. Percolation of rainfall or of irrigation water distributes mobile compounds, e.g., boron, sulfur, or nitrogen, throughout the soil after they are applied at the soil surface (Figure 3.1.). Movement is most rapid and pronounced in sandy soils or in soils with little organic matter. Because rate of rainfall is unpredictable, distribution

Table 3.1. Approximate contents of some nutrients in selected crops (Eaken, 1972)

	kg/ha							
Crop	Yield	N[a]	P	K	Ca	Mg	S	Zn
Grains								
Corn, grain	9,400	150	26	36	2	9	11	0.17
Corn, stover	10,000	110	18	130	29	22	16	0.34
Wheat, grain	2,700	55	12	14	1	7	4	0.16
Wheat, stover	3,400	20	2	30	7	3	6	0.06
Rice, rough	4,000	55	10	9	2	4	4	0.08
Rice, straw	5,600	33	5	60	9	6	—	—
Sorghum, grain	3,800	55	12	17	4	6	6	0.04
Sorghum, stover	6,700	73	10	86	32	20	—	—
Hay								
Alfalfa	9,000	200	20	162	125	24	21	0.47
Coastal Bermuda	17,900	340	34	243	66	27	39	—
Red clover	5,600	110	12	90	77	19	8	0.40
Timothy	5,600	67	12	86	20	7	6	0.24
Fruits and vegetables								
Dry bean	2,000	84	12	5	2	2	6	0.07
Cabbage	45,000	146	34	117	22	9	49	0.09
Potato (tuber)	27,000	90	15	135	3	7	7	0.06
Tomato (fruit)	45,000	134	20	144	8	12	16	0.18
Others								
Cotton (seed)	1,680	45	10	14	3	5	4	0.36
Cotton (stalks, leaves, burs)	2,240	39	5	32	31	9	17	—
Soybean	2,700	169	17	50	8	8	5	0.04
Sugar cane	67,000	108	26	243	31	27	27	—

[a]Legend: N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; S = sulphur; Zn = zinc.

of mobile nutrients throughout the soil cannot be controlled. To ensure an adequate, ready supply of nutrients, an excess may be applied and a wastestream may result.

With respect to ground water qality, N is of concern. Phosphorus and K fertilizers dissolve in the soil water but quickly are adsorbed into soil colloids. Phosphorus is highly immobile except when involved in soil surface erosion, but N in the nitrate form is highly mobile and escapes easily from the root zone to become a potential environmental contaminant as infiltrating water carries it to even deeper horizons. When rainfall exceeds evapotranspiration, some nitrate eventually reaches ground water. Drinking water concentrations higher than 10 parts per million (ppm) of nitrate-nitrogen have deleterious human health consequences. Nitrate also can reach surface waters, where it supports growth of undesirable plants such as algae. Rapidly growing algae are unattractive and may disturb natural ecosystems.

The problem of nitrate in the environment has been recognized, and farm practices designed to prevent this occurrence are being developed and implemented rapidly. Many states are implementing Best Management Practices (BMPs) designed to make the most efficient and economical use of nitrogen and phosphorus (Schulte and Walsh, 1993). Implementation of BMPs is encouraged in part by considerations for the environment (U.S. Environmental Protection Agency, 1993a).

Total fertilizer use is a function of number of acres planted, percentage of crop acreage actually fertilized, and rate of application. Information about these three factors for the period 1964 through 1988 appears in Figures 3.2 to 3.5. During the first half of this period, number of acres planted for the major crops, i.e., soybeans, wheat, and corn, increased. This trend ceased approximately after 1976, and the number of acres planted began to decrease about 4 yr later. These historical trends are a consequence of prevailing economic conditions. From 1964 to 1976, there was considerable concern about world food shortages, demand for food was great, and prices received by farmers were quite high. Beginning in about 1980, however, a worldwide surplus of farm products developed, and both prices and planted acreage decreased.

The percentage of crops receiving fertilizer, like the number of planted acres, increased from 1964 through 1976 and decreased thereafter. This percentage was very high for corn—nearly 100%, but barely

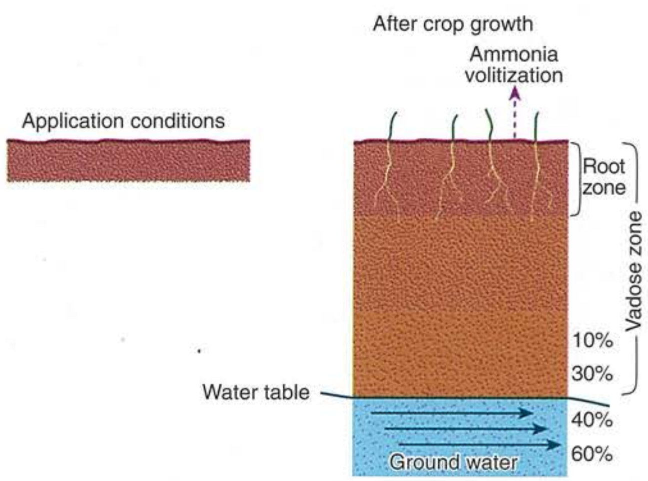

Figure 3.1. **Schematic diagram showing the distribution of nutrients throughout the soil after infiltrating water has carried some to lower soil.**

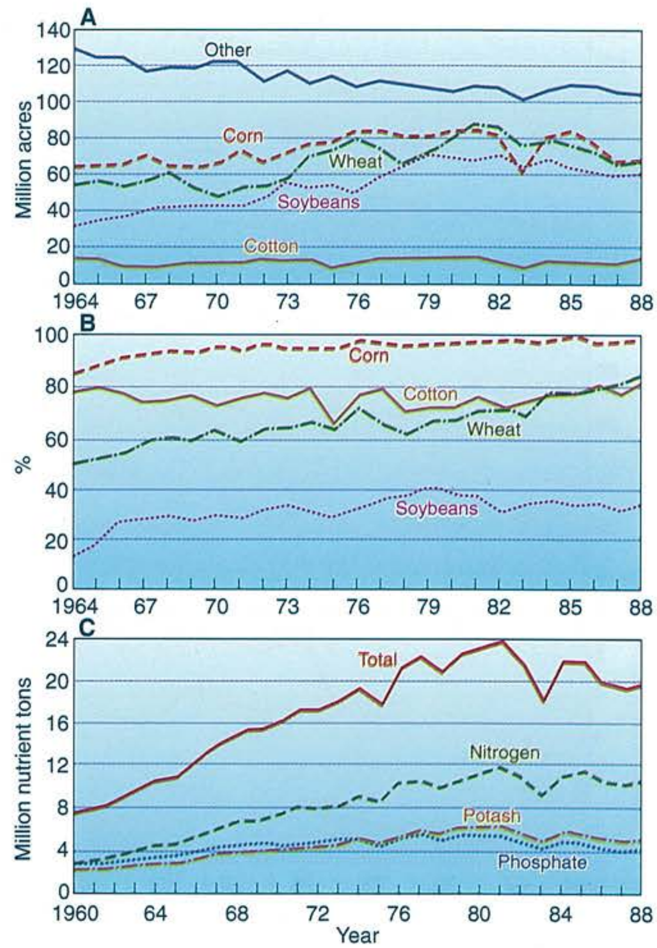

Figure 3.2. **Crop acreage planted (A), percentage of acreage receiving any fertilizer (B), and consumption of primary nutrients (C) as a function of time, from 1964 through 1988 (U.S. Department of Commerce, 1989).**

exceeded 40% for soybeans. The percentage of wheat crop acreage receiving fertilizer increased continually.

The combination of acres planted and percentage of crop acres receiving fertilizer and rate of fertilizer application illustrates the consumption of primary plant nutrients. Figure 3.2C shows a threefold increase in the amount of N fertilizer used from 1960 to 1980, when use began to fluctuate around a constant rate. Nitrogen, P, and K usage followed similar trends, increasing until the early 1980s and decreasing subsequently (Figures 3.2C through 3.5C).

Fertilizer application results not only in plant uptake but also in reactions with soil colloids. Soil microbiological processes, especially with N, P, and S, also occur. The net result of these reactions is that certain added nutrients are immobilized and become resistant to movement by rainfall percolation and/or irrigation water.

The soil testing and plant analysis programs developed by the fertilizer industry, crop consultants, extension agronomists, and horticulturists provide growers with recommendations regarding efficient use of fertilizer. Recommendations are designed to prevent undue buildup of nutrients in the soil to the level that ground water can be affected adversely through leaching; surface water, through runoff; or growing plants, through nutrient imbalance, induced deficiency, or toxicity.

For economic reasons, fertilizers generally are not applied in excess of amounts needed for optimal crop production. Obviously, unnecessary fertilizer application decreases profits. Moreover, both farmers and commercial applicators have become increasingly aware of the environmental consequences of excessive fertilizer use. Plant nutrients nonetheless can

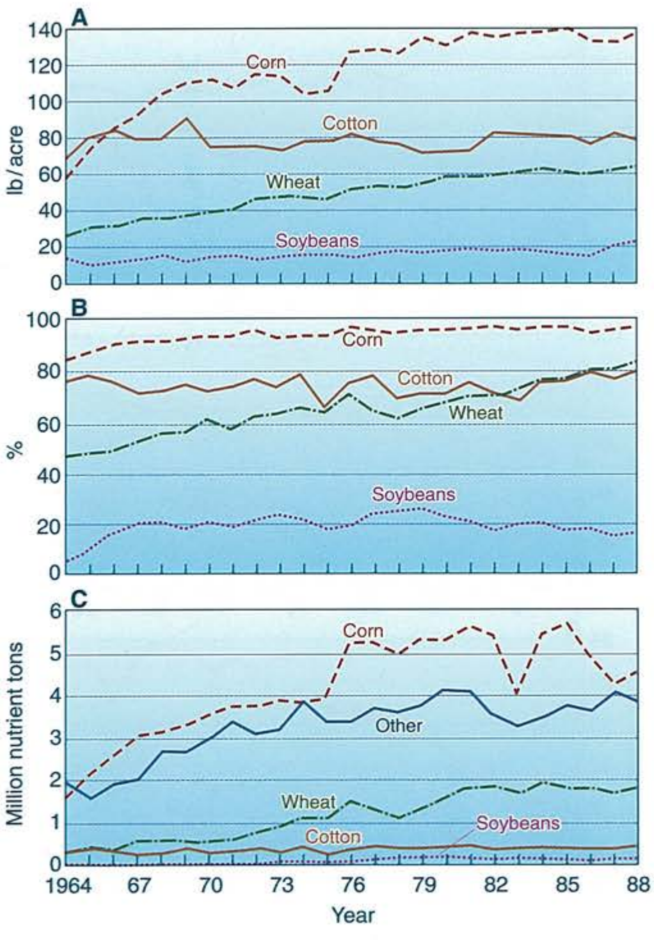

Figure 3.3. Nitrogen use. Rate of application (A), percentage of crop acreage receiving N (B), and estimated consumption (C) (U.S. Department of Commerce, 1989).

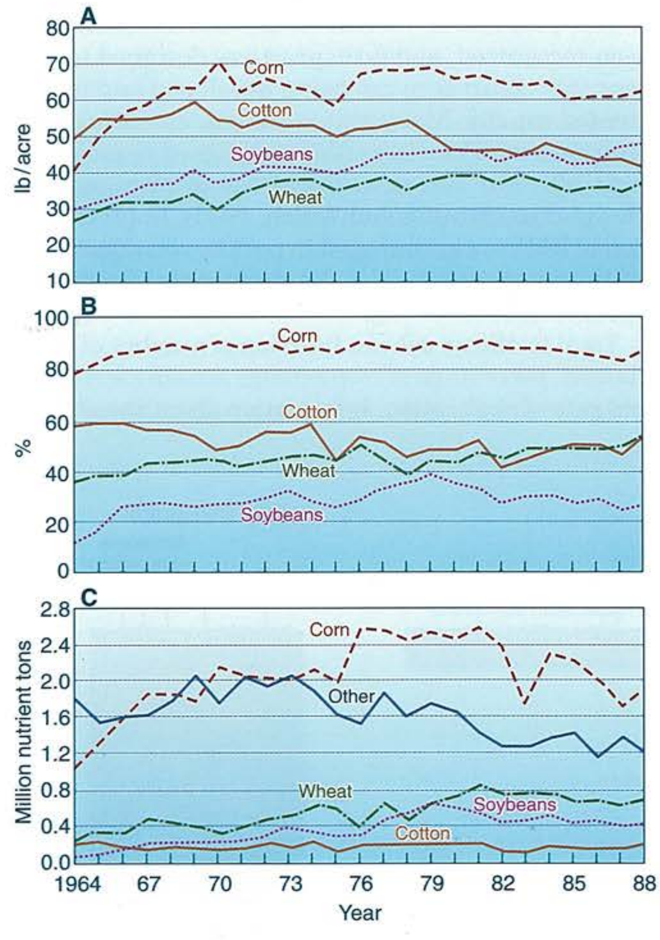

Figure 3.4. Phosphate use. Rate of application (A), percentage of crop acreage receiving P (B), and estimated rate of consumption (C) (U.S. Department of Commerce, 1989).

occur in excess in production fields.

Nitrogen use in agriculture increased through 1980, after which it leveled off (Figure 3.2C). Rates of application to grain crops tended to increase although use on corn fields stabilized after 1980 (Figure 3.3A). Because most corn growers use N (Figure 3.3B), most environmental concern about N use focuses on that crop.

Nitrate-nitrogen is the primary nutrient of human health concern in surface and ground waters used for drinking. Nitrate-nitrogen either is applied directly or is formed in the soil by microorganisms that can use the organically bound N present in the soil or the N present in other nitrogenous fertilizers. Use of N fertilizers tends to correlate with evidence of nitrate in ground water of light textured soils. But such a correlation ignores the complexity of biological, physical, and chemical factors regulating soil N behavior.

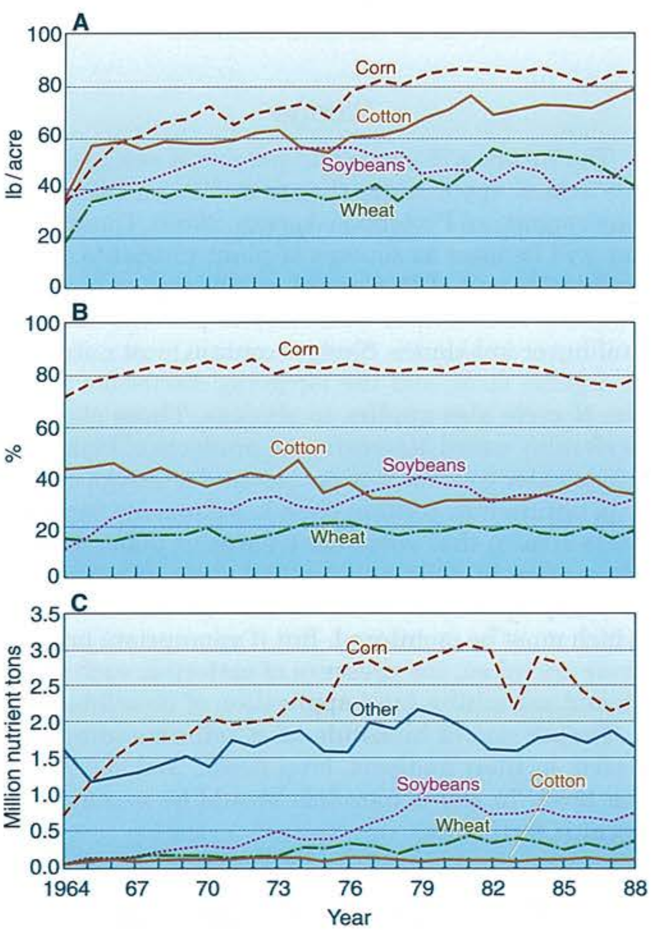

Figure 3.5. Potassium use. Rate of application (A), percentage of acreage receiving K (B), and estimated rate of consumption (C) (U.S. Department of Commerce, 1989).

In soils with a high organic matter content, this correlation cannot be expected.

Biological factors affecting the N cycle such as the C/N ratio of wastes are summarized in many references, e.g., Alexander (1961). Soil organic matter (SOM) averaging 5% N contains considerable N in an unavailable form. Research during the past 25 yr has shown clearly that SOM, including both C and N, is made up of pools differing in stability such as stable; active; and, in the case of N, inorganic (Balesdent et al., 1988; Jenkinson and Rayner, 1977).

Old organic N is centuries old, accumulated as the soil developed, and resists mineralization. This form generally is referred to as *humus*. *Stable organic N* is maintained at a given level when the agrosystem is managed properly. Appropriate rotations (corn-soybeans-wheat) and reduced till or no-till will maintain the stable organic N pool. *No-till* is a farming practice whereby the soil surface is undisturbed by tillage and seeding is done by equipment designed to cut through residues and the soil surface to place the seed at the correct depth for germination.

Active organic N is dominated by the microbial population and by organic soil amendments. It is sensitive to environmental conditions and to alterations of soil carbon (C):N ratio. Application of fertilizer N can affect the active organic N pool by altering the rate and results of N mineralization and immobilization. Although fertilizer N in nitrate (NO_3^-) and/or ammonium (NH_4^+) form is considered part of the *inorganic N* pool, it also is subject to microbial immobilization or to plant uptake, hence to conversion to active organic N.

The addition of fertilizer N to soil is measured easily. But the inputs of all facets of the soil-plant environment continuum are monitored and controlled less easily. For example, the shift in management from continuous alfalfa hay to continuous corn will affect all soil pools profoundly except the old organic N pool, which in time also may be affected. The net result of such a management change will be increased mineralization of N in the active organic and the stable organic pools and therefore increased available N (Asghari and Hanson, 1984).

When kept in place, the cropping system tends toward equilibrium between the N pools. The result, then, is a certain level of inorganic N in any agrosystem. As illustrated by Legg et al. (1989), when N balances are calculated, each farm and field must be considered a system. Thus, whether the applied N fertilizer is waste depends on the N cycle for the field to which the N is applied. In short, management of N fertilizer to prevent waste must be field by field.

Efforts are being made to develop increasingly precise tests to determine N need (Magdoff, 1991).

Phosphorus fertilizer use in the United States has declined since 1980 (Figure 3.2C). Its use on wheat has leveled off since 1980 while its use on corn has declined (Figure 3.4C). Similar trends have been observed for K fertilizers (Figures 3.2C and 3.5C).

Although both P and K can be applied to soils in excess, the hazard to ground water is minimal because neither is mobile in most soils (Barber, 1984b). Phosphorus is mobile in organic soils; K, in sandy soils. Both nutrients are retained relatively tightly by soil colloids albeit by different mechanisms. Although P has been implicated in the eutrophication of surface waters through runoff and erosion of cropped fields (Menzel et al., 1978), neither P nor K in ground water is considered a direct hazard to human or to livestock health.

Fertilizer production inputs become wastes only when the best management practices (BMPs) for given crops and soils are ignored. Soil tests, manure and plant analyses, annual nutrient budgeting strategies such as N credits from legumes, realistic crop yield goals, irrigation management, and compliance with land use regulations under federal programs all help prevent waste of fertilizer. Point sources of contamination also are a concern. Cleaning of fertilizer application equipment and unused product and fertilizer bags are potential contamination sources.

Lime

Soil acidity is a problem in many agricultural areas and limits yield in others (Adams, 1984). Soils are acidic because their parent materials were acidic and low in Ca^{2+}, Mg^{2+}, K^{+}, or sodium (Na^{+}), or because these elements have been or are being removed from the soil profile by leaching due to excess rainfall or crop harvesting. Use of leguminous plants is acidifying because of the net uptake of cations over anions and the exudation of protons (Mengel and Kirkby, 1987). Soil acidification is intensified by the use of acid-forming ammonium-nitrogenous fertilizers and by acid deposition from polluted air.

An *agricultural liming material* is defined as a material whose Ca and Mg compounds are capable of neutralizing soil acidity. These materials include quick lime, hydrated lime, limestone (both calcitic and dolomitic/marl), shells, and by-products such as slag (Barber, 1984a).

From 1935 to 1950, total application of agricultural limestone in the United States increased from about 2.5 million to 25 million t (metric tons)/yr. In the 1930s, federal soil-conservation programs offered lime-purchasing financial assistance, which stimulated application. Although limestone use, which is affected by changes both in cropping programs and in federal subsidy fund usage, decreased after 1950 and bottomed out in 1954, it recently has increased. Agronomists estimate that U.S. farmers profitably could use 80 million t lime/yr, an amount three times that used in 1981.

Liming materials usually are broadcast over the soil surface at rates of 2 to 12 t/hectare (ha), after which they are mixed with soil during tillage. Application rate is chosen so that the material applied reacts with the soil for 2 or 3 yr.

Adjustment of acid soil to an acidity level at which desired plants grow best is an accepted management practice (Mengel and Kirkby, 1987). Such adjustment benefits soil organisms that decompose crop residues and recycle nutrients within the soil. Products such as agricultural limestone used for neutralization of acid soils contain no harmful residues.

Sludge

The future will see expanded use of sewage sludges in land applications (Logan and Page, 1989; U.S. Environmental Protection Agency, 1989). These sludges will be used as sources of plant nutrients, especially of N and of P. Careful monitoring of land application sites will be necessary to prevent nutrient buildup or imbalance. Sludges contain most nutrients in organic form, and the foregoing discussion about the N cycle also applies to sludges. These sludges, preferably called *biosolids*, are products of biological wastewater treatment processes and although organic in nature may contain chemical elements from the wastestream that enter the treatment plant. Biosolids contain in addition to useful plant nutrients potentially hazardous elements such as cadmium (Cd), which must be monitored. But if appropriate precautions are taken, the presence of materials such as Cd should not inhibit land application of biosolids.

Proper use of biosolids as a soil amendment is based on their analysis, crop needs, and soil nutrient level. In short, biosolids should be managed as organic fertilizers.

Pest Control Chemicals

A *pesticide* is defined by the Federal Insecticide, Fungicide, and Rodenticide Act as ". . . any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any insects, rodents, nematodes, fungi, or weeds, or any other forms of life declared to be pests; and any substance or mixture of substances intended for use as a plant regulator, defoliant, or desiccant." Pesticides can be either natural or synthetic. Modern pesticide materials include synthetically produced organic chemicals, naturally occurring organic and inorganic chemicals, microbial agents (both naturally occurring organic and genetically engineered agents), and miscellaneous chemicals not commonly thought of as pest control agents, e.g., chlorine (Cl) added to swimming pools for algae control or to household disinfectants. Figure 3.6 illustrates EPA estimates of a steady increase in annual pesticide use rates, by pounds of active ingredients, for the period 1964 to 1993. Rates since 1980 have been fairly constant. Agricultural use is approximately three-fourths of total use. Growth in use has been slowed by lower application rates due to the introduction of more potent compounds, more efficient application methods, and lower farm commodity prices. Rate of use by type appears in Figure 3.7.

The issue of pesticides in waste management can be distinct from that of pesticides in the general environment, which may occur with drift or leaching to ground water. Regarding the first issue, the most obvious concern is the correct management of used pesticide containers and, on occasion, unused material. In many states, agencies coordinate collection programs to deal with this problem and to arrange for disposal in appropriate hazardous-waste sites. Distributors also are addressing the problem by changing product packaging. Chemicals used in the postharvest treatment of fruits and vegetables may be a consideration in the management of effluents from packinghouses. Another example of how pesticides can influence waste management is their use on crops grown for seed. Chemicals can be approved for use on such crops, but if the necessary residue data are not obtained to establish tolerance, then because it is assumed that some residue will remain, the screenings cannot be fed to livestock, and other disposal options must be considered.

The Pesticide Use/Risk Reduction initiative announced in June 1993 is a joint effort by the U.S. Department of Agriculture (USDA), the U.S. Food and Drug Administration, and the EPA to limit the use of pesticides posing unreasonable risks to humans and to the environment. Through a coordinated strategy, the federal government is committed to working with all affected interests—including commodity organizations; public interest groups; federal, state, and local government agencies; and researchers and industry representatives—to develop a plan reducing pesticide risks while permitting cost-effective pest control methods.

Crop Residues

Grains

Two classes of waste are associated with field crop production. Crop residue is left in the field after harvest of the economically valuable portion of the crop (Figure 3.8). Crop residues are not generic wastes in the sense of being "useless, unneeded or superfluous" (Friend and Guralnik, 1954). But extra effort may be required to make them useful or to prevent them from interfering with the next field operation. The second kind of waste includes pesticide and fertilizer containers, excess pesticides and other inputs, e.g., plastic

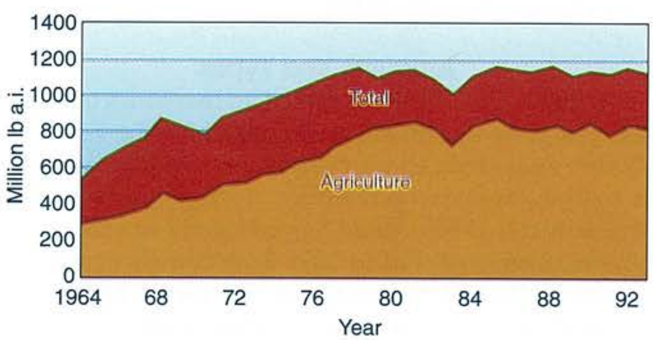

Figure 3.6. Estimates by the U.S. Environmental Protection Agency of total U.S. and U.S. agricultural sector pesticide use in million lb of active ingredients (a.i.) per year during 1964–1993 (Aspelin, 1994).

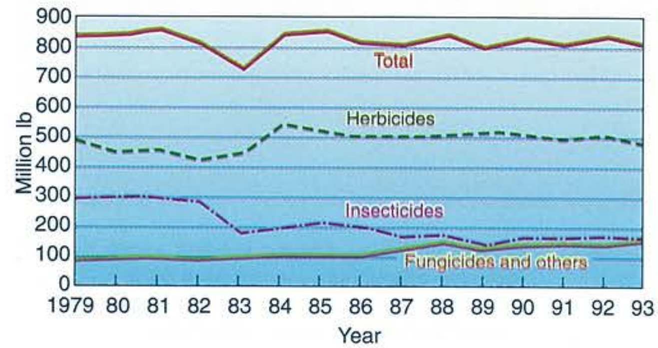

Figure 3.7 Estimates by the U.S. Environmental Protection Agency of the use rate of pesticides in agriculture in million lb of active ingredients (a.i.) by type during the period 1979–1993 (Aspelin, 1994).

sheets used for crop production. Crop residues will be considered in this section. Other waste products are considered elsewhere in the report.

Most grain crops, e.g., corn, grain sorghum, and soybeans, are spring seeded. Wheat may be seeded in either the fall or the spring, depending on geographic location and growing conditions. Seeding of grain crops, which are annuals, may be done in prepared seedbeds or according to no-till methods. Prepared seedbeds, considered the conventional method until just a few years ago, is being replaced by no-till culture. In the conventional tillage systems, a moldboard plow or chisel plow is used either to turn or to drastically disturb the soil before planting. Any residues on the soil surface would be incorporated into the soil.

In contrast, no-till culture involves no preplanting tillage. The planter units are designed to cut through this surface residue and to place the seed in the underlying soil. No-till culture is being used to decrease expenses and to aid in soil conservation by preventing runoff of precipitation from fields and the subsequent soil erosion.

Coarse grains, e.g., corn and grain sorghum, and soybeans usually are seeded in rows, with the planter adjusted to drop seeds at a specific spacing and depth and at a rate needed to attain a given plant population. Wheat usually is drill seeded in rows 4 to 8 in. apart (10 to 20 cm). Soybeans may be either drilled as wheat is or planted in rows as corn and grain sorghum are. Soybeans also may be grown in narrower rows than corn is (15 and 30 in., respectively).

Figure 3.8 Willamette Valley, Oregon farmers swath their tall fescue and perennial ryegrass seed fields in July and August and let the grass cure before removing seeds for sale. The straw is baled and used for mature cattle during the harsh winter weather and exported to countries such as Japan for livestock feed. Photograph courtesy of Agricultural Communications, College of Agricultural Sciences, Oregon State University, Corvallis.

Conventional tillage requires considerably more energy than no-till culture does. In the latter, crop seeding is accomplished by special no-till planters and drills that cut through residues on the soil surface to place seeds in soil at appropriate depths and row spacings. Primary and secondary tillages are eliminated, and time and energy are conserved. But increased pesticide use in some no-till or reduced till systems may offset fossil fuel savings partly.

Conventional culture removes crop residues from the land surface, where they could protect against aggregate breakdown, soil particle detachment, and erosion. On the other hand, conventional culture incorporates residues into the soil, where decomposition by soil microflora is more rapid than on the surface.

Weeds may be controlled in conventional culture mechanically or chemically, or by a combination of methods. In no-till culture, mechanical cultivation for weed control may cause residues on the soil surface to clog equipment. Residues in no-till culture may adsorb soil applied herbicides and cause nonuniform functioning so that increased quantities per unit area are required. No-till management also relies on low doses of foliarly applied herbicides, which may affect environmental quality minimally.

The vegetative portions of most crops, seed coverings, and—in the case of corn—cobs are left in the field and constitute crop residues from grain production, which are the subject of this section of the report. Grain crops usually are harvested with a combine adjusted for grain size and for location on the plant. A small amount of corn is harvested on the cob, usually for on-farm feeding. When corn and certain other crops are harvested for silage, little residue remains on the soil surface.

Amounts and Types

In 1980, the USDA published an inventory of farming practices to provide background for the Soil and Water Resources Conservation Act, which included a section on organic residues (U.S. Department of Agriculture, 1980). Table 3.2, adapted from that document, indicates that in 1977 54% of organic wastes in the United States was crop residues. There were 413 million a. (167 million ha) of nonfederal cropland in the United States. Thus, in 1977, there was slightly greater than 1 dry t of crop residue per a. (2.2 megagrams per ha [Mg ha^{-1}]) of cropland. Fourteen percent of this crop area was in hay; another significant quantity was in rotation pasture. Thus, if 20% of total cropland, or 82.6 million a. (33.5 million ha), was in hay and pasture (noncrop), there would be 1.3 dry t of crop residues per a. of cropped land (2.9 Mg ha^{-1}). Quantity and quality of residue from a crop depend on species, environment, especially moisture and N availability, and soil productive capacity.

The amount of aboveground residue remaining on the field after grain harvest depends on crop, e.g., grain corn, 7,200 pounds (lb)/a. (8.1 Mg ha^{-1}); grain sorghum, 7,400 lb/a. (8.3 Mg ha^{-1}); soybeans, 3,900 lb/a. (4.4 Mg ha^{-1}); and wheat, 2,600 lb/a. (2.9 Mg ha^{-1}) (deMooy et al., 1973; McCalla et al., 1977; Stotskopf, 1981; U.S. Department of Agriculture, 1987a). The *Harvest Index* (HI), defined as the mass of harvested or usable plant product as a fraction of total plant biomass produced per unit land area (or per plant), is the measure of crop residue. The HI depends on crop variety, moisture and nutrient availability, and sunlight intensity and duration.

Physical and Chemical Composition

Crop residues, which have unique chemical and physical characteristics (Table 3.3), help recycle nutrients back to the soil, thereby diminishing the need for applied nutrients. The dollar values of corn and grain sorghum-residue nutrients are especially high (Table 3.4). Estimated values are based both on assumed prices for N, phosphate (P_2O_5), and potash (K_2O)—which depend on season, year, and region and on residue quantities.

The C:N ratio of the residue becomes important when residues are returned to soil. The C:N ratios for corn, grain sorghum, and wheat suggest some initial N immobilization as a result of the carbonaceous nature of residues. As the decay process continues, and especially as microbes die, both the C:N ratio of the added biomass and the number of organisms feeding on that biomass decline, and N slowly is released in the available form (Alexander, 1961).

Soybean residue data given in Table 3.3 do not tell the entire N story. The roots of grasses tend to have C:N ratios similar to the tops. But roots of soybeans, as of all leguminous species, tend to have a much lower C:N ratio. In fact, midwestern farmers follow the rule of thumb that the residual effect of soybeans upon a succeeding grass crop amounts to 1 lb of N per bushel of soybeans harvested (1 kilogram [kg] N/60 kg soybean grain) (Tisdale et al., 1985). Most of this

Table 3.2. Quantity and use of organic wastes (U.S. Department of Agriculture, 1980)

Organic waste	Annual production (1,000 dry tons)	Total production (%)	Applied to land (%)
Animal manure	158,500	22	90
Crop residue	387,978	54	68
Sewage sludge and septage	3,932	< 1	23
Municipal refuse	130,500	18	1
Other	42,417	5	1

Table 3.4. Estimated value[a] in dollars per acre of nutrients in crop residues returned to the soil

Crop residue	Quantity of residue (lb/acre)	Nutrient ($) N	P	K	Total
Corn	7,200	17.38	7.00	13.80	38.18
Grain sorghum	7,400	17.82	6.25	13.92	37.99
Soybean	3,900	8.58	3.25	0.36	12.19
Wheat	2,600	3.52	0.50	0.36	4.38

[a]Assumes the values of \$0.22 for N, \$0.25 for P_2O_5 (2.29 x P), and \$0.12 for K_2O (1.2 x K). These values are per lb of nutrient.

Legend: N = nitrogen; P = phosphorus; K = potassium.

Table 3.3. Chemical composition of aboveground crop residues

Crop residue	C:N[a]	Percentage of dry matter N	P	K	Ca	Mg	Reference
Corn	36	1.1	0.17	1.34	0.30	0.19	McCalla et al., 1977
Grain sorghum	36	1.1	0.15	1.31	0.48	0.30	McCalla et al., 1977
Soybean	40	1.0	0.15	0.67	—	—	deMooy et al., 1973
Wheat	67	0.6	0.06	0.98	0.21	0.09	McCalla et al., 1977

[a]Assumes 40% C (Alexander, 1961).

Legend: C = carbon; N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium.

N must come from the decay of soybean roots and nodules.

The physical nature of the residues of the four crops exemplified differ. Corn and grain sorghum residues consist mainly of stalks as wide as 1 in. in diameter and of leaves. The latter generally decay readily; the former remain intact for 6 months (mo) to 1 yr. Cobs remain intact longer. Because wheat straw is relatively small in diameter (< 1/4 in., or < 30 millimeters [mm]) and hollow, microbes can attack readily if moisture and N are available. Soybean leaves drop to the soil surface and by harvest often disappear as a result of decay. The stalks of both grain sorghum and corn may interfere with tillage and/or no-till planting operations by being too coarse for the equipment to pass through without being accumulated by the equipment. Even finer small-grain residues may interfere with tillage and/or planting of subsequent crops, due to bulk. Soybean residues pose little problem to tilling or to planting.

Management

Retention of crop residues on the land where grown usually is the most practical and sound waste management practice. The organic nature of the residues and the by-products of decay contribute dynamically to improve water infiltration and retention and to ease of tillage. Increased infiltration tends to ameliorate precipitation runoff and erosion problems. Retention of organic residues on the soil surface, as in no-till culture, decreases impact of raindrops and subsequent detachment and movement of soil particles (Steichen, 1979; Walker and Pope, 1983).

Of the nutrients in crop residues, N likely is of most concern in the environment because it may leach from the root zone and enter the ground water. Generally, the recycling of N in a purely crop oriented system retains N found in the system residues as long as fertilizer N is not applied in excess (Legg et al., 1989; Power and Legg, 1978). Manure use is discussed in Chapter 4 of this document.

A significant portion of wheat and rice straw is burned in the field, especially in areas where a crop is planted immediately after wheat harvest, i.e., where double cropping is practiced. This burning creates smoke, which is both a hazard to traffic on adjoining roads and an air pollutant. The primary reason for field burning of grass seed is to control blind feed diseases (*Gleotinia tremulenta*) and ergot (*Claviceps purpurea*) (Hardison, 1960). Although residue losses due to burning do not affect yields adversely or decrease the occurrence of plant diseases in the subsequent growing season (Graves and Beadley, 1988), the air pollution problem has resulted in legislation limiting acreage burned annually.

Costs and Benefits

Corn, grain sorghum, and wheat residues often require mowing to ease future operations. Mowing cost was estimated at \$5 to \$6/a. (\$12 to \$13 ha^{-1}) (Moore et al., 1988). If these residues were to be removed for use as animal feed or for sale as either energy or paper mill raw material, they would have to be raked, baled, and hauled, costing an additional \$40/t (\$44/Mg) or more (Moore et al., 1988). As Epstein et al. (1978) stated, "Because collection and transportation of residues are costly and energy consuming, it seems unlikely that it will be feasible to transport crop residues over long distances to provide raw materials for energy conversion plants." The cost of removing crop residues in subsequent farming operations is site specific but normally exceeds by far the value obtainable by such means. The aforementioned benefits of residue retention strengthen the case against removal.

Potential for Reduction

One approach to minimizing residue is that of increasing HI. For example, since about 1950, wheat breeders have increased HI from the range of 0.23 to 0.30 to that of 0.35 to 0.40 (Mengel and Kirkby, 1987). Yet although modern grain crop cultivars tend to yield more grain than older cultivars do, residue quantity has not declined under good production management.

In fact, it is unlikely that the quantity of residue remaining in the field can be decreased much more, for there is a direct connection between residue quantity and plant leaf area. A large functioning leaf area is needed to maximize interception of solar radiation for conversion to plant product through photosynthesis.

Potential for Increased Utilization

In 1980, a CAST report discussed the writings of Robert Rodale and Sir Albert Howard, whose philosophy seems "to equate soil fertility maintenance with the return to the soil of organic matter produced by plant growth on the soil" (Council for Agricultural Science and Technology, 1980). The CAST report noted that plant nutrients are removed when crops are removed from land. Removal of both the grain and the crop residue accelerates decline in the soil supply of plant nutrients. If crop residues are used away from the field in which they are produced, costs of replacing nutrients to that field must be considered if long-term production is to be sustained.

Most aspects of crop residue management were summarized in an American Society of Agronomy publication (Oschwald, 1978), which makes a number of points relevant to this report:

> Some regions in the United States produce an abundance of crop residues, far in excess of that required to control erosion and maintain good soil tilth. . . . Crop residues are highly essential in most areas for protecting agricultural soils from erosion and loss of plant nutrients.
>
> Where crop residues are produced in excessive amounts, they tend to accumulate because of slow rates of decomposition. . . . Excess residues are often burned. . . . Certainly, much of this residue could be removed for utilization as livestock feed, fuel, fiber, chemicals, and the production of single cell protein.
>
> . . . we must think in terms of *partial* removal of residues rather than *total* removal . . . for erosion control and maintenance of soil productivity. (Oschwald, 1978)

Appropriate residue quantity left on the field depends on many factors, including the needs for erosion prevention and for soil tilth maintenance. Compliance with new regulations plays an increasingly important role, and economic considerations enter in.

Epstein et al. (1978) reviewed alternative uses of crop residues not needed for erosion control and productivity maintenance. Such uses included fuel (used directly and converted to synthetic fuels) and livestock feed. A third use gaining some application but not discussed by Epstein et al. (1978) is as a bulking agent in sludge and manure *composting*, or the microbial breakdown of organic wastes into stable, unobjectionable, and safe, humuslike materials spreadable on land. There is, of course, the age-old use of straw and chopped corn stalks as bedding for livestock.

As has been pointed out, costs involved in collection and transportation from field to point of use likely will continue to be the use limiting factor for crop residue. Epstein et al. (1978) concluded that the use of crop residues for fuels would, in the foreseeable future, occur on-farm or at most within a few miles of it, at a small synthetic fuel facility.

A National Research Council report (1983) addresses the issue of crop residue use for animal feed. Because lignin in the residues inhibits digestion, they tend to have limited nutritional value and therefore must be treated to enhance digestibility. Evolving technological innovations and economic conditions well may lead to increased and more effective use of crop residues as animal feed.

Forages

Forage crop production viewed on the national scale is exceedingly diverse. At one extreme is the semi-arid range, in which forage production from several acres is required to support one animal. At the other extreme is an intensively managed silage area, in which several tons of forage are produced annually from one acre to support several animals.

United States forage area has increased during the past four decades. In 1987, 42.5% of the land used for agriculture was in pasture and range (U.S. Department of Agriculture, 1989). Additionally, hay was produced on some 60 million a. (24 million ha) (U.S. Department of Agriculture, 1987a). The Conservation Reserve Program, recently expanded, provides incentives for increasing acreage for forage used for livestock.

There are four general kinds of forage production:

1. **Range**. Land is kept in permanent cover. Grazing and hay removal are managed to sustain species composition and dry-matter production of the *sward*, or grassy surface of land. Production per acre depends on rainfall and time of occurrence.
2. **Humid pasture**. Land may produce perennial grasses, perennial legumes, annual grasses, and some combinations of these groups. Productivity depends on grazing management factors (animal number per unit area and length of grazing period), species, rainfall, soil productive capacity, and landscape position.
3. **Hay**. Forage plant growth must be removed by means of mowing, conditioning, drying, and packaging. Haying may be used on both range and humid pastures in combination with grazing but often is limited by insufficient rainfall on the rangeland. Crops such as alfalfa, perennial grasses, and selected summer annuals, e.g., ryegrass or pearl millet, also may be managed strictly for use as hay.
4. **Silage**. Crops such as corn, oats, and sudan sorghum crosses may be harvested while green and preserved in silos for feeding to livestock after fermentation. Some crops are harvested as green chop for direct feeding to livestock. Both silage and green chop are harvested with forage choppers, which flail the plants into appropriately sized particles.

Because the harvesting of forage crops for hay and silage removes aboveground forage from fields, little waste remains there. Forage grasses and legumes may regrow. Because it sets the stage for future production, this regrowth usually is not waste, but rather a necessary part of the forage program. Once in contact with the soil, wastes on pasture and range distributed over the field are subject to microbial attack. Effective pasture management usually requires clipping to control weeds and seed head formation. This clipped material is returned to the soil surface and recycled into the soil.

Hay and silage usually are fed in closed lots, where livestock waste a certain amount. Quantity wasted depends on forage quality and on feed management strategy. Waste forage usually becomes mixed with manure (See Chapters 4 through 7).

In summary, forage production leaves little waste material for additional management. Material left behind is organic and recycled quickly into the soil. Such recycling is a requirement for continued ecological health of the production system.

Fruits and Vegetables

Wastes associated with fruit and vegetable production fall into two categories:

1. nonharvested plant parts and
2. materials used in producing and harvesting crops, e.g., plastic mulches, harvest containers, pesticide containers, and excess fuels and pesticides.

In the United States, fruit and vegetable production practices depend on crop and geographic area. With woody crops such as tree fruits and grapes, wood from annual pruning is generated and generally burned on-site. Specialty markets exist for certain production residues, e.g., in the Napa Valley of California, where approximately 6,500 lb of grape stems are removed annually for barbecuing (Marois, pers. com., 1990). When the orchard or the vineyard has ceased useful production, wood from all trees or vines usually is burned on-site. For most tree crops, this occurs approximately once every 30 yr. Some woods such as black walnut, cherry, and pecan may be marketed separately.

With nonwoody fruit and vegetable crops, nonharvested portions traditionally have been plowed back into the soil. This ancient agricultural practice returns valuable nutrients to the soil, improves soil structure, and removes the overwintering foodbase and shelter for plant pathogens and certain insect pests. Because crop residues are returned to the soil, few wastes are associated with fruit and vegetable production. But the disadvantages of conventional tillage include relatively high energy-inputs and exacerbated soil erosion. Therefore, interest in reduced tillage systems, e.g., conservation, minimum, and no-till, is growing. A great deal of evidence indicates that conservation tillage systems increase the occurrence and the severity of many plant diseases, decrease those of some, and have no effect on others (Sumner et al., 1981; Thresh, 1982).

Use of polyethylene mulches for weed control and for cover during soil fumigation is increasing steadily and to the former end decreases the amount of chemical herbicides released into the environment. More polyethylene mulches are used in Florida, where they are applied to approximately 100,000 a. annually, than in any other state (Hockmuth, pers. com., 1990). South Carolina and Texas are estimated to use polyethylene mulches on approximately 4,000 a. each; the New England states combined, on approximately 1,000 a. In California, polyethylene mulches are used on approximately 12,000 a., primarily for fumigation of strawberry beds, and are used with increasing frequency in the fumigation of citrus and grape replantings (Marois, pers. com., 1990). As the use of polyethylene films increases, so does the need for viable disposal methods.

Fresh-market fruits and vegetables do not produce the type or amount of wastes associated with processed foods. Percentages of vegetables sold at fresh market and processed appear in Table 3.5. When economic factors, labor shortages, or crop damage makes harvest infeasible, the entire crop may become agricultural waste. In 1986, 1.7% (22,600 a., or 9,200 ha) of potatoes was unharvested (Table 3.5, footnote). Approximately 5.0% of the peach crop and 10.0% of the apricot, cherry, pomegranate, and prune crops also were unharvested (Table 3.6). Certain crops such as apricot must be immediately sold at fresh market or processed, or they will be lost to postharvest disease.

Table 3.5. **Acreage and production of selected vegetable crops in the United States (adapted from U.S. Department of Agriculture, 1988)**

	Acres for harvest	Production (1,000 t)	Fresh market (%)	Processed (%)
All vegetables	2,413,800	23,194	47.3	52.7
Asparagus	99,840	12	59.1	40.9
Bean, snap	220,310	676	—	100.0
Broccoli	120,200	571	75.3	24.7
Carrot	93,120	1,277	70.1	29.9
Cauliflower	66,100	369	80.4	19.6
Celery[a]	33,940	892	—	—
Corn, sweet	620,520	3,637	21.1	78.8
Cucumber[b]	109,630	635	—	100.0
Honeydew melon	28,600	241	100.0	—
Lettuce	221,320	2,905	100.0	—
Onion[c]	123,720	2,250	—	—
Pea, green	290,300	440	—	—
Potato	1,304,700[d]	19,289	30.3[e]	53.3[e]
Sweet potato	43,300	603	—	—
Tomato	386,200	9,184	17.3	82.07

[a]Mostly fresh market, includes processing.

[b]For processing only; figures for fresh market unavailable.

[c]Market percentage unavailable.

[d]22,600 of these acres unharvested.

[e]7.1% seed, 1.1% livestock feed, 7.8% shrinkage and loss, 0.4% other; 1986 figures.

Table 3.6. **Production of selected fruit crops in the United States, 1987 (U.S. Department of Agriculture, 1988)**

Crop	Total production (t)	Utilized (%)
Apple	5,271,300	97.1
Apricot	115,000	91.1
Cherry	390,050	90.1
Citrus[a]		
Grapefruit	4,797,188	
Orange	7,516,781	
Other Citrus	1,708,800	
Cranberry	16,605	100.0
Grape	5,264,000	100.0
Nectarine	191,000	100.0
Olive	67,500	99.2
Peach	1,214,400	94.7
Pear	940,250	99.9
Papaya	33,500	100.0
Plum	245,000	100.0
Pomegranate	18,500	89.2
Prune	53,500	92.0

[a]Net contents of boxes differ. Figures estimated from average box weights.

4 Poultry-Farm Waste Management and Utilization

Summary

Integration and regional concentration of poultry production not only has decreased the cost and improved the efficiency of poultry production, but also has concentrated the generation of manure and litter, poultry mortality, and processing and hatchery wastes in production areas. Statistical information about animal based agricultural enterprises appears in Table 4.1. Almost all solid by-products of poultry processing plants currently are converted into animal by-product meals by the U.S. rendering industry. But most farm mortalities and hatchery wastes are being disposed of by methods other than recycling or rendering. Most of these wastes could be recycled as nutrient resources for animal food or crops.

One viable alternative use of a number of poultry wastes is land application. Poultry manure could supply a considerable portion of the nation's N, P, and K requirements for agronomic, horticultural, and/or silvicultural crops.

Over the last 20 yr, studies have provided increasing evidence that, if handled and used properly, composted poultry manures and litters also can be recycled as safe feedstuffs for ruminants. A technology being assessed for its efficacy in handling several types of poultry wastes is extrusion processing, now widely used in the manufacture of various aquaculture feeds. Fluidized bed drying/cooking and flash dehydrating can be used to dry and to cook poultry by-product wastes into feed ingredients. Feathers are generated are being processed to produce nearly pure keratin protein feather meal. Anaerobically fermented feathers offer a new process for feather waste treatment that might provide a valuable new feedstuff-protein for monogastric animals.

An alternative use of poultry manure is in the production of biogas (methane and carbon dioxide) by means of anaerobic bacteria. The methane produced can be captured and used as an energy source.

Numerous areas of research remain vital, including land application of poultry waste; processing and utilization of mortalities and hatchery wastes; composting of manures, litters, and mortalities; biogas recovery and utilization from manures; cost effectiveness and market impact of new waste-management techniques; and benefits of new policies regulating discharge of waste into the environment.

Introduction

The commercial poultry industry in the United States produces a number of different nutrient-rich by-products, some of which various technologies are being used to recycle or otherwise to treat in an environmentally sound manner. Industrial growth coupled with heightened environmental awareness underscores the need for new technologies to ensure that management of industry by-products prevents future pollution problems. The following section outlines the industry's growth and organization, its primary by-products, the technologies currently used in managing them, and the areas of by-product research needing further exploration.

Background

During the last 30 years, U.S. poultry meat production, gross poultry income, and per capita poultry-meat consumption have increased rapidly (Table 4.2) while the number of layers and the per capita consumption of eggs have declined. These declines almost have been offset by genetic and environmental improvements in the productivity of egg production stocks and by human population increases (Table 4.2). Consequently, the number of eggs produced per year has remained fairly constant over the last three decades, i.e., between 428 and 455 million dozen shell eggs and egg products consumed.

Changes in poultry production have resulted from improved genetic performance of the poultry stocks used, that is, in improved growth rate, feed efficiency, and egg production rates. In addition, improved nutrition, feeding systems, disease control, and automated poultry housing also have contributed to improved production. Improvements in the automation of processing and further processing along with the overall integration of the poultry industries and direct brand-name marketing of poultry products have contributed to decreased production costs and increased efficiency of poultry, meat, and egg production. Consequently, the consumption of poultry meat surpassed that of pork in 1984 and that of beef in 1987. Broiler consumption alone equaled beef consumption during 1990 (U.S. Department of Agriculture, 1994b).

Along with increases in production and consumption have come extensive integration and concentration of poultry producing organizations in certain regions of the United States. For example, in 1990, greater than 73% of the nation's 260 million turkeys were grown by integrated organizations in seven states (North Carolina, Minnesota, California, Arkansas, Missouri, Virginia, and Indiana). Similarly, 10 states (Arkansas, Georgia, Alabama, North Carolina, Mississippi, Texas, Maryland, Delaware, California, and Virginia) produced approximately 68% of the 5.5 billion broilers grown. Ten states (California, Indiana, Pennsylvania, Georgia, Ohio, Arkansas, Texas, North Carolina, Florida, and Alabama) produced 62% of the nation's approximately 270 million hens and pullets (U.S. Department of Agriculture, 1991). One state, Indiana, produces the majority of the nation's 25 million commercial ducks. A number of states are very involved in more than one of these types of poultry production.

Integration and regional concentration of poultry production not only decreased the cost and improved the efficiency of poultry production, but also correspondingly concentrated the production of manure and litter, poultry mortality, and processing and hatchery wastes in production areas (for an elaboration of concentrations within states, see Safley et al., 1990). In the form of organic fertilizers, some of these wastes are returned to the land; others are processed

Table 4.1. Animal industry (U.S. Department of Commerce, 1994)

Animals	Number of animals
Poultry	
Chickens, 3 months or older, not laying	351,310,317
Pullets, younger than 3 months	49,843,029
Turkeys	87,612,131
Broilers	888,617,180
Total	1,377,382,657
Cattle and calves	
Beef cows	32,545,976
Milk cows	9,491,818
Heifers and heifer calves	26,201,587
Steers	27,896,444
Total	96,135,825
Hogs and pigs	
Hogs and pigs	50,641,504
Hogs and pigs used for breeding	6,921,614
Total	57,563,118
Other livestock	
Sheep and lambs	10,770,391
Horses and ponies	2,049,522
Goats	2,515,541
Mink	1,767,777
Rabbits	789,406
Total	17,892,637

into animal feedstuffs. Still others (primarily mortality and hatchery wastes) are disposed of by burial in pits or in landfills. Traditionally, manures and litters have been applied to crop and pasture lands. But because of growing environmental concern, alternative uses have been investigated and adopted to facilitate use and recycling of these wastes.

Litters and manures are valuable resources as either soil amendment or fertilizer. Their application can return to the soil a large portion of the nutrients required for the growth of many agronomic, horticultural, and silvicultural crops. Manures furnish humus-forming materials that improve the *tilth*, or physical condition, of both light and heavy soils. Manures also improve soil aeration and water-holding capacity, which in turn generate activity of soil microorganisms (Hileman, 1967). Preparation of most soils for seeding also can be eased by addition of litters and/or manures.

During the past decade, the high volume of poultry and other animal wastes in some intensive animal production areas has caused concern about the potential for contamination of surface and ground waters in surrounding communities. The public wants reassurance that water supplies are safe and that the aesthetics and real estate values of surrounding properties are not being threatened by intensive production operations. Thus, even though great amounts of these wastes can be used for land application in the production area, environmentally and aesthetically acceptable methods must be developed for the conversion of poultry by-products into products acceptable for transportation and for use in areas outside the immediate production area.

Waste Types, Amounts, and Composition

Manure, housing litter, hatchery waste, processing waste, normal mortality, and wastewater are the main by-products of the U.S. poultry production in-

Table 4.2. United States poultry production, income, and consumption, by commodity group during 1950, 1970, 1980, and 1990 (adapted from M. R. Weimar and S. Cromer, 1990)

Year	Commodity group	No. animals marketed (million)	Gross farm income (million $)	Annual per capita consumption
1960	Broilers	1,795	1,014	23.5 lb
	Nonbroiler chickens	181	140	4.4 lb
	Turkeys	84	371	6.3 lb
	Egg layers	320[a]	1,842	320.7 eggs
Total			3,367	
1970	Broilers	2,987	1,475	37.0 lb
	Nonbroiler chickens	233	108	3.6 lb
	Turkeys	116	498	8.1 lb
	Egg layers	317[a]	2,210	310.6 eggs
Total			4,291	
1980	Broilers	3,963	4,303	47.4 lb
	Nonbroiler chickens	238	133	3.1 lb
	Turkeys	165	1,272	10.5 lb
	Egg layers	296[a]	3,267	272.4 eggs
Total			8,975	
1990[b]	Broilers	5,800	9,000	69.8 lb
	Nonbroiler chickens	200	175	2.0 lb
	Turkeys	285	2,500	15.2 lb
	Egg layers	269[a]	3,900	235.0 eggs
Total			15,575	

[a]Number of layers on hand January 1 of year indicated.

[b]Estimate based on 1989 statistics.

dustry. Estimates of total poultry manure and litter generated in 1992 in the United States appear in Table 4.3.

The approximately 54 million t of fresh manure produced during 1993 contained approximately 706,000 t N, 505,000 t P_2O_5, and 315,000 t K_2O (Barker and Zublena, 1995). Chemical composition data for various poultry manures appear in Tables 4.4 through 4.8. Most poultry manure is available for collection because almost all poultry is raised in confinement housing. Nutrients, however, are lost from collected manure by biodegradation prior to and during handling and storage; after land application, by volatilization, leaching, and denitrification; and due to lack of soil mineralization. Nutrients actually available for utilization by plants are nearly 30% (211,000 t) of the N, 65% (329,000 t) of the P_2O_5, and 67% (212,000 t) of the K_2O occurring in fresh manure (Barker and Zublena, 1995). Thus, poultry manure could supply a considerable portion of the nation's N, P, and K requirements for agronomic, pasture, and/or silvicultural crops.

As mentioned, most of the nation's broilers, turkeys, and ducks are raised in confinement housing. Forestry by-products, e.g., wood shavings and sawdust, generally are used as litter materials for confined poultry. Peanut hulls, rice hulls, and straw also can be used but generally are less absorbent than wood by-products. Recently, the development of methods to use some form of processed, i.e., shredded or pelleted, newspaper and/or cardboard as poultry litter material has received considerable attention.

Typically, several flocks are raised on the same base litter before it is removed completely and replaced. Such litters are richer in nutrients than fresh manure and often are used as organic fertilizers on cropland or as feedstuffs for ruminants. In certain areas, however, because of the concentration of poultry and swine, the combined amounts of these litters and manures exceed the agricultural crop nutrient demands (Barker and Zublena, 1995).

In North Carolina, for example, enough animal manure was produced during 1993 to supply 20% of the N and 66% of the P requirements for almost all principal row crops and pasture (Zublena and Barker, 1995). In fact, their assessment was that 100% or more of the agronomic crop and pasture requirements for N in 3 counties and for P_2O_5 in 18 could have been

Table 4.4. Average nutrient composition of broiler manures in pounds per ton (Zublena et al., 1993b)

Manure type	Total N[a]	Ammonium NH_4–N	Phosphorus P_2O_5	Potassium K_2O
Fresh (no litter)	26	10	17	11
Broiler house litter[b]	72	11	78	46
Roaster house litter[b]	73	12	75	45
Breeder house litter[b]	31	7	54	31
Stockpiled litter[c]	36	8	80	34

[a]N = nitrogen.

[b]Annual manure and litter accumulation; typical litter base is sawdust, wood shavings, or peanut hulls.

[c]Annual house accumulation removed to uncovered stockpile to be spread within six months.

Table 4.3. Estimated annual production of dry and/or liquid poultry manure in the United States during 1992[a]

		Collectable		
Commodity group	Total fresh manure (thousand t)	Scrape manure and litter (thousand t)	Liquid manure slurry (million gal.)	Lagoon liquid (million gal.)
Broiler breeders	6,861	1,741	—[b]	—
Commercial broilers	28,729	7,014	—	—
Turkey breeders	929	253	—	—
Commercial turkeys	5,748	1,700	—	—
Layer breeders	481	122	—	—
Commercial layers	11,225	4,715	340	1,226
Commercial ducks	184	98	—	—
Totals	54,157	15,643	340	1,226

[a]Estimates from the Department of Poultry Science, the Department of Soil Science, and the Department of Biological and Agricultural Engineering, North Carolina State University. Based on USDA annual numbers of animals produced andquantities produced per animal.

[b]Not applicable.

supplied by the animal and poultry manure from the species produced in these counties. Because similar situations exist around the nation, locally concentrated production areas have led to growing concerns about environmental pollution.

The U.S. poultry industry also must dispose of a great amount of solid waste from its processing plants and hatcheries and from normal on-farm mortality. Almost all solid by-products of poultry processing plants (approximately 25% of live weight, or approximately 153 million lb/wk or 4 million t/yr) currently are converted into animal by-product meals by the U.S. rendering industry. Most farm mortalities and hatchery wastes, however, are not rendered and currently are being disposed of by methods that are not always environmentally sound and that do not retrieve any of the integrator's or the producer's investment loss.

The weight of waste generated from normal farm mortalities also is substantial. A typical flock of 10,000 turkeys averaging 0.5% mortality per week (wk) produces 4.6 t of carcasses during an 18-wk growing period, and a flock of 10,000 broilers grown to 49 d of age averaging 0.1% daily mortality produces 0.5 t of carcasses. Therefore, the 6.5 billion commercial broilers, 300 million commercial turkeys, 270 million layers and pullets, 20 million ducks, 58 million broiler breeders, 3.85 million layer breeders, and 5.8 million turkey breeders raised in the United States in 1993 (U.S. Department of Agriculture, 1994b) produced approximately 638,000 t of poultry mortality waste to be disposed of that year. And most farm mortalities and hatchery wastes continue to be disposed of by methods other than recycling or rendering.

The production of so much poultry also results in the production of more than 200,000 t of broiler, turkey, and commercial layer hatchery waste. Dissolved air flotation (DAF) sludge from water treatment systems in poultry processing plants accounts for a considerable amount of poultry industry waste, which will be discussed later in this chapter. Approximately 840,000 t of poultry mortalities and hatchery wastes were generated by the U.S. poultry industry during 1993 and were disposed of primarily by means of on-farm burial in pits, incineration, or burial in landfills. Yet most of these wastes could have been

Table 4.5. Average nutrient composition of layer manures (Zublena et al., 1993b)

Manure type	Total N[a]	Ammonium NH_4–N	Phosphorus P_2O_5	Potassium K_2O
		lb/t		
Fresh (no litter)	26	6	22	11
Undercage scraped[b]	28	14	31	20
Highrise stored[c]	38	18	56	30
		lb/1,000 gal.		
Liquid slurry[d]	62	42	59	37
Anaerobic lagoon sludge	26	8	92	13
		lb/acre-in.		
Anaerobic lagoon liquid[e]	179	154	46	266

[a]N = nitrogen.

[b]Manure collected within two days.

[c]Annual manure accumulation on unpaved surface.

[d]Six-12 months' accumulation of manure, excess water usage, storage-surface rainfall surplus; omits fresh water for flushing.

[e]Liquid slurry plus lagoon surface rainfall surplus; omits fresh water for flushing.

Table 4.6. Average nutrient composition of turkey manures, in pounds per ton (Zublena et al., 1993b)

Manure type	Total N[a]	Ammonium NH_4–N	Phosphorus P_2O_5	Potassium K_2O
Fresh (no litter)	27	8	25	12
Brooder house litter[b]	45	9	52	32
Grower house litter[c]	57	16	72	40
Stockpiled litter[d]	36	8	72	33

[a]N = nitrogen.

[b]Based on cleanout after each flock.

[c]Based on annual cleanout after full production.

[d]Based on annual house accumulation removed to uncovered stockpile to be spread within six months.

Table 4.7. Average nutrient composition of duck manures, in pounds per ton (Zublena et al., 1993b)

Manure type	Total N[a]	Ammonium NH_4–N	Phosphorus P_2O_5	Potassium K_2O
Fresh (no litter)	28	5	23	17
House litter[b]	19	3	17	14
Stockpiled litter[c]	24	5	42	22

[a]N = nitrogen.

[b]Annual manure and litter accumulation; typical litter base is wood shavings.

[c]Annual house accumulation removed to uncovered stockpile to be spread within six months.

recycled as nutrient resources for animal feeds or crops.

Currently, the main methods for the disposal of farm mortalities, hatchery wastes, and other poultry by-products include landfill and on-farm burial, in disposal pits, incineration, and rendering. These methods, with the exception of rendering, although environmentally acceptable when conducted properly, could threaten environmental quality as a result of mismanagement, especially in nutrient-sensitive watersheds, areas near wells and water supplies, areas with surface water runoff, or areas with high water tables. Additionally, most disposal practices allow for no resource recovery for reuse. New landfill costs and landfill use prohibitions regarding animal mortality disposal are increasing so rapidly that landfilling already has become an infeasible disposal method for farm animal mortalities, hatchery wastes, and DAF sludges in some states and is expected to become so in most other states.

The continued pursuit of alternative methods emphasizing environmental safety and resource utilization of poultry by-products is necessary. Several alternative recycling methods are being studied at private and public institutions and at integrated companies throughout the nation and around the world. These methods include land application, direct feeding of poultry litter to ruminants, rendering, composting, fermentation and acid preservation, extrusion rendering, and anaerobic digestion-biogas production and utilization. Work under way, as well as a number of potential research programs for poultry waste management, will be discussed next.

Animal By-Product Feedstuffs

One viable alternative use of a number of poultry wastes is recovery for use as feedstuffs for livestock, pets, and other animals. Substantial research has been conducted, primarily in the southeastern United States over the past 30 yr, on the direct feeding of nonprocessed, ensilaged, deep stacked, or composted broiler and turkey litter to beef cattle, dairy cattle, and sheep. These studies have resulted in gener-

Table 4.8. Average secondary and micronutrient content of poultry manures (Zublena et al., 1993b)

	Ca[a]	Mg	S	Na	Fe	Mn	B	Mo	Zn	Cu
Manure type					lb/t					
Layer										
Undercage scraped	43.0	6.1	7.1	4.5	0.52	0.27	0.050	0.00390	0.32	0.036
Highrise stored	86.0	6.0	8.8	5.0	1.8	0.52	0.046	0.00038	0.37	0.043
Broiler litter										
Broiler house	41.0	8.0	15.0	13.0	1.3	0.67	0.054	0.00085	0.63	0.45
Roaster house	43.0	8.5	14.0	13.0	1.6	0.74	0.049	0.00082	0.68	0.51
Breeder house	94.0	6.8	8.5	8.6	1.3	0.57	0.035	0.00048	0.52	0.21
Stockpiled	54.0	8.0	12.0	6.2	1.5	0.59	0.041	0.00069	0.55	0.27
Turkey litter										
Brooder house	28.0	5.7	7.6	5.9	1.4	0.52	0.047	0.00081	0.46	0.36
Grower house	42.0	7.0	10.0	8.4	1.3	0.65	0.048	0.00092	0.64	0.51
Stockpiled	42.0	6.8	9.5	6.4	1.5	0.62	0.047	0.00095	0.56	0.34
Duck litter										
Duck house	22.0	2.7	3.1	2.8	0.98	0.31	0.021	0.00040	0.26	0.056
Stockpiled	27.0	4.4	5.6	8.8	1.2	0.47	0.030	0.00030	0.47	0.050
Manure type					lb/1,000 gal.					
Layer										
Liquid slurry	35.0	6.8	8.2	5.3	2.9	0.42	0.040	0.018	0.43	0.080
Lagoon sludge	35.0	7.2	12.0	4.2	2.2	2.3	0.082	0.014	0.80	0.14
Manure type					lb/acre-in.					
Layer										
Lagoon liquid	25.0	7.4	52.0	51.0	2.0	0.24	0.37	0.020	0.70	0.19

[a]Legend: Ca = calcium; Mg = magnesium; S = sulfur; Na = sodium; Fe = iron; Mn = manganese; B = boron; Mo = molybdenum; Zn = zinc; Cu = copper.

ally safe, effective systems of recovering, processing, and refeeding such wastes as sources of energy, protein, and minerals in animal production (Arave et al., 1985; Arave et al., 1988; Arave et al., 1990a, 1990b; Battacharya and Fontenot, 1965, 1966; Battacharya and Taylor, 1975; Bragg et al., 1975; Caswell et al., 1978; Cross and Jenny, 1976; Cullinson et al., 1976; deGraft-Hanson et al., 1990; Evans et al., 1978a, 1978b; Flipot et al., 1975; Fontenot, 1988; Gerken, 1990; Goering and Smith, 1977; Harmon et al., 1974, 1975a, 1975b; Kwak et al., 1989; McCaskey and Martin, 1988; McCaskey et al., 1987; McCaskey et al., 1988a, 1988b; McCaskey et al., 1989; Schuler et al., 1979; Smith and Wheeler, 1979; Stephenson et al., 1989, 1990; Sutton et al., 1990; Vandepopuliere et al., 1974; Vandepopuliere et al., 1977; Vuori and Nasi, 1977; Webb and Fontenot, 1975). Bhattacharya and Taylor (1975) reviewed early literature on the nutritional value of poultry waste as a feedstuff for livestock and poultry, the identification of possible agents in poultry manure and litter that may constitute human and animal health hazards, and the effect of processing method on the safety of such wastes.

The only animal health problem shown to be related to the feeding of poultry waste has been copper (Cu) toxicity in sheep that were fed broiler litter with high Cu levels (Fontenot and Webb, 1975). Beef cattle that were fed broiler litter with high Cu levels and with supplementary Cu levels of 200 ppm during the winter evidenced no deleterious effects (Fontenot, 1988; Webb et al., 1980).

Several researchers have studied the use of composted poultry litters as feedstuffs for poultry (Naber, 1985; Naber et al., 1990). Others have studied the feeding of hatchery wastes to poultry (Tadtiyanant et al., 1993; Vandepopuliere et al., 1974, Vandepopuliere et al., 1977; Wisman, 1964, 1965). The majority of wastes (including feathers, heads, feet, bones, blood, and entrails) from poultry processing plants are being recovered and processed by the rendering industry into meat, bone, blood, and feather meals for use as feed ingredients for various types of agricultural livestock, pets, poultry, and other animals.

Direct Land Application of Poultry Manures and Litters

Land application of animal manures for agricultural production is one of the oldest agricultural practices (Figure 4.1). Recently, however, the potential of these wastes for contaminating surface and ground waters has led to numerous studies of the chemical content of various manures and litters used as crop fertilizers, in relation to application rate and timing. Heavy or excessive applications of manure to farm fields can be a nonpoint source of water pollution (Cronce et al., 1990). Because each field, which has unique soil, geologic, and hydrologic characteristics determining the potential for surface or ground water contamination, requires a unique combination of soil and crop management practices, a number of federal and state agencies are becoming increasingly active in overseeing and aiding farmers on manure management methods.

Cronce et al. (1990) thoroughly reviewed the literature on existing manure application models, manure and agricultural nutrient management guides, soil data references, and runoff and recharge values for various rock types, as well as on research data and concepts from various state and federal research groups. Their review (Cronce et al., 1990) was used to produce a reference document (*Pennsylvania Manure Management Manual*), which should be useful for professionals working with farmers and community leaders to develop nutrient management plans to protect water resources. Manure application becomes a source for ground water pollution only when the rate of manure application is excessive or when time or place of application is inappropriate, e.g., on frozen ground or near wells. High rates of manure application occur most frequently when the objective is manure disposal instead of efficient fertilizer use. One example of this relation is the watershed draining toward the Chesapeake Bay, a region of intensive dairy farming and in which cow feed imports have resulted in excess manure production.

Figure 4.1. Land application of poultry litter by spreader truck. Photograph courtesy of Thomas A. Carter, Department of Poultry Science, North Carolina State University, Raleigh.

Poultry manures can be used as a nutrient source for corn, small grains, fruits, vegetables (Ritter, 1990), and many other crops. Mulford et al. (1987, see Ritter, 1990) studied the use of several different application methods using broiler litter for winter wheat production. They found that 8,180 kg of poultry manure broadcast at spring greenup provided a yield of 5,880 kg/ha in comparison with 5,994 kg/ha of winter wheat grain from the application of 134 kg/ha of N fertilizer in February and at Feekes growth stage 6 (Large, 1954). Other manure application methods (preplant and late fall) yielded considerably less.

Carr (1988) studied the effect of broiler litter treated with ferrous sulfate on nonirrigated-corn yields with conventional and no-till cultivation. Ferrous sulfate had been used to control the release of ammonia in poultry houses. He concluded that the highest fertilization rates produced the most corn, regardless of N source. The average 3-yr yield of corn receiving 179 kg/ha ammonium nitrate fertilizer and that receiving ferrous sulphate-treated litter at 179 kg/ha N equivalent were not significantly different in either the conventional till or the no-till system. In both, litter treated crops yielded more than non-treated crops did.

When manures are used, method and rate of application are crucial. Sims (1987) studied the effects of different application rates of poultry manure and of ammonium nitrate on corn yields, crop N uptake, and soil N. Fertilizer and broiler litter were applied to irrigated no-till and conventional till corn, at 0, 84, 168, and 252 kg potentially available N/ha, on Evesboro sandy loam soil. Yields, plant N concentrations, and N uptakes generally were equivalent in 2 of the 3 yr studied, but the broiler litter fields produced yields significantly smaller than those from organic fertilizer in the third year. Conventional till fields had significantly increased grain yields than no-till fields did in 2 of 3 yr.

Ritter (1990) compared how the yields of irrigated corn under conventional till and under no-till cultivation responded to commercial fertilizer, regular broiler litter, and composted broiler litter. Rye cover versus no cover crop also was used as a treatment variable in this study, which was conducted on a Matawan loamy sand soil. Fifty-six kg/ha N, as 30% liquid N, was applied at planting time; 67 kg/ha was sidedressed when the corn was 15 cm high, and 112 kg/ha when it was 60 cm high. Poultry manure was applied at the rate of 280 kg/ha N to the plots 2 wk before planting. The rye crop was killed with Roundup on April 19, and planting was done on May 19. Yields for the manure and for the commercial fertilizer treatments were the same.

The question for farmers applying manures to croplands is how much of the organic N in the manure is mineralized and made available to the crop. If the mineralization rate is underestimated and too much manure applied, the N will not be used and some nitrate may leach into the ground water (Ritter, 1990). If the rate is overestimated and too little manure applied, N deficiency may occur and decreased yield result. Manure N-mineralization rate estimates differ considerably from laboratory study to study. Temperature, time since incorporation, and soil moisture level seem to affect this rate. The Virginia Cooperative Extension Service suggests using an N mineralization rate of 50% for the year in which it is applied, and respective rates of 12, 5, and 2% for the three subsequent years (Collins, 1990b; see Ritter, 1990).

Nitrogen is lost from manure by volatilization of ammonia. Sims et al. (1989) suggest in the *Delaware Poultry Manure Management Guidelines* that ammonia losses due to volatilization should be estimated at 20, 40, 60, and 80% for manures incorporated into the soil 0 to 2, 2 to 4, 4 to 7, and > 7 d after application. Other investigators have suggested somewhat different volatilization rates (Ritter, 1990). North Carolina State University and the North Carolina Department of Agriculture use a nutrient availability coefficient combining a mineralization rate of 50% with varying volatilization losses based on waste source, waste management system, and land application method (Table 4.9). Ammonia losses for subsurface injection are estimated at 5% for liquid manure slurry and for lagoon liquid. When waste is applied and incorporated into the soil within 48 hr, ammonia losses are estimated at 10% for dry litter, 25% for semisolid manure and liquid manure slurry, and 15% for lagoon liquid. When manure is surface applied and unincorporated, ammonia losses are estimated at 75% for dry litter and semisolid manure, 65% for liquid manure slurry, and 50% for lagoon liquid. Ammonia losses for irrigation of liquid manure slurry and lagoon liquid are estimated, respectively, at 40 and 25% with cultivation and at 75 and 50% without. This unique system allows the producer to estimate easily, by means of one conversion number, the plant available nutrients in animal waste products (Barker and Zublena, 1995).

Overapplication of manures to certain soil types, in areas with high water-tables, and during excessive rainfall can result in leaching of nitrate into the ground water (Bachman, 1984; Liebhart et al., 1979; Ritter, 1990; Ritter and Chirnside, 1984; Robertson, 1977). Although poultry manures are an excellent source of nutrients and can be incorporated into many fertilizer programs, farmers using manures must practice sound soil fertility management to prevent nutrient imbalances, associated animal health risks, and surface and ground water contamination. Nutrient requirements of the crop must be matched with nutrients available in manure or litter. Value and appropriate use of poultry manure depend on its source and nutrient composition and also on its handling and management costs. Zublena et al. (1993b) provided an excellent discussion, guide, and worksheet for the proper land application of poultry manure.

Composting of Manures and Litters

Composting is a natural biological process whereby bacteria, actinomycetes, and fungi break down organic materials (Figures 4.2 and 4.3). It has become the most acceptable method of handling large quantities of animal and/or plant wastes and can be affected by a number of key factors including (1) nutrient balance, (2) moisture content, (3) temperature, and (4) aeration (de Bartoldi et al., 1984; Hansen and Mancl, 1988; Willson, et al., 1980). Nutrient balance is determined primarily according to the C:N ratio in the material to be composted. For optimal protein formation and growth, the organisms involved in the breakdown of the compost material require approximately 30 parts C to 1 part N. Composting is successful, however, when organic materials consist of a mixture of 20 to 40 parts C to 1 part N. As the ratio exceeds 30, composting slows. As it falls below 25, excess N is converted to ammonia, which is released into the air, resulting in undesirable odors. Phosphorus and trace elements also are needed by most compost microbes but normally are present at adequate levels in compost mixes with a proper C:N ratio.

Moisture content should be approximately 60% when materials to be composted are mixed (Hansen and Mancl, 1988). Depending on the components of the mixture, initial moisture content of the material can range from 50 to 70%. Aeration is inhibited when moisture exceeds 60% such that the aerobic process breaks down and the compost mass tends to become anaerobic and putrid. As the moisture content falls below 50%, bacterial action and decomposition rate decrease rapidly. As a general rule, a mixture of organic waste containing 50% moisture feels damp but not soggy (Hansen and Mancl, 1988).

Beginning at ambient temperature, the temperature in the properly prepared compost pile rises, for approximately 2 d, to 120 to 160°F (49 to 71°C). The temperature results from the breakdown of the organic matter by bacteria, actinomycetes, and fungi. Hundreds of types of microorganisms aid decomposition. These organisms are classified in three major

Table 4.9. First-year nitrogen availability coefficients for different poultry manures (Zublena et al., 1993b)

	P_2O_5 and K_2O availability coefficients			
Manure type	Injection[a]	Soil incorporation[b]	Broadcast[c]	Irrigation[d]
All types	0.8	0.8	0.7	0.7
	N availability coefficient			
Manure type	Injection[a]	Soil incorporation[b]	Broadcast[c]	Irrigation[d]
All poultry litters[e]	—	0.6	0.5	—
Layers (no litter)	—	0.6	0.4	—
Layer anaerobic lagoon sludge	0.6	0.6	0.4	0.4
Layer anaerobic liquid slurry	0.8	0.7	0.4	0.3
Layer liquid lagoon	0.9	0.8	0.5	0.5

[a]Surface-spread manure uncovered for one month or longer.

[b]Manure injected directly into soil and covered immediately.

[c]Surface-spread manure plowed or disked into soil within two days.

[d]Sprinkler-irrigated liquid uncovered for one month or longer.

[e]Includes in-house and stockpiled litters.

Figure 4.2. Poultry mortality composting building showing the initial compost bin prior to movement of the compost into the secondary bin. Photograph courtesy of Gerald B. Havenstein, Department of Poultry Science, North Carolina State University, Raleigh.

Figure 4.3. Movement of turkey compost (litter and mortalities) from the primary to the secondary bin. Photograph courtesy of Gerald B. Havenstein, Department of Poultry Science, North Carolina State University, Raleigh.

categories, namely, *psychrophilic* (< 40°F, or < 5°C), *mesophilic* (40 to 100°F, or 5 to 38°C), and *thermophilic* (100 to 150°F, or 38 to 65°C), based on the temperature range most favorable for their reproduction, metabolism, and growth.

As microorganisms decompose organic matter, heat is generated and temperature rises. As temperature rises, different types of microorganisms dominate as conditions become most favorable for their growth and reproduction. Composting is a dynamic process whereby one group of organisms dies and is succeeded by another until the next incremental change in nutrition and temperature occurs. The rate at which aerobic composting, a function of O_2 availability, occurs can be measured in terms of the rate of production of carbon dioxide (CO_2). The maximum rate occurs in the range from 85 to 130°F (29 to 54°C). As the temperature exceeds 130°F (54°C), composting rate drops until it becomes almost negligible, at about 160°F (71°C). Most weed seeds and microbes perish during composting. Three days at 131°F (55°C) killed parasites, as well as fecal and plant pathogens (Hansen and Mancl, 1988).

Composting of manure and litter has several positive effects on the value of these by-products as soil amendments. Biodegradation reduces mass and volume and facilitates improvement of soil physical characteristics (Hileman, 1967). Composting also greatly decreases the odor normally associated with manure and decreases or eliminates the ability of flies and other insects to reproduce in it. Once the initial organic breakdown has occurred, the compost provides nutrients that slowly are released for plant use (Henry and White, 1990). Hoitink and Fahy (1986) and Logsdon (1989) also showed that composting inhibits soilborne pathogens. A rapid composting process for cage layer manure also greatly decreased the level of coliforms, yeasts, and molds and eliminated *Salmonella*, *Campylobacter*, *Yersinia*, and *Listeria* (deGraft-Hanson et al., 1990). Furthermore, the composting process either destroyed the aflatoxins present or converted them to other substances.

Over the last 20 yr, numerous investigators of the composting of poultry manures and litters have examined various aspects of the process (Table 4.10). These studies have provided increasing evidence that, if handled and used properly, composted poultry manures and litters can be recycled as safe feedstuffs for ruminant animal production.

Composted poultry manures and litters also have considerable potential for direct land application as fertilizers and soil conditioners and as container potting substrates for horticultural products (Bugbee and Frink, 1989; Verdonck, 1983; Warren and Safley, 1990). Composted manures and litters overcome the objectionable odors and possess the disease transfer potential of fresh manures and provide nonobjectionable products that can be transported easily and used for many purposes.

Flush-Lagoon Systems for Manure Handling of Layer Wastes

The movement away from small, dispersed egg-production units to large, concentrated units and the desire to eliminate problems such as flies, odors, and rodents present at high levels in the pits of many poultry houses led in some warm areas of the United States to the development of egg production houses in which manure can be flushed into an open anaerobic lagoon. Lagoons became quite popular as convenient and economical waste management systems and originally were viewed as total disposal systems. Now they are viewed, especially in moisture-excess regions, as useful only in the pretreatment phase of the overall waste-management plan (Barker et al., 1988). Because of both high volumes of manure added and excess rainfall, lagoons often fill to capacity within one to three seasons. Once filling occurs, excess liquid is applied according to BMPs onto field crops, grasslands, or wood lots to prevent the lagoon from overflowing into the surrounding watershed.

Lagoons act as biological digesters using both aerobic and anaerobic bacteria. The former live primarily near the surface and are active only in the presence of O_2. Anaerobic bacteria predominate at greater depths and are active only in the absence of O_2. A third intermediate set of microorganisms, *facultative bacteria*, are active under both aerobic and anaerobic conditions. Barker et al. (1988) point out that lagoon systems have several advantages and disadvantages in the treatment of poultry waste (Table 4.11). Barker et al. (1988), Barth (1985), and Barth et al. (1990) thoroughly discuss the design, operation, and management of lagoon systems for egg production complexes.

Biogas Production from Poultry Manure

An alternative use for poultry manure is in the microbiological process by which organic wastes are degraded and converted to biogas (methane and car-

Table 4.10. Research from 1971 to 1990 on composting poultry manures and litters

Topic	References
General studies	Bragg et al., 1975; Caswell et al., 1978; deGraft-Hanson et al., 1990; Henry and White, 1990; Naber, 1988; Naber et al., 1990; Schuler et al., 1979; Sutton et al., 1990; Sweeten, 1988; Vuori and Nasi, 1977
Factors affecting rate and efficiency of the composting process	Galler and Davey, 1971; Hansen et al., 1988, 1989; Hansen and Mancl, 1988; Henry and White, 1990; Pos et al., 1971
Use of various carbon sources in the composting process	Naber et al., 1990
Physical and chemical composition of poultry litter compost	Henry and White, 1990; Sutton et al., 1990
Effects of various litter management practices on nutrient quality of compost produced	Henry and White, 1990; McCaskey et al., 1989; McCaskey and Martin, 1988; Stephenson et al., 1990; Sutton et al., 1990
Microbiological safety of compost produced	Bhattacharya and Taylor, 1975; deGraft-Hansen et al., 1990; McCaskey et al., 1988
Nutrient quality of compost produced for use as feed for	
broilers	Bragg et al., 1975; Naber et al., 1990
layers	Naber, 1985
ruminants	Kwak et al., 1989; Stephenson et al., 1990

Table 4.11. Advantages and disadvantages of poultry-waste treatment in lagoon systems (Barker et al., 1988)

Advantages	Disadvantages
Waste treatment ease and maintenance	Appreciable loss of manure fertilizer nitrogen value
Storage and disposal flexibility allowing opportune field spreading	Offensive odors if improperly designed and managed
Less land required for the total treatment system	Frequent sludge removal required if lagoon is undersized
Liquid able to be recycled for flushing wastes from the building pits and can be applied to land by simple irrigation	Ground water protection considerations
Low labor requirements and operating costs	High energy costs if mechanical aeration used

bon dioxide) by means of anaerobic bacteria. The biogas produced can be captured and used as an alternative energy source. The technology for the production of biogas from organic wastes has been understood for many decades and has been practiced in many parts of the world (Hobson et al., 1981; Shih, 1988a; Stafford et al., 1980).

Most studies of methane biogas production have used systems that operate conventionally in a stirred tank at ambient temperatures (generally from 50 to 80°F, or 10 to 27°C) or mesophilic temperatures (90 to 120°F, or 32 to 49°C) (Converse et al., 1981; Jantrania and White, 1985; Morrison et al., 1981; Safley et al., 1985). Such systems operate at fairly slow bioreaction rates and require both long retention times and large reactor-volumes. Because of size requirements, construction and maintenance costs for mesophilic digesters have been prohibitively high for most poultry producers (Thorton, 1978). Mesophilic systems also require high volumes of water for operation and discharge wastewaters that must be tested and treated for pathogen elimination (Shih, 1988a).

In recent years, Shih and coworkers (Huang et al., 1981, 1982; Shih, 1987a, 1987b; Shih, 1988a, 1988b; Steinsberger and Shih, 1984) reported on the development and the operation of an alternative low-cost thermophilic (50°C) anaerobic digestion system. This system used a portion of biogas produced to heat the digester so that it operates at a temperature where thermophilic anaerobic bacteria thrive. Because digestion at such temperatures occurs at a much higher rate than in mesophilic systems, the thermophilic system can be smaller and less expensive to treat the same amount of waste. Energy input was greater for the thermophilic system, but because of high energy-output, its net biogas production available for other uses was only 11% less (74% versus 85%) than that of the mesophilic system (Steinsberger and Shih, 1987). When digestion occurred at an elevated temperature, digester medium viscosity was low, and mixing resulted from the bubbles of biogas, or *effervescence*, produced. An energy intensive mixer is not required for this system, and because mass transfer of the low-viscosity digesting medium is easy, the digestion process adapts readily to a digester with a simple plug-flow design (Shih, 1988a). Thermophilic temperatures have been shown to destroy most if not all pathogens; thus, the digester generates a pathogen free by-product (Lee and Shih, 1988; Shih, 1988b).

In research by Steinsberger et al. (1987), by-product sludge from the digester was recovered and dried by means of biogas energy produced. The sludge contained 10% protein, 3% N, 4% P, 3% K, and 18% Ca. The P was shown to be 90% bioavailable when fed to growing chicks, but the availability of the other components was untested. Dried sludge resulting from the thermophilic process was shown to be a valuable feed supplement when used as < 10% of a growing chick diet.

Composting of Poultry Mortality

Over the past few years, considerable progress has been made toward the development of alternative methods of poultry mortality disposal. Traditional methods have involved landfill burial and/or underground decomposition pits (Wineland, 1990). One viable alternative gaining widespread use in several parts of the U.S. industry is the composting of poultry mortality with manure and a natural C source such as sawdust, wood shavings, or wheat straw. A number of studies have involved the development and the use of composters for handling mortality from large broiler, layer, and turkey flocks (Ackerman and Richard, 1990; Blevins, 1990; Donald and Blake, 1990a; Donald et al., 1990; Dutton, 1990; Murphy, 1988, 1990; Murphy and Handwerker, 1988). Properly conducted composting now has been shown to be a very acceptable poultry mortality disposal method and has been adopted as an officially approved method of dead bird disposal in several states, including North Carolina, Maryland, Delaware, Arkansas, and Alabama. Other states are considering adoption. Composter location and construction and composting requirements are thoroughly discussed by Murphy (1990) and by Donald and Blake (1990a).

Centralized Poultry Mortality Collection Sites for Rendering Pickup

Another means of handling poultry mortality is through a centralized collection site equipped with ramp, dumpster, and vehicle cleanup station, to which growers can bring dead animals. Daily hauling from the central site to a rendering plant is done by a local contracted hauler. This method eliminates landfill disposal, requires capital investment, and generates a small return from the sale of the renderable poultry carcasses. The capital investment cost of sites in North Carolina have ranged from $6,000 to $60,000, depending on the costs of land, construction, utilities, labor, maintenance, and daily carcass capacity requirements. The price that renderers are willing to pay for carcasses depends on the market price of rendered animal-by-product meals. Renderers pay approximately \$0.005/lb for poultry and approximately \$0.015 to \$0.025/lb for hog carcasses. Investment, maintenance, and transportation costs of a central pickup site cannot be defrayed by the sale of poultry carcasses alone, but sites accepting both swine and poultry can be profitable (Parsons and Ferket, 1991).

The primary concern of central collection sites pertains to biosecurity and to the potential for dispersal of pathogens from farm to farm by personnel and vehicles. Notwithstanding, the closing of landfills to poultry in North Carolina has forced the development of such collection sites over the past few years, and they seem to be succeeding (Carter, pers. com., 1995).

Fermentation and Chemical Preservation of Poultry Mortality

Biosecurity is a major concern among poultry producers disposing of mortalities in landfills or at central collection sites. This concern has resulted in several studies aimed at developing low-cost methods by which to preserve carcasses at the growing farm, where they can be collected on a scheduled basis and transported to a processing facility. Although disease spread during transportation remains a concern, carcass preservation by fermentation at the farm has the potential both to ensure supplies of poultry carcasses for processing into animal feedstuffs and to eliminate risks of contamination by bacterial pathogens (Cai et al., 1994; Dobbins, 1988; Malone, 1990; Murphy, 1988; Murphy et al., 1990) while permitting low-cost scheduled collections. Some viral pathogens may not be inactivated by the fermentation process (Urlings et al., 1993).

The different preservation procedures being investigated include various mineral acid solutions (Malone, 1990), alkaline solutions (Shafer and Carey, 1994), proteolytic yeast culture (Malone, 1990), and lactic acid fermentation (Dobbins, 1988; Murphy, 1990). Preservation of punctured or ground broiler carcasses by "pickling" in a weak mineral acid, such as 3.4% sulfuric acid, was successful as long as the temperature was maintained below 16°C, but the carcasses spoiled at higher temperatures (Malone, 1990). Another problem with mineral acid preservation is that the residual solution has an EPA classification as a hazardous waste. Use of alkaline solutions (2 M KOH or NaOH) turned broiler carcasses to a liquid state in 10 days without putrification and offensive odor (Shafer and Carey, 1994). However, the corrosive and highly reactive nature of alkaline solutions is a major concern for on-farm preservation of carcasses. In comparison to mineral acid and alkaline preservation, lactic acid fermentation is a more cost effective and practical means to preserve on-farm mortality for eventual recycling into feedstuffs. The silage produced exhibits long-term chemical and microbial stability at a low pH (4.0 to 5.0). This poultry silage is produced by grinding the carcasses into < 5 cm diameter particles, mixing in at least 6% (w/w) invert carbohydrate, inoculation with any lactic-acid producing bacteria (including those normally produced in the birds intestinal tract), and placing it into a sealed, but vented container to maintain anaerobic conditions. The invert carbohydrate sources used successfully for ensilage of poultry carcasses include, but are not limited to, lactose, sucrose, whey, whey permeate, condensed brewer's solubles, and corn meal (Cai et al., 1994, 1995; Conner et al., 1991; Murphy et al., 1990; Murphy and Silbert, 1990; Parsons and Ferket, 1991).

Endogenous gut microflora within the carcasses are primarily responsible for the fermentation process. Supplemental bacteria cultures may induce an accelerated rate of fermentation as well as provide a margin of safety under diverse fermentation conditions (Parsons and Ferket, 1991). Extensive optimization studies have been conducted (Cai et al., 1994; Conner et al., 1991; Murphy et al., 1990; Murphy and Silbert, 1990). Cautions have been issued against its use due to the potential for the growth of pathogens (Urlings et al., 1993a, 1993b). However, most pathogenic microorganisms (e.g., coliforms, *Salmonella spp.*, *Clostridia*) associated with carcasses are effectively inactivated during the fermentation process (Cai et al., 1994; Dobbins, 1988; Murphy and Silbert, 1990; Parsons and Ferket, 1991; Shotts et al., 1984). Due to the secondary growth of yeasts and molds, Hassan and Heath (1987) observed a rise in pH, which led to their recommendation that an antimycotic agent be added to achieve and maintain a low pH during fermentation and storage.

The commercial use of lactic acid fermentation to preserve poultry mortalities on the farm is in a preliminary stage of development. To date, most experience has been with layer and broiler mortalities. Malone (1992) reported that mortalities at a 65,000 cage layer unit were ground to one-half inch pieces and placed with dried whey (6% w/w), *Lactobacillus* silage inoculant, and water (two parts water with one part whey). The mixture was then augured to a vented stainless steel tank truck and allowed to ferment anaerobically to a silage at ambient temperature. Approximately 13 t of this silage were delivered monthly to a rendering plant. Blake and Donald (1992) reported that ground broiler mortalities mixed with whey (10% w/w) or ground corn (20% w/w) could produce a silage with pH < 5.0 in fiberglass tanks. Several studies involving the fermentation of turkey and swine mortalities have been conducted at North Carolina State University in cooperation with integrated companies (Ferket, pers. com., 1995) As a result of this research, Ferket and coworkers have developed an automated system that grinds, proportions carbohydrates and inoculants, and transfers the mixture to fermentation storage tanks (Stikeleather et al., 1995).

Extrusion Processing of Poultry Wastes for the Production of Animal Feedstuffs

Another technology being assessed for its efficacy in handling several types of poultry wastes is extrusion processing (Ferket, 1991). In use for more than 50 yr in the production of a variety of foodstuffs for humans, extrusion now is the primary means of processing pet foods (Hauck, 1990). It also is used widely in the manufacture of various feeds with integrity and buoyancy properties in water needed for aquaculture. In the rendering of animal by-products, extrusion technology requires 20% of the capital investment that conventional rendering does and can be tailored to process low to moderate volumes of material. The extruder uses friction heat, pressure, and attrition to cook, to sterilize, to dehydrate, and to stabilize by-products such that they become high quality feed-ingredients.

Research indicates that extrusion is a viable alternative means of converting animal by-products into nutritious and healthful feed ingredients for ruminants, swine, poultry, and several aquaculture species. Ferket (1991) provided an excellent discussion of the extrusion process, the types of extruders available, and how extrusion technology may be developed in the near future for the conversion of such by-products into useful feedstuffs for recycling back to the animal industries. Quality feed-products have been manufactured from extruded whole chicken mortalities (Blake et al., 1990; Hauge et al., 1987; Tadtiyant et al., 1993), poultry offal and feathers (Blake et al., 1990; Haque et al., 1991; Tadtiyant et al., 1993; Vandepopuliere, 1990), hatchery waste (Miller, 1984; Tadtiyant et al., 1993), ground whole hens (Haque et al., 1991), and inedible eggs and egg whites (Fronning and Berquist, 1990). The rigors and the heat involved in extrusion have been shown to destroy all bacteria, protozoa, mold spores, and viruses present in the raw materials (Reynolds, 1990). Researchers have concluded that feed ingredients subjected to extrusion are sterile and pose no risk of infectious agent transmission as long as recontamination does not occur.

Studies are under way on the use of extruders to manufacture feed ingredients and/or complete diets for ruminants, swine, poultry, and several aquaculture species from poultry mortalities, processing wastes, and hatchery wastes. Ferket (1991) explained what the extrusion process is, which extruders are available, and how extrusion technology soon may be developed for the conversion of by-products into useful feedstuffs. For example, Yoong et al. (1993) coextruded ground poultry carcasses and dried waste sweet potatoes (1:3 w/w) mixture to produce a high quality feed ingredient containing 10% crude protein and 3,624 Kcal metabolizable energy/kg. Subsequent turkey and broiler feeding trials using feed containing this extruded sweet potato product confirm its high feeding value relative to corn (Ferket et al., 1995). Coextruded sweet potato-poultry silage may be of greater value as a feedstuff for fish and crayfish, but this has not been fully tested.

Fluidized Bed Drying and Flash Dehydrating of Poultry By-Product Wastes

Because of their high moisture content and perishability, most by-product wastes cannot be used easily. Ferket and Jones (1992) described two new technologies—fluidized bed drying/cooking and flash dehydrating—that can be used to dry, cook, sterilize, and convert poultry by-product wastes into feed ingredient products. In the fluidized bed process, raw waste material is dried and cooked while suspended on a bed of hot-air jets. The solid material assumes the characteristics of a fluid; hence the term *fluidized bed*. This technology is being investigated for the processing of numerous poultry waste materials, e.g., fresh or semidried manures; poultry litter; composted materials such as litters, manures, dead birds, egg shells, inedible eggs, DAF sludge, offal, feathers, ground meat, carcasses, and bone scraps. Flash dehydration units are suited to the processing of offal and hatchery wastes at a rapid rate and can serve as conditioners/dehydrators for subsequent extrusion processing.

Poultry Feather Utilization

Feathers are generated in huge quantities: approximately 1.05 million t of raw feathers were produced in the United States during 1991 (Reiser, pers. com., 1991). These are being processed to produce approximately 300,000 t of nearly pure keratin protein feather meal (Moran et al., 1966), which currently is used as a protein supplement for animals. Before such use, feathers are steam pressure cooked or chemically treated to improve digestibility (Williams et al., 1990). These treatments, which destroy certain amino acids and require a significant amount of energy (Papadopoulos, 1985; Papadopoulos et al., 1985, 1986; Steiner et al., 1983), until recently seemed the only means of processing and using feathers.

Shih, Williams, and their coworkers recently reported the discovery and the isolation of a feather degrading bacterium, *Bacillus licheniformis,* which they named *PWD-1* (Williams and Shih, 1989; Williams et al., 1990, 1991). The PWD-1 strain was isolated from a thermophilic poultry manure digester and now can be grown with feathers as the sole substrate supplying C, N, and sulfur (Williams et al., 1990). Incubation of the bacterial culture with feathers as the substrate resulted in almost complete degradation of the keratin protein to peptides and to free amino acids after 7 to 10 d at 122°F (50°C). Glutamic acid, alanine, and the branched chain amino acids—isoleucine, leucine, and valine—consistently were shown to be the most abundantly produced free amino acids. Thus, application of PWD-1 to feathers may be a major breakthrough for improving the processing of feathers into more digestible animal-feedstuff. This degradation process is energy efficient and produces a digestible protein, feather lysate, as well as free amino acids (Williams et al., 1991).

Williams et al. (1991) initially studied feathers constituting 25% of feed protein in the diet and compared those treated under anaerobic or aerobic conditions with untreated feathers. Test diets were fed to broiler chicks from days 6 through 21 posthatch. The anaerobically fermented product, feather lysate, resulted in growth rates 6.9 and 9.3% higher than those of the aerobically fermented and nontreated feather products, respectively, and in growth rates 6.4% lower than those of a standard corn-soybean ration. In a subsequent experiment, 3 or 6% of feather lysate, untreated feathers, and commercial feather meal were fed to chicks on a basal diet containing 10% protein. Growth responses were compared with those of chicks fed soybean based diets varying from 10 to 19% protein. Feather-lysate supplemented with lysine, methionine, and histidine resulted in a growth rate identical to that obtained from soybean meal supplementation. The growth rate of chicks on commercial feather meal was significantly lower than that of those on feather lysate. Thus, anaerobically fermented feathers offer a new process for feather waste treatment that might provide a valuable new feedstuff-protein for monogastric animals. Approximately 20% of commercial feather meal currently is used in poultry diets; the balance is used in ruminant diets (Reiser, pers. com., 1991). Anaerobic fermentation of feathers by enzyme treatment could increase the value of feathers as a protein source for poultry and swine diets.

Subsequent work with *Bacillus licheniformis* resulted in the identification of the enzyme keratinase. This enzyme hydrolyses feathers and has been purified and characterized (Lin et al., 1992). Keratinase, when used as an additive to commercial feather meal improved the digestibility of feather meal from 77% to 90% (Lee et al., 1991). The discovery of keratinase provides an alternative method for upgrading the utilization and improving the digestibility of feather meal.

Potential Areas of Research on Poultry Wastes

Land Application

As discussed, much already is known about the land application of poultry manure, litter, hatchery and processing waste, and wastewater. But a number of areas require exploration:

1. Nutrient availability coefficients of various organic waste materials, as determined by means of laboratory tests and field experiments, with consideration given the effects of time and application method on different crop and soil types.
2. Residual nutrient availability of poultry by-product materials and their effects on soil physical and chemical properties, as determined by means of long-term field experiments.
3. Effectiveness of poultry waste handling systems in producing uniform value-added products, and the design of equipment for making uniform waste product applications.
4. Land application requirements for composted

poultry mortality. Measurements of nutrient cycling and of movement of nutrients into surface and ground water as influenced by the loading rate of poultry wastes.

5. Response of agronomic and horticultural crops and tree species to poultry waste applications, as response relates to site loading, topography, and climate.
6. Impacts of multiple poultry waste applications on agronomic and forest surface and ground waters, nutrient extraction, concentration points, insects and diseases, toxic buildup, leaching, surface water contamination, and crop and wood qualities.
7. Engineering of poultry waste application systems suitable for varying densities of tree species, age classes, and forest topographies.
8. Engineering development of the most easily and reliably calibrated waste application equipment, especially for low quantity land application levels.
9. Refinement of poultry waste application systems for silviculture, including harvesting systems, coppice hardwood rotations, and thinning systems.
10. Impacts of poultry manure and litter application on weed growth, and weed control recommendations after such applications.
11. Evaluations of wood quality for pulp, paper, and reconstituted wood products from waste-irrigated versus nonirrigated forests.
12. Impacts on wildlife of poultry waste applications, including changes in disease vectors, habitat development, wildlife usage, and animal characteristics such as growth rate, rack development, reproduction, and health.

Processing and Utilization of Mortalities and Hatchery Wastes

The United States has an established multimillion-dollar animal-by-product rendering industry. But farm mortality rendering is underutilized because collection, handling, and transport systems make rendering economically unfeasible. As discussed, a number of promising research projects on fermentation preservation and extrusion processing are under way. These seem to hold great promise for making the recycling of poultry mortalities economically viable. Such studies should be supplemented with expanded research in numerous areas:

1. Biological security risks and the economic evaluation of centralized collection sites for poultry mortalities.
2. Development and evaluation of the nutritive value of new animal-by-product meals from fermentation preserved, dried, and/or extruded poultry mortalities.
3. Evaluation of pathogen contamination risk, e.g., with *Salmonella*, *Campylobacter*, *Escherichia coli*, and *Listeria*, of poultry mortality by-product meals.
4. Evaluation of the economics of both dry and wet extrusion technologies as methods for rendering poultry mortalities and hatchery wastes.
5. Optimization of the chemical and/or the fermentation preservation methods of poultry mortality disposal, e.g., types and levels of microbial inoculations, temperatures, carbohydrate sources, pH values, and pathogen evaluations.
6. Development of equipment for large-scale mortality-preservation systems, e.g., its requirements, process automation procedures, and material handling.
7. Identification and investigation of the use of unique indigenous and genetically engineered bacteria in the preservation of poultry mortalities.
8. Development of biotechnology procedures for isolating and characterizing the enzymes produced by specific types of bacteria breaking down waste products. Exploration of the feasibility of laboratory produced enzymes to facilitate poultry mortality degradation.
9. Development of fluidized bed drying and flash dehydration for the production of new animal-nutrient sources from poultry mortality, offal, and hatchery wastes.

Composting Manures, Litters, and Mortalities

Composting has become an acceptable method of handling great quantities of animal and/or plant wastes. But most procedures require either multiple stages or mechanical turning to aerate composting materials and are both labor intensive and expensive. If composting is to be used extensively in resource recovery and poultry waste degradation, studies of how to speed composting and to decrease its expense are needed. Specifically, the following should be explored:

1. Develop low-cost innovative methods to reduce the time, labor, energy, and expense required by composting.

2. Explore poultry manure and poultry mortality composting methods using the most economical C source, e.g., woodshavings, sawdust, straw, corn or sorghum stover, newspaper, cardboard, or leaves.
3. Develop value-added products using composted materials, e.g., slow-release fertilizers, mushroom compost, container potting mixtures, urban landscape replacement soils, pelleted manures, and composts aesthetically acceptable and easily transported and spread with fertilizer equipment (Anderson, 1990).
4. Explore the use of composted manures and litters in silage mixtures and the development of value-added feed cubes for ruminants.
5. Explore methods for aerating compost mixtures that would eliminate the turning requirements.

Other Compost Related Research

Several issues related to the use of composted products need to be addressed, such as what their effects on human health are and what the environmental fate of their components will be. Future research efforts should include the following:

1. Studies of the viabilities of insect eggs, cysts, spores, bacteria, viral particles, and weed seeds after composting. Such studies should include the organisms present in the material before composting, which have the potential to affect the plants and/or the animals (including humans) subsequently exposed to composted materials.
2. Studies of the insects and the rodents that may be attracted to the compost and might serve as vectors in disease transmission; studies should determine the impact, if any, of such vectors and any means of diminishing and/or eliminating it.
3. Studies of the effect of incomplete and/or nonuniformly composting on the value of composted products.
4. Studies of the effect of dead bird and/or manure particle size on composting dynamics and product quality.
5. Development of methods for the rapid determination of C, N, P, and moisture in waste products to be composted and in the composted products themselves to allow rapid quality control measures for products.
6. Develop methods for measuring the quality and maturity of composted products.

Anaerobic Digestion of Manures—Biogas Recovery and Utilization

The conversion of poultry manure into biogas has been the subject of intense research for more than two decades, and much has been learned about how manure has been used as an energy and a nutrient source. Because of unfavorable economics, producers have not been motivated to adopt these new practices. Hence, new efficient techniques for the production of biogas from manure are needed.

The following research activities are relevant to enhanced anaerobic digestion:

1. Development of anaerobic digesters compatible with the nonhomogeneity of animal wastes.
2. Development of anaerobic digesters compatible with hydraulic-flush manure removal systems.
3. Development of anaerobic digesters with minimal capital and operational cost requirements.
4. Development of anaerobic digesters operable at fluctuating ambient temperatures.
5. Development of lagoon design criteria compatible with low-cost covers and optimal anaerobic digestion.
6. Determination and quantification of biogas production rates from lagoons and thermophilic digesters with different sources and combinations of wastes.
7. Development and optimization of biogas utilization techniques.

Other Waste Research

Organic compounds such as poultry manure, poultry litter, processing offal, poultry mortality, and hatchery waste have many potential uses, some of which have been conceptualized but minimally researched for their application and economic feasibility. Several potential waste research areas follow:

1. Development of microorganisms and enzymes for degrading and liberating amino acids from keratinaceous and other hard to utilize waste materials so that they can be used as feed-stuffs or fertilizers.
2. Investigation of microwave technologies to burn manure and litter at very high temperatures to produce pure carbon-black, oil, and basic minerals. Success with this method recently has been reported in Europe (van der Sluis, 1990).
3. Development of methods for improving the digestibility of common feedstuffs so as to lower C,

N, and P levels in animal manures, e.g., by using phytase enzymes to improve the digestibility of plant P.

Economic Research Related to Waste Management and Utilization

A pressing need exists for the economic evaluation of all facets of poultry waste management and use, e.g., the economics both of waste treatment systems and of organic material transport as fertilizer or as feedstuff source. The cost effectiveness and the market impact of new technologies should be evaluated, as should the costs and the benefits of new policies regulating discharge of waste into the environment.

Little or no economic impact research is under way to evaluate emerging technologies for processing and recycling of poultry mortalities. Nor has an economic analysis been made of the potential values of composted manures and litters for various agronomic, horticultural, or silvicultural uses. Such research is needed because it could affect the development stages of these emerging technologies. Economists should analyze the cost-benefit ratios of alternative waste handling procedures. Analyses also should include new products with the potential to compete with existing products. Ultimately, economic analysis will guide the adoption of new waste management techniques.

Social and Political Aspects of Waste Management and Utilization

Waste management technology has important social implications, and social scientists can contribute in two important ways to facilitate the acceptance and the application of new waste-management technologies (Hoban, 1991). Specifically, they can foster in-depth understanding of how producers make business decisions about whether to use a new technology. Second, they can provide insight into how the nonfarm public will perceive the benefits and the risks of these new technologies.

Research should be initiated to evaluate the social implications of poultry waste utilization. Insufficient attention has been paid the social and the political implications of waste management and these implications are integral to future waste technology development and transfer. Surveys aimed at characterizing how groups perceive and accept new technologies are needed. Surveys of producers and of other industry representatives such as the one recently completed by Hoban et al. (1995) can help identify incentives for, as well as barriers to, the adoption of these technologies and thereby help society develop, implement, and evaluate technology transfer strategies. Nonfarm surveys should be aimed at understanding the knowledge and perceptions that different groups have about waste management techniques, so as to provide the basis for planning and implementing public education and participation programs. Social scientists also can assist with the evaluation of public policies affecting the willingness and the ability of producers to implement new technologies.

5 Swine Production-Waste Management and Utilization

Summary

The trend in the last two decades has been toward enclosed swine production facilities. Recommended BMPs for hog drylot production include installing and maintaining an effective soil-erosion control program and using the stocking rates, rotations, and controlled forage uses that curtail runoff, waste accumulation, and disease.

Approximately 150,000 t of hog mortality must be managed in the United States annually. Traditional options have been landfilling, burying, incinerating, and rendering. Rendering recycles carcasses into safe and useful by-products such as meat and bone meal, animal fat, and plastics. Raw hog waste combined with corn and fermented under anaerobic conditions undergoes a lactic acid fermentation, which quickly kills large reservoirs of fecal coliform bacteria as well as pathogenic *Salmonella* and dysentery organisms added to the mixture. The product of the fermentation process can be used as a component of animal rations and thereby assist in the management of animal manure.

Land application is another important alternative use of swine production manure. A continuing challenge is to develop and to implement land application systems meeting surface water, ground water, and air quality standards and not risking food chain contamination or soil quality degradation.

Constructed wetlands, built on upland sites, simulate natural wetlands in which physical, chemical, and biological processes remove contaminants from wastewater. These systems recently have begun to be considered for treatment of relatively concentrated livestock wastewaters. Concern exists, however, about vegetation tolerance to high wastewater-ammonia levels, seasonal temperature effects on nutrient removal efficiencies, and long-term accumulation of nutrients and settled biomass within cells.

The quality of air surrounding animal housing and waste management systems is of increasing interest to the public and policymakers. Unlike water quality problems, which can be assessed in terms of finite standards, however, air quality problems for the most part are subjective. High initial costs have limited the number of biogas digesters in the United States.

Introduction

See Table 4.1 for a presentation of the U.S. on-farm inventory of hogs and pigs, as reported in the 1992 Census of Agriculture (U.S. Department of Commerce, 1994). Ten leading hog-producing states accounted for 81% of U.S. on-farm inventory (Table 5.1). Production was heaviest in the Midwest, with rapid growth in North Carolina. Table 5.2 indicates farm sizes in the largest hog-producing states. In Iowa, small farms with fewer than 100 head accounted for

23% of total hog farms in the state but for only 2% of the state's total animal inventory. In Missouri, 54% of all hog farms had fewer than 100 head, accounting for 7% of total inventory; in North Carolina, 60% had fewer than 100 head, accounting for 1%. At the other extreme, 4% of all South Dakota hog farms had more than 1,000 head, accounting for 34% of total inventory; in Illinois, 10% had more than 1,000 head, accounting for 52%, in North Carolina, 19% had more than 1,000 head, accounting for 92%.

During the past decade, the pork industry has both consolidated and grown. Increasing numbers of animals are being raised in housing facilities, in which factors such as environmental condition can be controlled more closely than in outdoor dirt lot (drylot) or pasture production. The industry is becoming increasingly integrated, particularly in North Carolina; this evolution, however, is quite different from that of the poultry industry. Contract pork production usually entails supply of feed and/or animals, not complete vertical integration.

Table 5.1. Leading U.S. hog producing states in 1992 (U.S. Department of Commerce, 1994)

State	Farms	Inventory	Percent of total
U.S.	191,347	57,563,118	—
Iowa	31,790	14,153,158	25
Illinois	13,433	5,641,115	10
North Carolina	4,311	5,100,979	9
Indiana	11,987	4,618,663	8
Minnesota	13,125	4,668,590	8
Nebraska	10,826	4,187,389	7
Missouri	11,894	2,908,509	5
Ohio	9,392	1,957,945	3
South Dakota	6,710	1,978,195	3
Kansas	5,684	1,584,048	3
Total	119,152	46,798,591	81

Table 5.2. Hog farm size distribution within states (U.S. Department of Commerce, 1994)

	Farms with < 100 head		Farms with > 1,000 head	
State	Farms	Inventory	Farms	Inventory
Iowa	7,293	308,245	3,326	5,890,376
Illinois	5,018	114,979	1,388	2,915,791
Indiana	5,093	173,273	1,072	2,417,604
Minnesota	4,907	169,839	994	1,966,740
Nebraska	3,504	144,216	728	1,875,239
Missouri	6,468	204,153	528	1,176,620
North Carolina	2,605	60,042	802	4,708,465
Ohio	1,138	151,961	388	692,666
South Dakota	2,410	97,759	258	665,886
Kansas	2,954	93,897	273	767,273
Total	102,665	2,608,659	11,896	28,933,549

Manure and Nutrients Generated

Table 5.3 illustrates concentrations and amounts of the various parameters of fresh manure (American Society of Agricultural Engineers, 1993a). These values should be recognized as contingent on a wide range of factors such as animal diet, age, usage, productivity, management, and location. For design purposes, whenever site specific data are available or actual sample analyses can be performed, such information should be considered in lieu of averages. According to these average unit values, the U.S. hog and pig industry annually generates approximately 100 million t fresh manure (12.3 million t dry solids). Total primary nutrients in fresh manure amount to 593,000 t N, 454,000 t phosphate (P_2O_5), and 416,000 t potassium (K_2O).

Production Systems

Pastures and Drylots

Some hog enterprises consist of drylots or pastures in which manure cannot be collected easily for reuse. To the soil system, unconfined animals contribute manure nutrients that can be assimilated or otherwise used naturally by vegetation if animal densities

Table 5.3. Hog fresh manure production and characteristics (American Society of Agricultural Engineers, 1993a)

Parameter	Concentration ppm, wet basis	Mass, lb/day per 1,000 lb animal mass
Manure	—	82
Total solids	103,000	8.5
Volatile solids	83,000	6.8
Total Kjeldahl nitrogen as N	6,100	0.50
Ammonia-ammonium nitrogen as N	3,800	0.31
Total phosphorus as P_2O_5	4,700	0.38
Potassium as K_2O	4,400	0.36
Calcium	4,000	0.33
Magnesium	900	0.074
Sulfur	910	0.074
Manganese	21	0.0018
Copper	15	0.0012
Zinc	62	0.0051

are low enough to maintain pasture conditions. Hogs are fed on the ground so that labor and land can substitute for capital. A survey conducted by the National Pork Producers Council in 1974 indicated that approximately 50% of the hogs in the United States were produced on pasture or on drylot (Overcash et al., 1983). The trend in the last two decades has been toward enclosed production facilities, and the percentage of hogs produced on lots or pastures therefore has decreased.

The Midwest Plan Service (MWPS) (1983) recommended a pasture density of no more than 10 gestating sows, 7 sows and litters, or 50 to 100 growing-finishing hogs/a., depending on rainfall and soil fertility. Dobson (1975) recommended no more than 30 market hogs/a. on permanent pasture such as bermuda grass or fescue and ladino clover. When this density is higher, bare areas appear. For pasture to survive, animals must be removed during the dormant season or lots rested according to a rotation scheme.

Although lots with $\geq$ 100 hogs/a. fail to support vegetative cover, the most widely practiced stocking densities range from 50 to 200 hogs/a. Actual lot location as well as stocking density is determined according to such factors as annual rainfall, temperature, shade cover, soil type, vegetation, topography, drainage, and surface water proximity.

Higher stocking-densities can be maintained on sandy soils that drain well and have high infiltration capacities. Manure buildup and compaction on such soils are minimal because animal activity keeps waste well mixed with the sandy lot surface. Nitrate leaching potential is greater, however, in sandy soils. Drylots should be rotated after either two groups of animals or one year's production, so that diseases and parasites can be controlled and the soil surface can rejuvenate. The lots also should be seeded to grasses or allowed to remain fallow for at least 2 yr before being returned to production.

Low stocking-densities usually are necessary on highly organic, heavy clay soils. In low-rainfall areas, surface compaction results in packed manure and infiltration decreases dramatically, increasing runoff potential when rains do occur. When these lots are removed from rotation, the manure layer usually is incorporated into the soil or scraped and spread onto cropland. The lot also may be deep plowed with subsoilers to break up the compacted surface layer and to increase infiltration. In high-rainfall areas, animal activity in drylots causes muddy conditions that diminish the efficiency of feed utilization and increase the potential for odor generation, mosquito production, and disease. Animal mortality rates on dirt lots are higher than in confined housing.

Hogs raised on drylots usually are fed by means of self-feeding troughs, which, to obtain maximal drainage away from feeders, are located at the highest elevation just inside the fenceline. A concrete or wooden pad usually surrounds feeders to prevent the area from becoming a wallow; but because hogs tend to congregate there, muddy and compacted soil conditions usually prevail. Most manure is deposited near feeders.

Large hog drylots characteristic of Coastal Plain conditions usually slope toward a low-lying wetland with an ill-defined drainageway or streambed. Intensive monitoring of a Coastal Plain stream receiving rainfall runoff from 7.5 a. of sandy drylots with 450 hogs/a. indicated that although stream levels of P, N and chloride were elevated, with the P increase most pronounced, drylots seemed to have had minimal impacts on receiving stream biology (Barker et al., 1983). Approximately 2% of the defecated waste was transported from lot surface during rainfall runoff. Robbins et al. (1971) reported higher stream-water concentrations of fecal coliform, BOD, and P in a watershed with a 6-a. drylot for 200 market hogs than in a similar watershed with no domestic animals. Stream N concentrations were the same in the two watersheds.

Recommended BMPs for hog drylot production include

1. installing and maintaining an effective soil-erosion control program;
2. studying the stocking rates, rotations, and controlled forage uses that curtail erosion and waste accumulation;
3. promoting congregation in areas remote from streams and other major drainage channels; and
4. restricting animal access to very erodible areas and to critical stream reaches in which animals tend to wallow or to wade.

Concrete-Slab-Floor Facilities

Two primary types of concrete-slab facilities are used in swine production: (1) units 100% roofed and (2) units 50% open or more. Bedding materials in the form of wood shaving, sawdust, or straw may be used in concrete-slab facilities. In solid form, manure and bedding are scraped and removed from completely roofed buildings in cold regions. Use of bedding is not as prevalent in warm areas and manure is handled as a slurry. A sloping gutter along the lower side of a sloped concrete floor collects spilled water, wasted feed, urine, and manure, which are scraped off or washed away every 1 to 3 d (less frequently under winter conditions). Hand scraping followed by washing with high-pressure hoses decreases the volume of washwater added to the waste handling system. Certain solid-floor facilities slope to relatively wide, shallow flush gutters automated to use recycled lagoon liquid for cleaning several times daily. This design limits the need for hand labor, decreases the amount of washwater added to the system, and facilitates cleanliness. If clean water is used for hose washing or for gutter flushing, hydraulic wasteload will increase as much as tenfold.

The other type of slab facility is a paved feedlot, 50% or less of which is under a partly open-sided, roofed building. The floor area slopes to a wide, shallow gutter at the low edge. Before being hauled directly to the field or stockpiled until spreading, manure is scraped mechanically from these lots once or twice a week in the warm season and once every 1 to 3 mo during winter. In low-rainfall climates, substantial drying of manure and volatilizing of nutrients can occur from the lot surface before cleaning. In high-rainfall climates, odor potential is increased and rainfall runoff from open lots must be either collected for land application or filtered through grassed waterways (Vanderholm et al., 1979).

Slotted-Floor, Enclosed Buildings

The environments of production facilities are controlled to some extent or naturally ventilated with floor surfaces either partly or entirely slotted over manure collection gutters or pits. Because animals work the manure through floor slots, manure is separated quickly from the animal, with minimal hand labor. Manure collected under the slotted floor either is removed infrequently by pumping or by gravity discharge to an outdoor holding tank or lagoon; or is removed frequently by mechanical scraping, pit recharging, or flushing with recycled lagoon liquid. The more frequently the manure is removed from enclosed buildings, the more healthful the environment will be for both animals and workers. Underfloor ventilation systems also decrease odors and gases and improve environmental conditions within buildings (Driggers, 1987), waste volumes from which are increased only by overwatering, overfeeding, or water and feed spillage.

Waste Collection and Treatment Systems

Production Facility Underfloor-Manure Management

Pit Storage

Manure under slotted-floor facilities can be managed according to a variety of methods (Midwest Plan Service, 1983). Underfloor collection pits 2 to 8 ft deep store manure, urine, spilled waste, and wasted feed for intervals of as long as 12 mo. Nutrients are conserved during storage for maximal use with minimal waste. Because of the relative difficulty of planning adequate outdoor storage and treatment facilities, however, pit collection is used most often in cold climates. Disadvantages of pit storage are the release of gases from the stored manure into the animal production area and the workers' environment, and the difficult removal of settled solids from the bottom. Moreover, agitation of pit contents can release dangerous levels of hydrogen sulfide in enclosed spaces.

Gravity Drainage

Methods of overcoming some disadvantages of prolonged underfloor pit storage include gravity drainage to an outside storage facility. Gravity drainage can take the form either of wide, flat storage pits being drained once every 1 to 3 mo or of narrow Y-,U-, or V-shaped pull-plug gutters drained when full, or once every 3 d to 1 wk. Pit agitation usually is unnecessary before gravity drainage.

Mechanical Scrape

Mechanical alley scrapers are used to remove manure from underfloor pits frequently, i.e., at least once daily in cold climates. Compared with pit storage, the in-house environment is safer, but ammonia still is released from a slurry film left on the pit surface and from urine and other liquids accumulated between scrapings. A disadvantage of mechanical scrapers is maintenance requirements.

Flush and Pit Recharge

In warm climates, waterwash systems are used frequently to remove wastes from 2- to 3-ft-deep underfloor pits, either by means of pit recharging (Barker and Driggers, 1985) or frequent flushing (Barker and Driggers, 1981) with recycled lagoon liquid. These freeze protected systems require an outdoor holding pond or a lagoon for flushed waste collection. When all manure solids are removed several times daily, gas accumulation inside the production environment decreases and animal performance improves. Pit recharge systems have the added advantage of diluting urine and manure solids between weekly recharge events.

Growth rate of young pigs exposed to 50 ppm ammonia was 12% lower than that of control pigs; rate of pigs exposed to 100 to 150 ppm ammonia was 30% lower. Additionally, the pigs exposed to 100 to 150 ppm ammonia evidenced coughing and other health problems (Drummond et al., 1980). Studies by Donham et al. (1985) indicated that prolonged exposure of unprotected workers to elevated levels of manure gases and dusts inside production facilities may have chronic effects on human health. Muehling (1989) reported that ammonia levels inside hog production facilities were between 50 and 70 ppm, which were reduced to between 5 and 15 ppm when pit storage or underfloor scrapers were replaced with pit recharge. Barker and Driggers (1985) discussed the effect of conversion from pit storage to pit recharge at a 600-sow farrow-to-finish farm; hogs went to market 6 lb heavier, 10 d earlier, and consumed 0.1 lb less feed/1.0 lb gain. Mortality dropped from 4.0 to 0.75%, and the need for injectable or water administered medication decreased by 50%.

External Liquid-Manure Storage

Storage

Most primary nutrients are conserved during storage of manure. Outside, liquid manure usually is contained in either belowground earthen basins (Figure 5.1) or in aboveground prefabricated tanks (Midwest Plan Service, 1983) designed for 3 to 12 mo of temporary storage. The former allow longer storage periods but have a larger surface area and therefore collect more rainfall. These basins must be located so as to prevent ground water contamination. Manure usually is loaded into earthen basins from the top or through gravity loading pipes entering near the bottom. By maintaining a mat of solids floating on the surface, bottom loading discourages fly production and odor release. Prefabricated aboveground tanks generally cost more per unit capacity because of their comparatively stringent requirements in terms of structure and transfer equipment.

Figure 5.1. Lagoon system for swine manure. Photograph courtesy of Gerald B. Havenstein, Department of Poultry Science, North Carolina State University, Raleigh.

Before being emptied, liquid-manure storage units must be mixed by means of agitator/chopper pumps, which liberate some gases and odors. The mixed contents either are pumped into liquid-manure spreaders for hauling or are spread on land through slurry irrigation.

Settling Basin

Settling basins allow large manure solids to settle and manure liquids to drain. Few solids are added to holding ponds and lagoons, and loading rate, odor potential, and sludge buildup rate thus are diminished. When solids are prevented from entering vegetative filters, soil clogging decreases, filtering efficiency improves, and concentrated fertilizer value of retained solids increases.

Gravity settling may occur in shallow concrete basins 2 to 3 ft deep with a porous dam or a perforated pipe outlet (Midwest Plan Service, 1983). Half or more of total solids can be recovered and removed by a front-end loader every 1 to 2 mo. An alternative is a rectangular metallic or concrete settling tank with a 3-to-1 length-to-width ratio, an 8 ft depth, and a peak-flow wastewater detention time of 10 to 30 minutes (min). Most solids in hog manure settle in about 10 min although additional settling occurs for hours (Moore et al., 1975); a third alternative is to use an earthen settling basin for 6 to 12 mo storage for solids, with liquids draining to a secondary pond or lagoon. Solids in a settling basin are handled similarly to those in liquid-manure storage.

Lagoon Treatment

Lagoons used for the biological treatment of hog manure have the advantages of

1. ease and convenience of waste treatment,
2. flexibility of storage and disposal,
3. less land for total treatment,

4. liquid recycling for pit waste removal,
5. land application by simple irrigation, and
6. low labor requirements and operating costs.

The lagoons also have disadvantages:

1. appreciably diminished nutrient value,
2. offensive odors (if lagoons are designed or managed improperly),
3. frequent sludge removal (if they are undersized),
4. leakage into ground water (if they are sited or constructed improperly), and
5. high energy-costs (if they are mechanically aerated).

Anaerobic Treatment

Anaerobic lagoons are the most common means of hog manure treatment. Anaerobic bacteria, present in the intestinal tract of warm-blooded animals, can decompose more organic matter per unit lagoon volume than aerobic bacteria can. Because the anaerobic process obviates maintenance of dissolved O_2, lagoons can be deep and surface area small. Although incomplete anaerobic decomposition of organics can result in offensive by-products, primarily in hydrogen sulfide, ammonia, and intermediate organic acids, an anaerobic lagoon can be sized and managed to operate with minimal disagreeable odor.

Design Capacity

More so than surface area, liquid volume is the basis for anaerobic lagoon design. Appropriate sizing criteria are the primary operational needs to control odor, minimize sludge buildup, and manage N. As lagoon capacity increases, odor potential, sludge buildup rate, and pathogenic organisms diminish while N losses increase. Because bacterial activity increases with temperature, lagoons work best in areas without cold winters. Lagoons thus are much more prevalent in hog-waste management systems in warmer southern climates than in northern or midwestern climates.

References for swine anaerobic lagoon capacities for various geographical regions of the United States include the ASAE (1993b), the MWPS (1985), and Barker (1983). The minimal total capacity of an anaerobic lagoon should include appropriate design treatment capacity; additional storage for sludge accumulation; temporary storage for rainfall and wastewater inputs; surface storage for a 25-yr, 24-hr design rainfall event; and a *freeboard*, or indicator of the highest water-mark, to prevent embankment overtopping.

Site Investigation

Soil experts should analyze soil characteristics and determine the suitability of a site for lagoon construction. Location on very permeable soils that will not seal or on shallow soils over high water-tables or either fractured or cavernous rock may precipitate ground water contamination. Several studies (Barrington and Madramootoo, 1989; Collins et al., 1975; Huffman and Westerman, 1991; Ritter et al., 1984) have shown that with proper siting and construction, hog lagoons receiving raw manure eventually seal soil and decrease soil permeability. The sealing mechanism is mainly physical, i.e., organic solids are trapped within soil pores at the soil surface, but biological mechanisms also help bind manure solids to soil particles, thereby strengthening the seal. Chemical constituents of manure also may help disperse soil particles. With proper initial site selection and construction, then, the contamination of ground water by hog waste treatment lagoons can be avoided.

Management

New lagoons should be half filled with water before wasteloading begins. Starting up during warm weather and seeding with bottom sludge from a working lagoon will speed establishment of a stable bacterial population. Manure should be added to anaerobic lagoons as frequently as possible, preferably at least daily. Infrequent shock loadings can cause sharp increases in odor production and broad fluctuations in nutrient content. Lagoon liquid drawdown by irrigation should begin before the liquid reaches the maximum normal wastewater-storage level. So that adequate volume always is available for optimal bacterial activity, liquid should not be pumped below design treatment level.

An anaerobic lagoon in proper balance will have a pH from 7 to 8 (slightly basic). The pH in new lagoons without adequate dilution water or in overloaded lagoons can decrease to 6.5 or below (acidic) and thereby create odor problems. This condition can be corrected temporarily if agricultural lime is distributed evenly over the liquid surface.

Sludge Removal

Even when bacterial digestion is efficient, significant amounts of sludge accumulate in an anaerobic lagoon. Although lagoons can be designed with enough storage to minimize the frequency of bottom sludge removals (American Society of Agricultural Engineers, 1993b), at some point the treatment capacity of most lagoons will be diminished greatly as a result of sludge accumulation.

The solids content of lagoon sludge ranges from 5 to 15%, and careful selection of removal equipment is necessary. The method used most frequently entails vigorous mixing of sludge and lagoon liquid by means of an agitator/chopper pump or propeller agitator. The sludge mixture is pumped through a gun-sprinkler slurry irrigation system onto cropland and disked into the soil. An alternative consists of partial lagoon dewatering onto cropland, followed by sludge agitation and finally by pumping of the slurry mixture into a liquid-manure field spreader. A third alternative is lagoon dewatering onto cropland, followed by dredging with a dragline. The sludge may be hauled and spread directly by spreaders equipped to handle slurries or stockpiled near the lagoon and allowed to drain further before spreading.

Aerobic Treatment

The main advantages of aerated lagoons are that aerobic digestion tends to be more complete than anaerobic digestion and its product more odor free. In naturally aerobic lagoons or oxidation ponds, O_2 enters the pond by diffusion across the air/water interface. Uptake rate can be enhanced by water agitation. Algae generate O_2 through photosynthesis, which takes place when sunlight can penetrate to water depths at which the organisms occur. Water depths of aerobic ponds are shallow—from 3 to 5 ft. Because of the need for O_2 transfer, naturally aerobic lagoons are designed on the basis of surface area rather than on that of volume (U.S. Department of Agriculture, 1978). Large land areas—as much as 25 times the surface area required for anaerobic lagoons—are required for naturally aerobic lagoons. Thus, naturally aerobic lagoons are impractical for primary oxidation and generally not recommended in the treatment of hog production waste.

Mechanically aerated lagoons combine the odor control advantages of aerobic digestion with relatively small surface requirements. Aerators are used mainly to control odors in sensitive areas and to remove N at land application sites with limited land. Aerated lagoons have met these objectives successfully by providing sufficient O_2 to satisfy 50% of the COD of waste, assuming an aerator O_2 transfer rate of 3 lb/hp-hr (Barker, 1983). If the entire surface of the lagoon is to be mixed by floating surface aerators, the surface area should not exceed 1,000 ft^2/hp of aeration.

A major disadvantage of mechanically aerated lagoons is the expense of operating electrically powered aerators continuously; larger, anaerobic lagoons may perform similarly at less expense. Because they convert more input organics to biomass, aerated lagoons also yield more sludge than anaerobic units do. Suspension of bottom sludge by the aerators can increase lagoon-liquid concentrations and stimulate foaming. Nitrogen levels of mechanically aerated lagoon liquids decrease significantly as a result of ammonia loss to the atmosphere.

Multistage Lagoons

Two-stage lagoons have advantages over single, primary lagoons. More than two lagoons in a series rarely are beneficial because aquatic biomass begins to grow in the third stage. Secondary lagoons provide temporary storage before land application. Aerobic systems need a second lagoon to provide storage and to allow the primary lagoon to function solely for biological treatment. A second stage also allows a maximum liquid volume to be maintained in primary anaerobic lagoons so that incoming waste can be stabilized. For hog operations in which lagoon liquid is recycled for open-gutter flushing and in which animals have direct access to flush water, the second lagoon insures against the return of disease organisms from the primary lagoon before a reasonable die-off period. Pumping from a secondary lagoon decreases the solids pickup due to seasonal biological mixing and water turnovers that is common in primary lagoons.

Land Application

Land application is an important alternative for hog manure use. If applied properly, organic waste products can serve as sources of low-cost fertilizer for agricultural, horticultural, and silvicultural production systems. Organic materials also can be used as soil conditioners. Use of land for disposal of animal waste increasingly conflicts with nonagricultural uses. A continuing challenge is to develop and to implement land application systems meeting surface water, ground water, and air quality standards and not risking food chain contamination or soil quality degradation. Improved feed-ration design, manure solids separation for composting, and biological digestion are becoming increasingly important steps in the treatment sequence culminating in land application.

Hog manure can be an excellent source of nutrients for crop production. The key to proper management is to determine the nutrient content of manure and soil, the plant-available percentages of nutrients, and the nutrient requirements of plants. Additionally, appropriate method and timing of application prevent both underfertilization, which can affect crop yield (Burns et al., 1990), and overfertilization, which can affect soil productivity (King et al., 1990) and degrade surface and ground water quality (Evans et al., 1984; Westerman et al., 1985) or air quality.

Nutrient Content

The concentrations of nutrients in hog manure depend on operation and management methods and differ over time for a given operation. Summaries of average values for different manure handling and treatment methods are available (Barker and Zublena, 1995; Midwest Plan Service, 1985). Table 5.4 summarizes typical nutrient contents. Whenever possible, site specific data from collected and analyzed manure samples should be used.

Nutrient Availability

Certain elements are released when organic matter is decomposed by soil microorganisms. Other elements can combine with soil constituents and become unavailable. Depending on its chemical form, application method, and soil moisture level, N also may be lost to the atmosphere through volatilization or denitrification.

Nitrogen in the organic fraction of manure is released slowly, with a portion being mineralized and released during the year after application. Studies have indicated that approximately 50% of organic N is mineralized during the first year of application, with a relatively small percentage of residual N released in succeeding years (Pratt and Castallanos, 1981; Reddy et al., 1979a). Thirty-seven percent of total N in hog liquid-manure slurry is organic in form; 19% in lagoon liquid is organic (Table 5.4).

Liquid-manure slurries offer the most concentrated source of plant nutrients. Storage requires agitation so that the slurry is mixed into a uniform consistency among spreader loads. Liquid slurries usually are handled with enclosed tank spreaders, whose capacities range from 1,000 to 9,000 gal. Flotation tires limit soil compaction. Liquid-spreaders offer the option of knifing manure directly into the ground through injection shanks. Direct injection decreases ammonia losses to 5%, and soil incorporation of broadcast or surface applied manure within 48 hr of application can result in as great as a 25% loss of ammonia. Unincorporated, surface applied manure can lose 75% or more of ammonia after 1 mo (Klausner and Guest, 1981; Reddy et al., 1979b; U.S. Department of Agriculture, 1979). Periodic spreading equipment calibration defines the combination of settings and travel speeds needed to apply manure at a desired rate (Brodie and Smith, 1991).

The contents of most anaerobic lagoons and settling basins are applied most economically to land by means of irrigation. Solids-free lagoon liquid is applied through single, small-diameter, straight-bore sprinkler nozzles. Pump suction intakes are floated near the lagoon liquid surface. Larger, gun-type sprinklers are used for lagoons or waste storage facilities with high concentrations of solids or liquid sludge irrigation. As great as half of ammonia in lagoon liquid can be lost through sprinkler irrigation, either by volatilization or by wind drift (Safley et al., 1992). Irrigation equipment should be field calibrated periodically to verify that operating characteristics are unchanged. Denitrification losses occur in O_2 depleted conditions usually manifested in poorly drained, saturated, heavy clay, or organic soils.

Greater than 90% of total P in hog manure is in the orthophosphate form, which is readily available for plant use. Phosphorus is a relatively immobile ion adsorbed to soil particles. The major mechanism for loss of phosphorus from soil to surface waters is through soil erosion and sediment transport—thus the need for appropriate conservation practices. If manure is applied to supply total N requirements of crops, then excess P usually is applied. This excess P

Table 5.4. Nutrient composition of hog manure after handling and storage (Barker and Zublena et al., 1995)

Manure type	Total solids (ppm)	Total N TKN[a] (ppm)	Ammonia(um)–N NH_3–N (ppm)	Phosphorus P_2O_5 (ppm)	Potassium K_2O (ppm)
Paved lot scraped	180,000	6,500	2,800	6,600	4,500
Liquid slurry	51,000	3,200	2,000	2,300	1,800
Lagoon liquid	3,200	560	460	220	580
Lagoon sludge	100,000	2,900	710	6,300	780

[a]TKN = total Kjeldahl nitrogen.

application presents no problem to most crops but can pose a potential pollution problem when excess runoff and soil erosion carries it into receiving waters. When manure is applied to supply crop P requirements, increased acreages are required, as are supplemental nutrients usually; but usage of manure nutrients is maximized. Some studies have emphasized that soils have a finite capacity to adsorb P from solution (Goodrich and Monke, 1980; Pratt and Lippert, 1986; Reddy et al., 1980). Continuous flushing with irrigation may cause P to move to greater depths in the soil profile.

Crop Type

Crop type and growth stage play major roles in determining when application should occur and to what extent manure nutrients will be used. Because row crops, for reasons of equipment access, generally receive application either preplant or postharvest, the opportunity to conserve N during soil incorporation is enhanced. Grassland application offers a firmer base for equipment than row cropping does during rainy conditions and requires less land because most grasses use more N than row crops do (Midwest Plan Service, 1985; Zublena et al., 1993a). Application to vigorous stands of alfalfa may be inadvisable under certain circumstances.

Application Rates

Land application rates for manure are determined by matching the available nutrient content with the receiving crop's nutrient requirement. In North Carolina, an N availability coefficient combines an organic N mineralization rate of 50% with varying ammonia volatilization losses based on waste source, waste management system, and land application method. This unique system allows the user to estimate plant-available nutrients by means of a single conversion number (Zublena et al., 1993a). Worksheets for the proper land application of swine manure are provided by Zublena et al. (1993a) and by the Pennsylvania Department of Environmental Resources (1986).

Manure should be applied as nearly as possible to the period of maximum plant uptake of nutrients. Fall incorporations of manure lead to conversion of ammonium nitrogen to nitrate. In areas of high rainfall, leaching of nitrate may be excessive during crop dormancy. Use of low application rates on coarsely textured soils throughout the growing season limits nitrate leaching. Small grains or suitable grasses grown as winter cover crops decrease leaching and enhance nutrient recovery.

When hog manure is applied at agronomic rates, soil salinity (or excess salts) usually is not a problem in regions with surplus rainfall. In low-rainfall or irrigated areas, the salinity content of manures applied to cropland must be monitored closely to avoid crop stress (U.S. Department of Agriculture, 1979). Nutrient imbalances should be monitored through soil testing and plant analysis because an increased concentration of one element may affect the availability of another to plants. Large Cu supplements in hog rations necessitate monitoring of Cu levels in soils receiving liquid slurries or lagoon sludges.

In addition to the nutrient supply, proper soil pH is required to promote organic matter decomposition, to improve crop yield, and to ensure nutrient availability. The biological conversion of organic N to nitrate is an acid-forming process that will diminish soil pH continuously unless an adequate liming program is followed.

Land application of hog manure potentially alters other soil properties. Soil tilth is improved by the addition of organic matter. The soil infiltration rate, especially in fine-textured soils, increases with the incorporation of manure slurries. Increased infiltration diminishes soil erosion potential. Hog manure stimulates plant growth by increasing soil water-holding capacity. On sandy soils, organic matter decreases leaching and increases crop yields by facilitating plant water and nutrient use.

Nutrient Assessment

To optimize geographic usage of fertilizer nutrients from hog manure, nutrient assessments can

1. indicate where animals are located and identify clustering effects, e.g., high densities of livestock production around support facilities such as feed mills and processing plants;
2. indicate quantities of manure nutrients available for plant growth and how they supplement inorganic nutrient sources in a given area;
3. indicate the potential for nutrient contamination of water resources; and
4. influence decisions regarding future local or area-wide growth and development.

Before manure nutrients available and collectable after storage and treatment can be estimated, estimates must be made of (1) the percentage of time spent by animals in confinement compared with that spent on drylot or pasture, (2) the percentage of hog farms using specific methods of waste management, (3) the method of land application, and (4) the plant-available nutrients for fertilization.

Table 5.5 estimates manure and primary nutrient production at various stages of manure collection and use as plant fertilizer, under North Carolina conditions (Barker and Zublena, 1995). The assumptions underlying this table likely will be different for other states. As can be seen from the table, in North Carolina, 17, 21, and 23% of the respective primary nutrients N, P, and K in the manure voided by total animal inventory can be used for plant fertilization.

Constructed Wetlands

Constructed wetlands have been used, with various degrees of success, as a component of both municipal- and domestic-wastewater and storm-water runoff treatment in Europe and in the United States (Gersberg et al., 1984; Hammer, 1989). These systems, built on upland sites, simulate natural wetlands in which physical, chemical, and biological processes such as evapotranspiration, adsorption, sedimentation, and biological transformation remove contaminants from wastewater. Wastewater treatment depends on aquatic plants and on the microorganisms associated with them. Once microorganisms establish on aquatic plant roots, they form a symbiotic relationship that degrades organic compounds and removes nutrients from wastewater surrounding root systems (Wolverton, 1986).

Constructed wetlands only recently have begun to be considered for treatment of relatively concentrated livestock wastewaters. Systems for hog lagoon-liquid treatment have been established in Alabama (Hammer, 1989; Maddox and Kingsley, 1989) and in Mississippi (Strong and Ulmer, 1989). Additional efforts are under way in Kentucky, Minnesota, and North Carolina. A project for hog and dairy operations has been initiated to evaluate an assembly of aquatic plant species for use in constructed wetlands in Alabama and Georgia (Surrency, 1991). Initial results indicate that three-celled systems with giant bulrushes in the first cell and grasses in the subsequent cells decrease total N by 90% and total P by 80%.

None of the constructed wetlands projects for treatment of hog wastewaters has been operational for longer than 5 yr. Concerns exist about vegetation tolerance to high wastewater-ammonia levels, seasonal temperature effects on nutrient removal efficiencies, and long-term accumulations of nutrients and settled biomass within cells. Rogers et al. (1991) indicated that increased emphasis on proper mass balance and on aquatic plant roles is necessary if a

Table 5.5. North Carolina collectable hog manure and plant available nutrients in 1993 (Barker and Zublena, 1995)

Nutrient type	Manure	Nitrogen TKN[a]	Phosphorus P_2O_5	Potassium K_2O
Total fresh manure				
Tons per year	9,036,100	53,369	40,347	38,777
Percent of fresh manure	100	100	100	100
Collectable fresh manure				
Tons per year	8,002,903	46,811	35,563	34,177
Percent of fresh manure	89	88	88	88
Collectable nutrients after storage/treatment				
Tons per year	—	16,076	11,519	12,529
Percent of fresh manure	—	30	29	32
Plant available nutrients after field losses				
Tons per year	—	9,138	8,483	8,991
Percent of fresh manure	—	17	21	23

[a]TKN = total Kjeldahl nitrogen.

Assumptions:

1. 88% enclosed housing; 12% drylot or pasture.
2. 3% concrete slab scraped manure; 12% liquid manure slurry; 85% lagoon treatment.
3. Scrape and slurry: 75% NH_4, P, K plant availability, 50% organic N mineralization.
4. Lagoon liquid: 50% NH_4 plant availability and organic N mineralization, 70% P, K plant availability.

predictive understanding of wetland wastewater treatment is to be developed.

Refeeding

Hog manure solids may supplement animal feed rations. Weiner (1983) reported that raw hog waste combined with corn and fermented under anaerobic conditions undergoes a lactic acid fermentation, which quickly kills large reservoirs of fecal coliform bacteria as well as pathogenic *Salmonella* and dysentery organisms added to the mixture. The product of the fermentation process can be used as a component of animal rations and can assist in the management of animal waste.

Solids fractions with nutritional value can be harvested from flushed hog wastes by means of mechanical screening (Hill et al., 1984). Recovered materials have been shown to contain 11 to 12% crude protein, of which 75% is amino acids (Newton et al., 1980; Prince et al., 1983a). Approximately 50% of the energy in screened waste is digestible and 46% metabolizable whereas 17% of crude protein is digestible by sows (Van Dyke et al., 1983). And at least 60% of dry matter in sow gestation diets can be replaced by this material (Prince et al., 1983b). When fed to steers, the dry matter, crude protein, and neutral detergent fiber of screened hog waste are significantly more digestible than similar components in quality corn silage and may be nearly as digestible as the components found in other grain process by-products such as brewers' and distillers' grains (Newton et al., 1980).

Biogas Recovery and Utilization

Anaerobic digesters are planned and managed to optimize the bacterial decomposition of organic matter. Organic material is stabilized, and gaseous by-products, primarily methane and carbon dioxide, are formed. The expected methane yield from a digester system is needed for evaluation of the site specific economics and for on-site energy use, management, and marketing. Hill (1984) recommended a methane productivity of 24 ft^3/1,000 lb live weight/d for hog wastes. When this methane yield value is used and the assumption made that optimally 100% of wastes could be collected and digested, manure from U.S. pork production has an annual energy potential of $4.9 \infty 10^{13}$ British Thermal Units. Biogas energy usually is used either for on-farm heating by means of a boiler or a furnace (Safley and Lusk, 1990) or for cogeneration of electricity (Koelsch et al., 1990; Safley et al., 1987; Siebenmorgen et al., 1988).

Early digesters were designed to be operated in the mesophilic (Fischer et al., 1981; Pos et al., 1985) or the thermophilic (Hashimoto, 1983; Hill et al., 1985) temperature range. Higher temperatures allow higher loading rates and thus smaller digesters, but the dynamics of thermophilic biological processes are more susceptible to disruptions and to failures at these higher temperatures. Flushing systems for waste removal from production systems widely used in warmer climates increase size and cost of digesters. High initial costs have limited the number of digesters in the United States.

Methanogenesis has been observed at temperatures approaching 0°C (*psychrophilic anaerobic digestion*) (Stevens and Schulte, 1979). Cullimore et al. (1985) indicated that biogas production was initiated between 3° and 9°C in an anaerobic lagoon and that the minimal temperature at which biogas was produced decreased as lagoon age increased. Because flushing systems and anaerobic lagoons already are in widespread use in warm regions, attention is being focused on earthen lagoon flow-through digesters with floating covers operating at ambient temperatures.

Several successful covered psychrophilic digesters have been reported. Chandler et al. (1983) reported on a California project in which an 11,500 ft^2 floating cover was installed on a 20-ft-deep anaerobic lagoon serving a 1,000 to 1,100 sow farrow-to-finish hog unit. Biogas production averaging 69% methane ranged from 2.2 to 3.0 ft^3/ft^2 covered lagoon surface per day. Lagoon-liquid temperatures ranged from 11° to 22°C during the year. The gas was used to fuel a 75-kilowatt engine-driven electrical generator. Balsari and Bozza (1988) described a covered lagoon digester for treating hog waste in Italy. Biogas production rates ranged from 1.4 to 5.3 ft^3/lb volatile solids added to the lagoon daily. Methane content of the biogas ranged from 70 to 75%. Safley and Westerman (1990) proposed a design methodology for the psychrophilic anaerobic digestion of animal manure.

Atmospheric Emissions

Another discussion point related to pork production is the air quality surrounding animal housing and waste management systems. Air quality concerns are of three types: (1) worker health and animal health/performance inside housing facilities, a topic already discussed; (2) dust and odor surrounding the facilities; and (3) gaseous emissions into the atmosphere. Unlike water quality problems, which can be assessed in terms of finite standards by means of technologies, air quality problems for the most part are subjective. Thus, the challenge of developing objective methods of assessing odor associated with hog enterprises remains.

Ammonia-Nitrogen

Gases emitted into the atmosphere are of concern because of their contributions to N deposition in rainfall and to global greenhouse effects. Growers in Europe have been forced to deal with this issue along with other aspects of waste management. Methods that decrease the amount of land needed for safe application of wastes often enhance release of ammonia into the atmosphere.

Winkel (1988) determined ammonia emission values from hog production facilities in the Netherlands by tracing the flow of N from feed consumption to land application. Collins (1990a) estimated the atmospheric ammonia loadings from a 1,000-sow farrow-to-finish production complex in Virginia with mechanically ventilated, slotted-floor barns from which manure was removed several times daily by flushing with recycled lagoon liquid. Results were comparable to those reported from Europe. Threshold limit values did not violate the Virginia air quality standard for ammonia, or a maximum of 25 ppm. Collins concluded that (1) further study was needed to corroborate the data and (2) the extent of possible damage from such releases remained uncertain.

Burton and Beauchamp (1986) used an N budget procedure to estimate the loss of manure N from three hog barns with liquid-manure systems in Ontario, Canada. Over periods of approximately 1.5 yr, between 5 and 27% of excreted N was lost as ammonia. The extent of N loss generally was related to manure management within the barn. The greater the exposure of fresh manure, the greater the N loss. Temperature had both direct and indirect effects (through increased ventilation rates) on ammonia losses.

Safley et al. (1992) conducted experiments using center pivot and large-nozzle equipment to determine N losses occurring during sprinkler irrigation of hog lagoon liquid. Ammonia-N losses ranged from 14 to 38%, and 62 to 100% of this loss could be accounted for volumetrically as wind drift or as liquid evaporation. The pH of applied lagoon liquid increased during irrigation. Using (1) a conventional tank spreader with a splash plate, (2) a low-trajectory surface spreader with a boom equipped with 15 trailing hoses, and (3) a subsurface injector, Phillips et al. (1988) compared odor and ammonia emissions after spreading pig slurry on grassland. Ammonia emission rates were measured during the period from minutes after spreading until 73 hr later. The investigators concluded that (1) the low-trajectory spreader produced 30% less odor but 50% more ammonia emission than the conventional spreader did, (2) the injection produced far less odor and ammonia emission than either of the other methods did, and (3) the emission rate fell rapidly after spreading so that within 24 hr all rates were below 17% of the initial emission rate.

Methane

Methane from both animal gastrointestinal emissions and production and waste management systems is considered significant in terms of its potential impact on atmospheric air quality, ozone concentration, and global climate. Casada and Safley (1990), who conducted a comprehensive review and summary of estimated global methane emissions from livestock and poultry manure, suggest that U.S. pork production contributes 1.25 million t methane (56 trillion ft^3) annually to the atmosphere, or 30% of total U.S. livestock and poultry contribution. United States pork production contributes 4% of global livestock and poultry methane emissions.

Mortality Management

Estimates of normal animal death losses in hog production enterprises are as high as 20 t/yr from a 1,000-sow farrow-to-finish unit (Morrow and Ferket, 1993). This estimate implies that more than 150,000 t of hog mortality must be managed in the United States annually. Traditional options have been landfilling, burying, incinerating, and rendering. Although each option has its advantages and limitations, efforts are being made to explore alternatives. Public landfills in many states no longer accept animal carcasses. On-site burial or pit disposal of carcasses is receiving close scrutiny in areas with high water-tables or soils vulnerable to nutrient leaching (Ritter and Harris, 1988). Incineration is costly and energy intensive and contributes to air emissions (Donald and Blake, 1990b).

Rendering recycles carcasses into safe and useful by-products such as meat and bone meal, animal fat, and paints and plastics. Whereas renderers usually offered pickup and services free, in some areas they now are charging a fee due to increased transportation costs and depressed prices for by-products. A local North Carolina livestock producers' association has overcome some of the obstacles to rendering collection by using a centralized carcass collection site for animals and birds (Barker and Williams, 1991). Growers bring farm mortalities to a truck left at the site and used to transport carcasses daily to a rendering plant 60 miles away. The rendering plant pays the association for the carcasses, based on current prices for meat, bone meal, and fat. During the spring of 1991, weekly collections of hog mortality averaged 30,000 to 44,000 lb worth \$0.024 to \$0.027/lb. Gross returns to the association averaged nearly \$1,000/wk during this period, and profit resulted. For 5 yr of operation, no disease transfer problems have been reported.

The most recent alternative explored for on-site management and use of farm mortalities is composting. The poultry industry has been using this process successfully for the past 7 yr (Conner et al., 1991; Murphy, 1988). Personal communication with Fulhage (1991) indicates that trials conducted in Missouri for composting small pig carcasses (up to 30 lb), afterbirths, and large carcasses (up to 400 lb) were achieving success similar to that achieved in poultry composting. North Carolina and Arkansas are conducting similar trials.

6 Environmental Management for Commercial Cattle Feedlots

Summary

Statistical information about animal based agricultural enterprises appears in Table 4.1. Dry manure production by all beef cattle and calves is approximately 97 million t/yr. Concentrating cattle in feedlots has numerous advantages in terms of productivity and quality control and is a practice widely accepted in the United States. But such concentration increases the potential for both water and air pollution.

Feedlots in the Great Plains and in the southwestern United States now must control discharges and meet state and/or federal regulations prohibiting discharge of waste water from feedlot property. Holding ponds should be designed according to design criteria developed by the USDA Natural Resource Conservation Service.

In hot, dry weather, feedlot cattle can create high dust-concentrations in the 2 hr around dusk, when cattle activity increases. Under calm conditions, feedlot dust can drift over nearby highways and buildings. The EPA has established cattle feedlot-emission factors based on worst-case assumptions.

Odor is likely to cause complaints farther downwind than dust emissions are and is more difficult to manage. Odor complaints are most likely after significant precipitation events, when pens are wet, and in warm weather. For open cattle-feedlots, manure treatment for odor control consists of maintaining aerobic conditions to the extent possible. Primary odor-control approaches are to keep manure dry and inventory minimal. A site should be chosen where under stable atmospheric conditions the wind has lower than a 5% probability of carrying odor toward the nearest neighbor or town.

The approach to manure collection should be that of "manure harvesting" instead of "cleaning pens." By using methods designed to maintain a surface seal, to promote drainage, and to collect a quality product, machine operators can facilitate manure harvest. Feedlot runoff collected in holding ponds can be applied to land and/or left to evaporate. Sprinkler, unlike furrow, irrigation allows control of runoff application rates and is the preferred approach.

Manure application rates depend on many factors, and the feedlot manager should work with a professional agronomist to determine proper rate. Overapplication of feedlot manure can depress yield, waste manure, and increase water pollution potential. The greatest benefits and the fewest problems have resulted from low application rates meeting fertilizer requirements.

Introduction

Feedlot managers are focusing on manure and wastewater management to control water and air pollution, to provide well-maintained feedlot conditions for cattle, to recover nutrients in the form of fertilizer, and to maintain or to improve feedlot efficiency. The necessary technologies are well established, and regulations are in place at federal and state levels. Because cattle feeders increasingly are paying attention to these technologies, the cattle feeding industry should remain a prominent agricultural sector in the twenty-first century. Meanwhile, additional research needs to be focused on assessment and control of odor and other forms of air pollution and on tradeoffs between air- and water-pollution control measures. These data should aid in the design and the operation of productive and environmentally sound feedlots.

Manure Production and Distribution

Van Dyne and Gilbertson (1978) used animal numbers as reported in the 1974 Census of Agriculture to calculate total U.S. manure production, dry basis, for all livestock and poultry species. Taking into account regionally predominant types of manure and wastewater handling systems, these investigators found that total annual manure production was 112 million dry t and that the manure contained 4.1 million t N, 1.1 million t P, and 2.4 million t K. Volatilization, leaching, and runoff losses decreased dry weight by 10%, total N by 36%, P by 5%, and K by 4%. Recoverable (collectable) manure and nutrients were estimated by subtraction of the portion of materials voided on pasture areas. Economically recoverable dry manure was estimated at 52 million t, and the fractions contributed by various animals were estimated as follows: dairy cattle, 39%; feeder cattle, 31%; hogs, 11%; laying hens, 6%; broilers, 5%; sheep, 3%; and turkeys, 2%.

The estimates of Van Dyne and Gilbertson (1978) were based on American Society of Agricultural Engineers (ASAE) (1976) engineering standards, which reflect manure constituent production per 1,000 lb animal live weight. Revised standards were adopted in 1988 to reflect current research data, and standard deviations were calculated to reflect variability (American Society of Agricultural Engineers, 1993a). Data concerning beef cattle on feedlot rations are summarized in Table 6.1.

Revised manure production values (American Society of Agricultural Engineers, 1988), together with livestock and poultry statistics for 1986 through 1989 and assumed values for average animal live weights, recently were used to estimate total U.S. manure and nutrient production by livestock and poultry (Sweeten, 1990b). According to these estimates, total quantities of dry manure, N, P, and K initially voided were approximately 159.0, 6.5, 2.0, and 4.1 million t/yr, respectively, dry-weight basis. Dry manure production by all beef cattle and calves is approximately 97 million t/yr. Of this, beef cattle in grazing production systems contribute about 88%; beef cattle on feed, the remainder. Manure solids and N production rates on an as voided basis within intensive systems versus extensive cattle production systems differ by several orders of magnitude, as a function of animal spacing per unit live weight (Sweeten and Reddell, 1978). On open feedlots, as-voided dry-manure generation rates range from 100 to 1,000 t/a./yr; manure N production rates, from 10,000 to 100,000 lb/a./yr.

Feedlot Water-Pollution and Wastewater Management

A *feedlot*, or concentrated animal-feeding facility, is fenced or enclosed otherwise as open lots or confinement buildings. Concentrating cattle in feedlots has numerous advantages in terms of productivity and quality control and is a practice widely accepted in the United States. But concentration of cattle in feedlots increases the potential for both water and air pollution.

Table 6.1. Daily production of fresh manure by beef cattle in feedlots, based on American Society of Agricultural Engineers, Engineering Standard D–384.1 (American Society of Agricultural Engineers, 1993a)

Parameters	Per 1,000 lb liveweight: Mean (lb/day)	Per 1,000 lb liveweight: Mean + SD[a] (lb/day)	Average manure per 1,000 head feedlot cattle (850 lb/hd) (lb/day)
Total wet manure	58.0	75.0	49,300
Total solids (dry matter)	8.5	11.1	7,225
Volatile (ash-free) solids	7.2	7.77	6,120
Biochemical oxygen demand	1.6	2.35	1,360
Chemical oxygen demand	7.8	10.5	6,630
Total Kjeldahl nitrogen	0.34	0.413	289
Ammonia N	0.086	0.138	73
Total phosphorus (P)	0.092	0.11978	78
Potassium (K)	0.21	0.271	179
Calcium	0.14	0.25	119
Magnesium	0.049	0.064	42
Sulfur	0.045	0.0502	38
Sodium	0.030	0.053	26
Iron	0.078	0.0137	7
pH	7.0	7.34	—

[a]SD = standard deviation.

Runoff

Runoff from cattle feedlots contains relatively high concentrations of nutrients, salts, pathogens, and oxygen (O)-demanding organic matter, which is measured as 5-day (d) biochemical O_2 demand ($[BOD]_5$) or as chemical O_2 demand (COD) (Reddell and Wise, 1974; U.S. Environmental Protection Agency, 1973). Typical concentrations of cattle feedlot runoff appear in Table 6.2 (Clark et al., 1975a), Table 6.3 (Clark et al., 1975b; Sweeten et al., 1981), and Table 6.4 (Sweeten, 1990a).

Researchers have characterized the relationship between cattle feedlot runoff and rainfall (Clark et al., 1975a; Gilbertson et al., 1981): about 0.5 in. of rainfall is required to induce runoff (Gilbertson et al., 1980). Thereafter, less runoff per inch of rainfall should occur in dry than in wet climates (Clark et al., 1975a). Holding ponds should be designed according to design criteria developed by the USDA Natural Resource Conservation Service (NRCS). Because the annual amount of runoff expected is about 20 to 33% of annual rainfall in the Great Plains cattle feeding regions (Phillips, 1981), a 200-a. feedlot in an area annually receiving 24 in. of rainfall will produce an annual average of 1,200 a.-in. of runoff, which must be stored and disposed of.

Table 6.2. Average chemical characteristics of runoff from beef cattle feedyards in the Great Plains (Clark et al., 1975a)

Location	Total solids (ppm)	Electrical conductivity (mmhos/cm)	Chemical oxygen demand (ppm)	Total nitrogen (ppm)	Total phosphorus (ppm)	Sodium (ppm)	Calcium (ppm)	Magnesium (ppm)	Potassium (ppm)	Chloride (ppm)
Bellville, TX	9,000	NA[a]	4,000	85	85	230	NA	NA	340	410
Bushland, TX	15,000	8.4	15,700	1,080	205	588	449	199	1,320	1,729
Ft. Collins, CO	17,500	8.6	17,800	NA	93	NA	NA	NA	NA	NA
McKinney, TX	11,430	6.7	7,210	NA	69	408	698	69	761	450
Mead, NE	15,200	3.2	3,100	NA	300	478	181	146	1,864	700
Pratt, KS	7,500	5.4	5,000	NA	50	511	166	110	815	NA
Sioux Falls, SD	2,990	NA	2,160	NA	47	NA	NA	NA	NA	NA

[a]NA = not available.

Table 6.3. Average concentration of nutrients, salts, and other water quality parameters from stored cattle feedlot runoff in Texas[a,b]

Water quality parameters	South Texas[c] holding ponds	Texas High Plains[a,d]		
		Runoff, fresh	Holding ponds	Playas
Nitrogen, ppm	180	1,083	145	20
Phosphorus, ppm	—	205	43	12
Potassium, ppm	1,145	1,320	445	60
Sodium, ppm	230	588	256	54
Calcium, ppm	180	449	99	55
Magnesium, ppm	20	199	72	30
Chloride, ppm	1,000	1,729	623	86
COD[e], ppm	1,100	—	—	—
Total solids, ppm	2,470	—	—	—
Sodium adsorption ratio (SAR)	4.2	5.3	4.6	1.4
Electrical conductance (mmhos/cm)	4.5	8.4	4.5	1.0

[a]To convert to lb/acre-inch, multiply concentrations (ppm) by 0.226.
[b]Quality of runoff after it had been in the runoff holding pond for several weeks. Playas typically catch runoff from areas other than the feedlot; thus, there is an increased dilution effect.
[c]From Sweeten et al. (1981).
[d]From Clark et al. (1975b).
[e]COD = Chemical oxygen demand.

Water Pollution Regulations

Legislation regarding runoff from feedlots began evolving during the late 1960s and 1970s. Feedlots in the Great Plains and in the southwestern United States now must control discharges and meet state and/or federal regulations prohibiting discharge of wastewater from feedlot property (U.S. Environmental Protection Agency, 1974, 1976).

The Texas Natural Resource Conservation Commission (TNRCC) (1987) has adopted a regulation stating that there shall be no discharge from livestock feeding facilities. Animal waste materials must be either collected and used or disposed of on agricultural land. The regulation has three primary types of requirements: (1) protection of surface water, (2) protection of ground water, and (3) proper land application of manure and wastewater. Beef cattle feedlots containing more than 1,000 head of cattle must have a state permit whereas smaller feedlots must meet the no-discharge requirements for water pollution control but require no permit.

When obtaining a TNRCC permit, feedlot operators must estimate daily and annual productions of manure, wet and dry bases, as well as of major constituents such as volatile solids; nutrients, i.e., N, P, and K; salts, e.g., Na and Cl; and O_2 demand. Finally, operators must compute a nutrient balance. The basis for their calculations is the set of standards outlined in *Manure Production and Characteristics* by the ASAE (1988).

Surface-water protection measures for open, dirt surfaced feedlots include diversion of clean water around the feedlot and collection of rainfall runoff. Runoff holding ponds must be designed to collect and to store all runoff from a 25-yr frequency, 24-hr storm. This design rainfall event is approximately 5 in. in the main cattle feeding regions of the southern High Plains. Runoff from the design storm is calculated using USDA-NRCS design criteria. For a design rainfall of 5.0 in. from the 25-yr, 24-hr storm, design runoff is about 3.8 in. Runoff retention facilities must be built outside the 100-yr flood plain and must be dewatered within 21 d of being filled by rainfall runoff to greater than 50% storage volume. Irrigation is the most effective means of dewatering.

Table 6.4. Nitrogen, phosphorus, and solids concentrations in a typical cattle feedlot runoff holding pond (Sweeten, 1990a)

							Salinity index	
Feedlot	Sample date	No. samples	Total N (ppm)	NH_3–N (ppm)	P (ppm)	Total solids (ppm)	EC[a]	SAR[b]
Effluent used for irrigation								
A	08/23/88	5	173	151	28	4,264	5.1	2.9
A	10/26/88	1	129	119	33	2,370	3.8	2.4
B	10/01/88	4	217	161	96	14,425	14.9	7.2
C	10/13/88	1	118	107	148	3,770	4.3	3.5
C	08/00/88	2	172	148	10	5,315	9.1	6.8
C	05/27/88	1	89	61	9	8,990	8.4	11.7
C	01/21/88	6	136	98	56	5,242	4.6	7.6
C	08/14/87	3	181	120	12	4,403	8.0	5.4
D	10/08/84	2	90	75	—	3,215	3.8	3.3
E	12/08/87	2	364	282	—	7,865	8.2	16.3
Mean			167	132	49	5,986	7.0	6.7
SD (Standard deviation)			81	62	50	3,589	3.5	4.4
Agitated sediment and effluent								
A	10/17/89	2	211	162	45	26,700	4.2	2.4
A	10/20/89	3	198	154	276	21,700	3.8	1.2
A	10/26/89	3	202	151	42	28,400	4.0	2.3
Mean			204	156	121	25,600	4.0	2.0
SD (Standard deviation)			7	6	134	3,483	0.2	0.7

[a]EC = Specific conductance or electrical conductivity (mmhos/cm).

[b]SAR = Sodium Adsorption ratio = (Na/0.5 (Ca + Mg))** 0.5, where Na, Ca, and Mg concentrations are in milliequivalents per liter.

Seepage Control

In Texas, ground water quality is protected by feedlot regulations, which include seepage standards (Texas Natural Resource Conservation Commission, 1987). A runoff holding pond or lagoon must be built in, or lined with, a compacted thickness of at least 12 in. of soil material—at least 30% of which passes through a No. 200 mesh sieve, a liquid limit of 30% or greater, and a plasticity index of 15 or higher. These three criteria require a sandy clay loam, a clay loam, or a clay soil and together are consistent with the goal of attaining a permeability coefficient of approximately 1×10^{-7} cm/second (sec), a relation stipulated in some permits. A 1993 U.S. Environmental Protection Agency Region 6 general permit for Texas, Oklahoma, New Mexico, and Louisiana requires a liner material with 1.5 ft. thickness and hydrolic conductivity of 1×10^{-7}/sec or meeting USDA-NRCS Technical Note 716 (U.S. Environmental Protection Agency, 1993b).

Holding ponds and manure treatment lagoons are partly self sealing because soil pores in fine textured soils clog with bacterial cells and organic matter (Barrington and Jutras, 1983). California research involving an unlined cattle manure storage pond initially measured seepage rate at 1.3×10^{-4} cm/sec, but after 6 mo the rate had decreased nearly a hundredfold, to 3.5×10^{-6} cm/sec (Robinson, 1973). Seepage beneath feedlot-runoff holding ponds decreases with time (Lehman and Clark, 1975) so that ultimately very little nitrate or chloride movement occurs (Clark, 1975; Lehman et al., 1970).

Land Application of Runoff

Feedlot runoff collected in holding ponds can be applied to land and/or left in ponds to evaporate. Sprinkler irrigation allows control of runoff application rates to a greater extent than furrow irrigation and is the preferred approach. Level border irrigation also facilitates uniform application of feedlot effluent.

Feedlot-runoff application rates usually are limited by N, salinity, or Na content (Butchbaker, 1973). Nitrogen concentrations are 89 to 364 milligrams (mg)/liter (L) (Table 6.4), with 80% or greater in the form of ammonium (Sweeten, 1990a). Feedlot runoff stored in holding ponds generally has an electrical conductivity of 1 to 10 millimhos (mmhos)/cm, depending on factors such as cattle ration and evaporation rate. Clark et al. (1975b) determined a mean value of 4.5 mmhos/cm for feedlot runoff stored in holding ponds in the Texas High Plains, and Butchbaker (1973) found a mean value of 5.5 mmhos/cm for Kansas. Most salinity occurs in the form of K and chloride although Na and ammonium also are important parameters.

Runoff held in evaporation ponds has evidenced very high salt concentrations, with electrical conductivity of higher than 20 mmhos/cm (Sweeten, 1990a), or approximately 12,000 to 15,000 ppm total dissolved solids (TDS). Thus, evaporation pond effluent may be unsuitable for irrigation. Ideally, a feedlot manager should dilute pond water before using it in irrigation (Powers et al., 1973).

Salt tolerances have been established for most crops (Food and Agriculture Organization, 1985; Stewart and Meek, 1977). In soil and applied effluent, salinity levels causing 10, 25, and 50% reductions in yields were reported by Stewart and Meek (1977). Feedlot runoff can be applied to salt tolerant crops such as sorghum, barley, wheat, rye, and bermuda grass (Butchbaker, 1973). But corn is less tolerant (Wallingford et al., 1974).

Solid Manure: Land Application

Manure application rates depend on many factors, including manure analysis, physical and chemical soil characteristics, crop type, yield goal, soil drainage, climate, ground water depth, and geology. For this reason, the feedlot manager should work with a professional agronomist to determine proper application rate. Overapplication of feedlot manure can depress yield, waste manure, and increase water pollution potential.

Manure application rate usually should be selected on the basis of plant-available N and P (Gilbertson et al., 1979b). Soil fertility guides are available to explain how many lb of N-P-K are required for specific crop and yield goals. For grain sorghum with a yield goal of 7,000 lb/a., annual crop requirements will be approximately 150 lb/a. N, 80 lb/a. P_2O_5, and 120 lb/a. K_2O. Feedlot manure contains about 2.0 to 2.5% N, 0.8 to 1.0% phosphorus (P_2O_5), and 1.5 to 2.0% potassium (K_2O), dry-weight basis (Arrington and Pachek, 1981). For feedlot manure in which 40 to 50% of N is available, manure should be applied at the rate of approximately 8 t/a., dry basis.

Researchers at Texas A&M University determined corn silage and grain sorghum yields resulting from feedlot-manure application rates at 36 to 51% moisture and applied at 0, 10, 25, 50, 100, 150, 300, 600, and 900 t/a. for 2 yr (Reddell, 1974). Peak yield occurred at the 25 t/a. application rate for sorghum grain and at the 10 and 25 t/a. rates for corn silage.

Using manure application rates of 0 to 268 t/a./yr, dry basis, Stewart and Meek (1977) compared check-plot yield data with crop yield data from three cattle feeding states. At Brawley, California, a desert climate, peak sorghum grain yields occurred at manure application rates of 33 t/a., and yield reductions from 33 to 129 t/a. occurred at higher rates. Near Amarillo, Texas (Bushland), an irrigated sorghum yield on a Pullman clay loam soil peaked at a manure application rate of only 10 t/a. and decreased at higher application rates, because of minimal leaching. For corn silage in central Kansas, yields peaked at 45 to 90 t/a. and decreased at 90 to 268 t/a.

Researchers from the USDA Agricultural Research Service (ARS) applied feedlot manure at various rates to sorghum near Amarillo, Texas over a 7-yr period (Mathers et al., 1975.) As Table 6.5 indicates, yield of sorghum grain with no manure applied was 4,490 lb/a. When feedlot manure was applied at annual rates of 10, 30, 60, and 120 t/a., with an average moisture content of about 40%, grain yields increased. Peak yields, or an average of 6,640 lb/a./yr, occurred at 10 t/a./yr.

The cost benefits of sorghum yield relative to application rate (Mathers et al., 1975) are calculated in Table 6.5. The lowest application rate, 10 t/a., was the most cost effective, yielding $9.70/t manure applied, which easily offset the $3.50/t cost of manure hauling and spreading. At the 60 t/a. application rate and higher, however, yield increase was only $1.40/t manure, an increase that failed to offset hauling and spreading costs. The lowest application rate resulted in about the same soil nitrate concentration as no fertilizer did. At the highest application rate, 120 t/a., soil nitrate concentration increased to about 50 ppm (Mathers and Stewart, 1971). Part of the excess N applied, i.e., that not taken up by the crop, had the potential to leach. Again, the greatest benefits and the fewest problems resulted from low application rates meeting fertilizer requirements.

The effects of manure application on sorghum, corn, and wheat during an 11-yr period were studied at Bushland, Texas. Residual benefits of manure at high rates on corn and wheat were evident in terms of sustained yields after manure application ceased (Mathers and Stewart, 1984).

Feedlot manure sometimes can correct micronutrient deficiencies such as iron chlorosis in sorghum. Manure applied to a calcareous soil, i.e., Arch fine sandy loam, in the Texas Panhandle increased grain sorghum yields nearly threefold—from 2,320 lb/a. with no manure to 6,210 lb/a. with 5 t/a. of manure and to 5,820 lb/a. with 15 t/a. manure (Mathers et al., 1980; Thomas and Mathers, 1979). When commercial N and P fertilizer was applied, yield actually was 49% lower than that of the control.

A guide using N content to determine manure application rate was developed by the USDA-ARS (Gilbertson et al., 1979b) (Table 6.6). This guide takes into account both the slow rate of release of organic N from manure and the N concentration. If, for example, cattle manure contains 2% N on a dry basis, 7 t/a. of dry manure is required for the first year to supply 100 lb available N/a. Release of residual organic N lowers manure requirement to 5.8 t/a. in the second year and to 4.4 t/a. in the fifth.

Table 6.5. Value of feedlot manure for grain sorghum production in Bushland, Texas, 1969–1973 (Mathers et al., 1975)

Annual Treatment	Average yield (lb/acre/yr)	Yield increase[a] (lb/acre/yr)	Incremental yield value	
			$/acre/yr	$/t
Check—no fertilizer	4,490	—	—	—
N[b] (240 and 120 lb N/acre)	4,490	1,950	87.75	—
N-P-K (240 and 120 lb N/acre)	4,490	1,920	86.40	—
Manure				
10 t/acre	6,640	2,150	96.75	9.70
30 t/acre	6,490	2,000	90.00	3.00
60 t/acre	6,360	1,870	84.15	1.40
120 t/acre	5,120	630	28.35	0.24
240 (3-yr trmt and 2-yr recovery)	900/6,800	−1,230	−55.35	−0.23
240 (1-yr trmt and 4-yr recovery)	330/6,750	976	43.92	0.18

[a]Assumes price of sorghum grain is $4.50/100 lb.

[b]N = nitrogen, P = phosphorus, K = potassium.

Air Pollution

Feedlot Dust

In hot, dry weather, feedlot cattle can create high dust-concentrations, especially for the approximately 2 hr around dusk, when cattle activity increases. Dust usually is minimal in the morning (Elam et al., 1971). Under calm conditions, feedlot dust can drift over nearby highways and buildings.

In 1970, the California Cattle Feeders Association (CCFA) sponsored a study of dust emissions at 25 cattle feedlots (Algeo et al., 1972). Standard high-volume samplers were stationed to monitor dust concentrations upwind and downwind of the lots. Before 1987, the EPA primary and secondary standards for total suspended particulate (TSP) were 260 and 150 micrograms (μg)/m³, respectively. The range measured in the CCFA research was from 54 to 1,268 μg/m³, and the overall average for the 25 feedlots was 654 μg/m³ (Algeo et al., 1972); Peters and Blackwood 1977). At some feedlots, dust emissions were within EPA guidelines, possibly because of sprinkling or other management practices. Using the California data, the EPA established beef cattle feedlot-emission factors (U.S. Environmental Protection Agency, 1986) based on worst-case assumptions (Peters and Blackwood, 1977).

At Texas A&M University, dust emissions were measured in replicated experiments at three feedlots (Sweeten et al., 1988). Net increases in TSP concentrations, that is, in upwind minus downwind TSP concentrations, averaged 412 μg/m³; range was 16 to 1,700 μg/m³. These values were 37% smaller than those in the California dust emission studies but still exceeded state and federal TSP standards in effect before 1987.

In July 1987, the EPA (1987b) changed the basis of ambient-air quality standards from TSP concentration to a *PM-10* (median aerodynamic particle size of 10 microns) of 150 μg/m³. In the Texas studies with one type of PM-10 sampler, property line results met the new EPA ambient standard; with the other type of sampler, results exceeded the standard (Sweeten et al., 1988). The PM–10 dust concentrations were 19 and 40% below the TSP measurements for the same sampling sites. Data indicate that if surface manure moisture is maintained above 30%, dust concentrations (net TSP) will be less than 150 μg/m³.

Dust control methods include watering unpaved roads, watering feedlot surfaces with mobile tankers or solid set sprinklers, and controlling cattle stocking rate in relation to precipitation and evaporation (Sweeten, 1982). The amount of manure moisture generated by cattle depends directly on live weight and inversely on stocking rate (Sweeten, 1990a). At an average spacing of 200 ft²/head, this amounts to an equivalent depth on the pen surface of 17.4 in./yr (440 mm/yr). Beef cattle weighing 1,000 lb/head excrete 8.22 m³, or 2,172 gallons (gal.), of moisture annually (American Society of Agricultural Engineers, 1993a).

Mobile tankers offer an excellent opportunity to apply water to both roads and feedlot surfaces (Sweeten, 1982). By means of a specially designed nozzle, water is applied in a fan pattern to cover 60 to 80% of pen surfaces, excluding shaded areas. Approximately 0.1 to 0.2 in. water (H_2O)/d can be applied by operating the tanker along feed and cattle alleys. Scraping the feedlot surface frequently with a box scraper decreases the amount of water necessary and removes loose, powdery manure before it exacerbates dust problems.

Feedlot Odor and Control

Odor is likely to cause complaints farther downwind than dust emissions are likely to carry and is more difficult to manage. Odor complaints are most likely after significant precipitation events, when pens are wet, and in warm weather.

For open cattle-feedlots, manure treatment for odor control consists of maintaining aerobic conditions to the extent possible. Primary odor-control approaches are to keep manure dry and inventory minimal (Sweeten and Miner, 1979). All pens must be drained adequately. If feedlot surfaces, alleys, and ditches are kept clean and graded to shed water rapidly, recovery after rainfall will be hastened. Thus, drainage channels can be paved, and manure on the concrete apron behind feedbunks, which usually is

Table 6.6. Tons of dry manure needed to supply 100 lb of available nitrogen during the cropping year (Gilbertson et al., 1979b)

Length of time applied (yr)	Nitrogen content of manure (% dry weight)					
	1.0	1.5	2.0	2.5	3.0	4.0
1	22.2	11.6	7.0	4.6	3.1	1.4
2	15.6	9.0	5.8	3.9	2.8	1.4
3	12.7	7.7	5.1	3.6	2.6	1.4
4	11.0	6.9	4.7	3.4	2.5	1.3
5	9.8	6.3	4.4	3.2	2.4	1.3
10	6.9	4.9	3.7	2.8	2.2	1.3
15	5.6	4.2	3.3	2.6	2.0	1.2

damp, should be collected at least monthly. Feedlot surface can be oriented to have a favorable sun angle much of the day, and runoff holding ponds can be pumped down promptly. When necessary, treatments such as oxidizing chemicals, odor absorbing compounds, and bacterial/enzyme products can be used (Miner and Stroh, 1976; Paine, 1973; Ritter, 1980).

Selecting a site with minimal probability of wind direction toward neighbors, especially at times of unfavorable atmospheric stability, can compensate partly for limited distance. A site should be chosen where under stable atmospheric conditions the wind has lower than a 5% probability of carrying odor toward the nearest neighbor or town.

Managing Settled Solids in Holding Ponds

Feedlots should use sedimentation basins, channels, or traps allowing solids to settle in small, accessible locations, which are conducive to rapid drying and frequent collection. Types of settling basins include shallow earthen basins or concrete pits 3 to 4 feet (ft) deep with a grooved concrete entry ramp for solids removal. Outlets consist of a buried culvert with a vertical riser pipe with perforations or vertical slot openings 0.75 to 1.0 in. wide protected by an expanded metal trash rack or by weirs (Loudon et al., 1993). Another method of settling solids is placing just outside feedpens an earthen channel with less than 1% slope. This channel discharges supernatant to a holding pond by weir overflow and/or by vertical slot inlet pipe.

A runoff sediment basin adjacent to the feedlot should have a volume equivalent to 1.25 a.-in./a. of feedlot surface (Gilbertson et al., 1979a). If the settling basin is remote from the holding pond, the volume should be as high as 3 a.-in./a., i.e., 3 in. equivalent runoff depth. Building sediment basins inside feedpens is discouraged because water should be drained rapidly from pens.

Settling basins should be cleaned promptly to restore their capacity and to remove wet manure so as to decrease odor and to destroy fly breeding sites. Methods of sediment removal from basins and runoff holding ponds include use of draglines, dozers, wheel loaders, elevating scrapers, floating dredges, and slurry agitators and pumps (Lindemann et al., 1985; Sweeten et al., 1981; Sweeten and McDonald, 1979).

The nutrient content of runoff holding-pond sediment is substantial in that it is composed of greater than 3% total N and greater than 1% P (Sweeten, 1990a; Sweeten et al., 1981). Potassium and Na levels usually are low because these elements are leached out with the liquid fraction so that the potential salt hazard is less than with the runoff itself.

Feedlot Slope and Mounds

For good drainage, feedpen slopes should be 2 to 6% (Paine et al., 1976). The main slope should be away from the feedbunk and toward the back of the pen. Building feedlots on steep slopes, i.e., slopes exceeding 8%, is unwarranted and may lead to erosion problems. Because they cause excess runoff and sediment transport to the lower pens, long slopes with pen-to-pen drainage are undesirable. The flow path for runoff to a drainage collection channel should be as short as possible (Sweeten, 1990a).

Uniformly well-drained feedlots probably do not need mounds. But in flat feedpens, i.e., pens with 0 to 2% slope, well-constructed and well-drained mounds are valuable because they provide cattle with a dry place to stand or to lie. Additional references pertaining to design of feedlot mounds appear in Sweeten et al. (1988).

Managing the Feedlot Surface

The feedlot floor usually consists of a compacted interfacial manure/soil layer acting as a biological seal and decreasing water infiltration rate to lower than 0.002 in./hr (Mielke and Mazurak, 1976; Mielke et al., 1974). This zone of reduced infiltration restricts the leaching of salts, nitrate, and ammonium into the subsoil, thereby reducing the potential for ground water pollution (Schuman and McCalla, 1975).

Bulk density of the manure layer on a feedlot surface has been measured at 47 to 58 lb/ft^3 (Mielke et al., 1974). Immediately below this manure layer, the compacted manure/soil interface has been shown to have a density of 62 to 106 lb/ft^3; the density of the underlying soil, 75 to 100 lb/ft^3. Inasmuch as feedlot manure has about one-half the density of the underlying soil, less energy should be needed to collect the organic matter only while leaving the soil. The manure itself usually has a shear plane facilitating manure collection above the interfacial layer.

When a compacted layer of manure remains on the feedlot surface, leaching of nutrients and salts into the underlying soil profile decreases (Algeo et al., 1972; Norstadt and Duke, 1982; Schuman and McCalla, 1975). Elliott et al. (1972) collected soil water samples at 1.5, 2.3, and 3.5 ft beneath a level cattle-feedlot surface on a silt loam/sand soil profile. Nitrate concentrations in deep soil generally were lower than

1 ppm, compared with 0.3 to 101.0 ppm in the top 3 in. Low nitrate-N concentrations below 3 in. indicate that anaerobic conditions have caused denitrification.

Solid-Manure Collection

The approach to manure collection should be that of "manure harvesting" instead of "cleaning pens." By using methods designed to maintain a surface seal, to promote drainage, and to collect a quality product, machine operators can facilitate manure harvest.

Solid manure can be collected in several ways (Sweeten and Reddell, 1979). The elevating scraper has a high collection rate (114 t/hr) and the highest energy-efficiency (1.18 horsepower [hp]/hr) of all such methods. Moreover, it is a precise cutting machine able to slice through manure and to leave an undisturbed manure/soil layer and a relatively smooth feedlot surface. Tractor-drawn box scrapers frequently are used to collect loose surface manure for dust and odor control, to maintain smooth drainage surfaces, and to build up mounds. Road graders sometimes are used to collect damp manure in feedbunk aprons and surface manure in windrows. Manure collected by the graders is collected later by wheel loaders or elevating scrapers. Operators frequently need to collect manure accumulating beneath fence lines; if this is unattended, water may pond on the feedlot surface and create a breeding ground for flies.

To avoid formation of a firm manure pack, manure must be collected from all pens before expected periods of cold and/or wet weather. Much of this manure falls within about 50 ft of the feedbunk and traps moisture. The feedbunk apron should be cleaned frequently by means of a wheel loader, elevating scraper, or road grader. The concrete apron needs to be 8 to 12 ft wide, or wider—at least one width of the tire tracks.

Solid-Manure Collection Practices in Texas Feedlots

Solid manure from open, unpaved dirt feedlots in Texas is collected mainly by private contractors who usually serve several feedlots. Manure is collected and loaded into a fleet of trucks that haul and spread manure at typical application rates of 5 to 25 t/a., wet basis.

In 1989, 12 contractors who collected manure from Texas cattle feedlots serving 1.4 million head of cattle on feed were surveyed to obtain information about their payments to feedlots, charges to farmers, and manure application rates on crops (Sweeten and Withers, 1990). Manure collection costs were \$2.15/t plus \$0.12/t-mile. So, for a 10-mile, one-way haul, cost to farmer averaged \$3.35/t applied manure. For a 10 t/a. application rate, the cost thus is \$33.50/a. for manure fertilizer. Most manure is hauled 5 to 15 miles.

The contractors' survey showed that crops are being fertilized properly with manure, at an average rate of 12 t/a./yr, as-received basis, on irrigated land. Application rates for dryland crops are about 6.5 t/a./yr, approximately half those for irrigated crops.

Feedlot managers are focusing on manure and wastewater management to control water and air pollution, to provide well-maintained feedlot conditions for cattle, to recover nutrients in the form of fertilizer, and to maintain or to improve feedlot efficiency. The necessary technologies are well established, and regulations are in place at federal and state levels. Because cattle feeders increasingly are paying attention to these technologies, the cattle feeding industry should remain a prominent agricultural sector in the twenty-first century. Meanwhile, additional research needs to be focused on assessment and control of odor and other forms of air pollution and on tradeoffs between air- and water-pollution control measures. These data should aid in the design and the operation of productive and environmentally sound feedlots.

7 Dairy-Farm Waste Management and Utilization

Summary

In the United States, there are approximately 255,000 farms with at least one dairy cow, and an estimated 160,000 commercial dairy farms have an average herd size of 42. Statistical information about animal based agricultural enterprises appears in Table 4.1. Changes in technology coupled with increasing production of milk/cow have enabled farmers to increase production from 5,000 to 14,000 lb/cow/yr.

The milking center can be a nonpoint source for pollution, placing the dairy producer in violation of environmental laws and regulations. Waste management system design takes into account such factors as drylot area, cow number and size, cleaning method, desired storage period, water volume used in preparing cows for milking on a daily basis, sanitary operation in milking parlor and in milk house, and floor flushing practice. Practices affecting water usage and feed system determine to a great extent the success of waste minimization efforts.

Milking center waste can be used in several ways, e.g., as an animal feed. Additionally, fertilizer value can be recovered from the wastestream; the liquid phase can be used for irrigation; the fibrous solids can be used as a bedding material after composting and drying; and the waste can be by-processed anaerobically to produce and to capture methane (CH_4) as an energy source for farm operations, e.g., milk house heating or hot water sanitizing. Milk waste also has been used routinely by producers to supplement animal feed rations for calves, to which more than 1.6 billion lb of milk, or 1.1% of milk produced, was fed in 1988.

Introduction

On dairy farms, major point sources for waste generation are the animal housing facility, the milking parlor, the milk handling equipment, and the barnyard. Dairy waste consists primarily of manure but also contains significant quantities of feed, bedding, and soil. A unique aspect of milking center waste-generation is that a high volume of water is used for cleaning and is discharged with milk, cleaning chemicals, and sanitizers. Occasionally, milking centers may need to dispose of raw milk not permitted to enter commercial channels. When milking center wastes are mismanaged, obnoxious odors, dirty cows, slippery foot surfaces, increased mastitis in the herd, and deficiencies in milking parlor and milk house conditions, all of which can impair milk quality, may be encountered.

Zall (1972) conducted surveys on 24 New York state dairy farms to characterize the wastestreams generated. Overall waste value averages for these 24 dairy farms appear in Table 7.1.

Table 7.1. Milking center waste volumes and BOD_5[a] lb determined from 24 New York state farms in June 1971 (Zall, 1972)

Operation characteristics	Averages for all farms
Number of cows in herd	100.00
Total gal. waste/day	405.00
Total lb BOD_5/day	12.70
Settleable solids, as volume, ml/L	49.50
Gal. waste/cow/day	4.10
Lb BOD_5/cow/day	0.13

[a]BOD_5 = five-day biochemical oxygen demand.

Waste Management

Figures 7.1, 7.2, and 7.3 schematically profile common waste-management practices used by dairy producers. These waste handling systems address several Grade A requirements and comply with state and federal environmental laws and regulations. Management objectives are

1. to decrease odors and fly breeding grounds,
2. to decrease labor requirements,
3. to provide flexibility for the spreading of manure on land,
4. to keep cows and barnyard clean,
5. to prevent pollution and contamination of surface and ground water supplies, and
6. to minimize fertilizer losses from the degradation of organic constituents present in the manure.

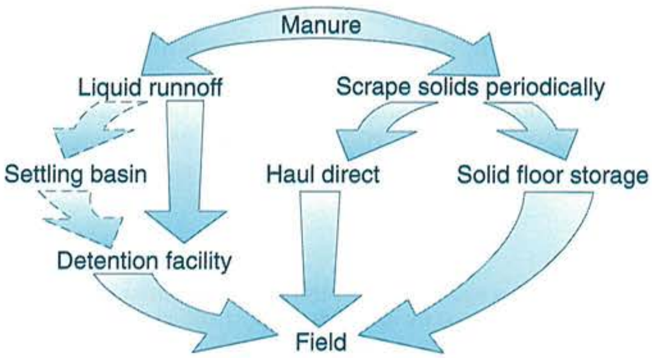

Figure 7.1. Solid-handling systems for dairy (Mentzer et al., 1969).

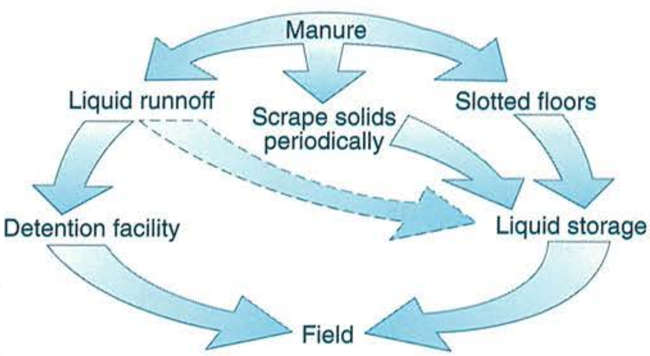

Figure 7.2. Liquid-handling systems for dairy (Mentzer et al., 1969).

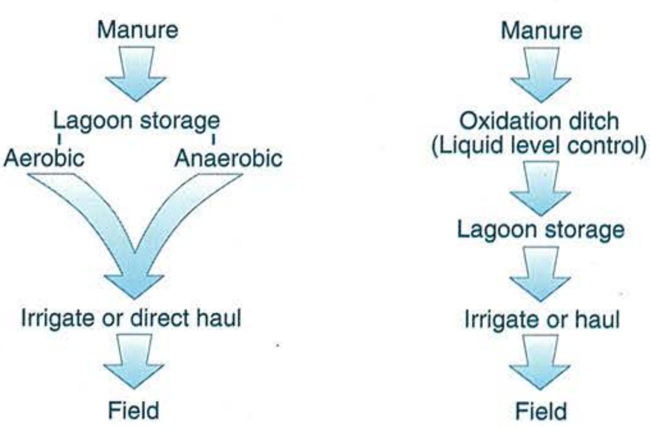

Figure 7.3. Partial treatment systems (Mentzer et al., 1969).

To achieve these objectives, waste management system design takes into account such factors as drylot area, cow number and size, cleaning method, desired storage period (minimum of 90 d), water volume used in preparing cows for milking on a daily basis, sanitary operations in milking parlor and in milk house, and floor flushing practice.

Waste Minimization

Practices affecting (1) water usage and (2) feed system determine to a great extent the success of waste minimization efforts. The amount of water used to prepare each cow for milking, the programmed cleaning-in-place operation for milking equipment, the cleaning of bulk tanks, and the flushing of concrete surfaces also are important. The best opportunities to decrease daily water usage arise during preparation of cows for milking and manual flushing of concrete surfaces, because these operations traditionally are controlled by people. Incorporation of automatic shut-off valves on water supply hoses in milking parlor, milk house, and barnyard have proved the most effective means of reducing water usage.

Feed frequently is found in significant quantities in the wastestream. Thus, the dairy producer pays not only for feed but for related waste-disposal labor. Wasted feed also represents a lost resource in that it is unavailable to the cow for conversion into a revenue generating product.

Although water and feed conservation programs are important, the dairy producer must bear in mind the importance of the farm's topography, or drainage conditions. In addition to serving as a vehicle for transporting pollutants to surface and ground waters, storm water runoff and melting snow can contribute significantly to milking center wastestream. Stream discoloration, toxicity conditions involving ammonia-N, and stream O_2 depletion may result, and unwanted bacterial populations may be added to the stream. In short, the milking center can become a nonpoint source for pollution, placing the dairy producer in violation of environmental laws and regulations. The milking center complex therefore should provide adequate slopes for its drylot systems; use road ditches and terraces as drainways; equip all buildings with gutters discharging roof water away from the lot and from waste collecting facilities; and install proper slopes away from buildings, feedbunks, and waterers.

Waste Utilization

Milking center waste can be used in several ways, e.g., as an animal feed. Additionally, fertilizer value can be recovered from the wastestream; the liquid phase can be used for irrigation; the fibrous solids can be used as a bedding material after composting and drying; and the waste can be by-processed anaerobically to produce and to capture methane (CH_4) as an energy source for farm operations, e.g., milk house heating or hot water sanitizing. Milk waste also has been used routinely by the producer to supplement animal feed rations for calves, to which more than 1.6 billion lb of milk, or 1.1% of milk produced, was fed in 1988.

The fertilizer value recovered from dairy waste is influenced by the methods used for handling, storing, and applying to land. The most valuable component of dairy waste is N, but this is lost easily. The greatest N losses occur for solid type waste collected in an open lot (55% loss) and for liquid-type waste handled in a lagoon system (80% loss). Moreover, when these wastes are applied to land, an additional N loss of 25% is common. Table 7.2 summarizes the average yearly fertilizer value expected in the dairy wastestream from a dairy cow, per 1,000 lb live weight.

Economic and Societal Importance of the Dairy Industry

Total milk production in the United States is approximately 150 billion lb (69.4 million t) annually. Of this volume, about one-third is used for fluid milk products; one-third, for cheese and cultured products; and one-third, for butter and powder. According to 1987 data (Bulletin of the International Dairy Federation, 1989; *Milkfacts*, 1990), dairy farmers were paid \$17.5 billion for raw milk. This raw material, processed into market products, generated more than \$40 billion in sales (Novakovic, pers. com., 1990).

In the United States, there are 254,800 farms (Bar, pers. com., 1991) with at least one dairy cow, and an estimated 160,000 commercial dairy farms have an average herd size of 42 cows. About 10% of these farms each have more than 100 cows. Changes in technology coupled with increasing production of milk per cow have enabled farmers to increase production from 5,000 to 14,000 lb/cow/yr. And farm labor per cow in 1988 was only 20% of that in 1950 (Bulletin of the International Dairy Federation, 1989).

Table 7.2. Average amount of fertilizer derived from the manure produced by dairy cows, per 1,000 lb liveweight per year for four methods of application to the land (Sutton et al., 1974)

	Method of land application			
Handling and disposal method	Broadcast (lb)	Broadcast and cultivation (lb)	Knifing (lb)	Irrigation (lb)
Manure pack				
N	77	91	—	—
P_2O_5	50	50	—	—
K_2O	112	112	—	—
Manure pit				
N	87	—	114	84
P_2O_5	54	—	54	45
K_2O	107	—	107	89
Daily scrape				
N	89	106	—	—
P_2O_5	52	52	—	—
K_2O	104	104	—	—
Open lot				
N	51	61	—	—
P_2O_5	30	30	—	—
K_2O	59	59	—	—
Lagoon				
N	—	—	—	23
P_2O_5	—	—	—	14
K_2O	—	—	—	80

Legend: N = nitrogen; P_2O_5 = phosphate; K_2O = potash.

8 Processing Wastes

Grain Processing for Oils

Summary

Wastestreams due to a number of processes, e.g., milling and extracting, are output from an edible-oil facility. Other sources of wastewater are contaminated runoff from truck and rail loadout areas and from tank farm drainage.

Major sources of air emission include (1) dust particulates from grain an meal handling, (2) hexane released during solvent extraction, (3) odors from meal drying and deodorizing, and (4) particulate emissions from coal fired boilers. Odor problems are eliminated in three steps. The first involves a distillate recovery systems, which recovers as a by-product, most of the fatty acids and many of the odors in the deodorizer vapor discharge. The second involves a closed-loop cooling system that keeps the fat laden hot-well water out of the cooling tower. The third involves a vapor scrubbing or oxidizing system, which eliminates the volatile organic compounds not yet removed.

Generating and handling solid and hazardous wastes have not constituted major problems in the industry although a number of significant sources of waste, e.g., bleaching clays, bleaching earth, and Ni catalysts, are causing increased concern.

The most important single factor affecting wastewater loading is the handling of refinery soapstock. Four methods for disposal or treatment are used routinely, viz., (1) acidulating soapstock for fatty acid value, (2) selling as raw soapstock on the open market, (3) spraying on meal as a fat additive, and (4) partly neutralizing and dewatering soapstock.

Introduction

The extracting, refining, and processing of edible oils produce a variety of waste products. This chapter, which focuses on conventional caustic refinements and on related downstream processes, briefly reviews major processes and facilities, especially as they relate to waste generation and control.

Process Components and Major Waste Sources

Figure 8.1 is a conceptual flow diagram showing the major processes occurring in a typical edible-oil facility. The diagram shows the major steps leading to final product, e.g., margarine, salad dressing, or mayonnaise, and the waste streams associated with each step. Table 8.1 relates waste loadings with waste streams. Waste streams due to

1. milling and extracting,
2. caustic refining,
3. further processing and handling (for example, bleaching and winterizing),
4. deodorizing,
5. acidulating,
6. tank car washing,
7. packaging,
8. margarine production, and
9. salad dressing and mayonnaise production

are considered.

Wastewater Loadings

Table 8.1 lists primary processes and associated waste loadings. Separate totals are presented with and without salad dressing and mayonnaise because these processes often are absent in a facility. Certain oil processing and refining operations have no oilseed processing facilities but instead bring in crude vegetable oil. To account for this practice, adjustments can be made to the figures in the table.

Only freon extractables (FOG) and BOD_5 are listed. At an edible-oil operation, numerous other parameters often are discussed, monitored, and interpreted, but, except under rare circumstances, treatment and control strategies ultimately involve these two items primarily. Loadings are presented as averages and as maxima. The variable operations of a fats and oil facility are such, however, that a true average is less relevant than an operating range. Maxima are

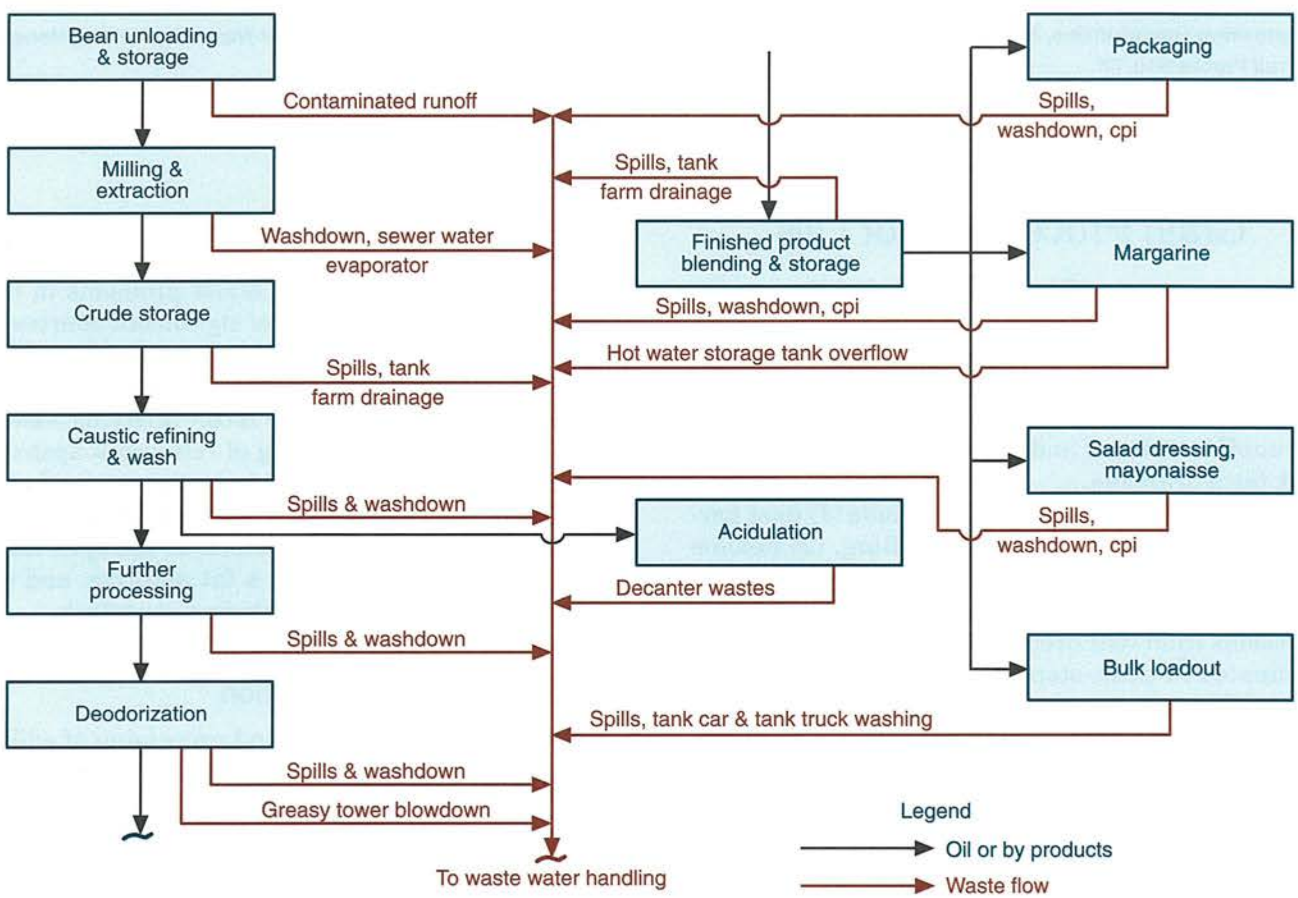

Figure 8.1. Flow diagram of edible-oil handling facilities.

reasonable upper figures, with higher loadings possible when spillage occurs or the process is controlled inadequately.

Seven criteria guided the presentation of data in Table 8.1:

1. milling and extracting: 80,000 bu/d;
2. caustic refining with single-stage water wash: 60,000 lb/hr, nondegummed soybean oil;
3. semicontinual deodorizing with scrub cooler, barometric condenser with atmospheric cooling tower;
4. acidulating of soapstock and washwater with 90 to 95% recovery efficiency;
5. bottling line and/or other extensive liquid-oil packaging;
6. margarine, mayonnaise, and salad dressing production and packaging; and
7. washing of tank cars for finished oil only (cars carrying crude oil excluded).

Obviously, operations of atypical size or those omitting certain processes will have different waste loads. This applies especially to operations involved in acidulation or in mayonnaise and salad dressing processing. The effects of process control and its impacts on wastewater loading are outlined in the next section.

As noted, these loadings are representative for an operation run reasonably well from a process loss-control standpoint. But actual loadings depend on how well plants are run. Additionally, rates in Table 8.1 assume that all waste streams have been subject to at least a modest degree of gravity separation to aid removal of gross quantities of floatable oils and solids.

A final source of wastewater is contaminated runoff from truck and rail loadout areas and from tank farm drainage. During rainy periods, runoff from these sources can contribute the equivalent of 5 to 10 gal./min to total daily average flow and in fact may affect peak flows to a much greater extent.

Two other parameters of special interest are nickel (Ni) and P. The former may enter the wastewater stream from clean-up or from minor losses in hydrogenation process areas due to Ni catalysts. Caustic cleanings of filter screens from the catalyst are a particularly significant source of Ni, which often can be controlled.

Crude oils, particularly soybean oil, contain significant quantities of organic P in the form of phosphatides. During caustic refining and washing processes, these compounds are removed to a great extent from the oil phase. If refinery washwaters and soapstocks are acidulated, then P is carried into the water phase and converted into a largely inorganic form by means of acid digestion. Other sources of P exist in an edible-oil operation, but most P comes from the mechanism just described.

The edible-oil facilities described can generate in

Table 8.1. Fats and oils processes and wastewater loads from a well run facility

Process	Flow rate (gal./d[a], avg)	BOD[b] (lb/d)		FOG[c] (lb/d)	
		(avg)	(max)	(avg)	(max)
Milling and extracting	75,000	370	600	25	65
Caustic refining	11,000	220	1,000	115	400
Further processing	5,000	150	30	75	150
Deodorizing	5,000	40	100	20	50
Acidulating	19,000	3,200	5,000	25	800
Tank car washing	5,000	250	1,500	125	250
Packaging	10,000	250	1,000	125	500
Subtotal	130,000	4,480	8,500	510	2,215
Margarine	70,000	600	1,000	300	500
Salad dressing/mayonnaise	50,000	2,000	3,500	1,000	1,700
Total	250,000	7,080	13,000	1,810	4,415

[a]gal./d = gallons per day.

[b]BOD = biochemical oxygen demand.

[c]FOG = fats, oils, and grease.

the total wastestream between 500 and 1,000 lb P/d. Level depends on crude oil type, geographic area, and other factors relevant to P amount in oilseed.

Air Emissions

Major sources of air emission include (1) dust particulates from grain and meal handling, (2) hexane released during solvent extraction, (3) odors from meal drying and deodorizing, and (4) particulate emissions from coal fired boilers. Table 8.2 summarizes loadings and/or limitations in three of these areas.

Grain dust arises from a variety of sources during handling and milling of oilseeds. Elevator losses as a whole usually are estimated at 3%. Dust collectors in the form of cyclones, bag houses, and related filters are universally used to control dust.

Solvent extraction. The industry as a whole has not been regulated as stringently for volatile organic-compound loss, e.g., hexane solvent loss, as many large emitters have. But the industry controls itself to some extent because of the high cost of lost solvent. The generally accepted limit for the entire operation is 0.26 lb hexane/100.0 lb beans crushed. A well-run mineral oil absorber at the end of the process is needed to stay within this limit.

Odor is a qualitative parameter from the standpoint of both measurement and control. The main sources of odor are meal drying and refined oil deodorizing. That acidulation has been an odor producer in some isolated instances generally has been the result of poor design and operation and usually is associated with batch, open topped kettles.

Both of the other two processes, meal drying and refined oil deodorizing, are inherent producers of odors, subjecting meal and oil to high temperatures so that volatile fractions will be driven off. Deodorization is done to strip odor causing compounds from oil. As will be discussed, the control of this odor has become an integral part of the processes themselves.

Deodorization of fats and oils is necessary to remove disagreeable flavors and odors naturally present or created during processing. Soybean oil deodorization produces odors that historically have produced the greatest odor-control challenge.

Table 8.2. Major air emission sources

Source	Loss rate
Hexane at extraction	0.26 lb/100 lb – crush
Odor in meal dryer and deodorizer	—
Coal fired boilers, particulates	0.03–0.05 lb/M M BTU input

Odor problems are eliminated in three steps. The first involves a distillate recovery system, which recovers as a by-product, of most of the fatty acids and many of the odors in the deodorizer vapor discharge. The second involves a closed-loop cooling system that keeps the fat laden hot-well water out of the cooling tower. The third involves a vapor scrubbing or oxidizing system, which eliminates the volatile organic compounds not yet removed.

A typical distillate recovery system consists of a scrub cooler located at some point in the deodorizer vacuum system. The deodorizer vapor effluent is stripped of approximately 95% of condensable organic material by direct contact in the cooler. Before being returned to the stripping tower, circulating distillate is cooled to remove condensation heat. Several equipment companies offer design and equipment packages for this function.

The remaining deodorizer vapors and the stripping steam are condensed in either barometric or shell-and-tube condensers. When additional control is unnecessary, the liquid discharge of both condensers and the air discharge of the last ejector are sent to a hot well. From there, cooling water passes to a cooling tower before being recirculated to condensers. This system is the source of normal soybean processing odor from processing facilities and usually involves direct condenser discharge—often gravity driven—to a hot well and then to a cooling tower. As part of a plant's oily-wastewater handling needs, cooling tower overflow and blowdown are discharged to be treated at a pretreatment facility.

If odors from the cooling tower require additional control, cooling water from the hot well is pumped through plate heat exchangers and indirect cooling is allowed for. But because of fouling problems, an extra heat exchanger must be provided to enable off-line heat exchanger cleaning. Either steam or water and detergent are used for cleaning. One benefit of steam is that fatty material is reclaimed more easily. The closed-loop system is more expensive to install, requires more equipment, and has higher energy costs to pump water and motive steam in the vacuum system.

If necessary, the third step of the odor control system involves passage of the last ejector stage air to either a Dowtherm or a Therminol boiler. As a portion of combustion air, vapor is oxidized almost completely. Other, less desirable, alternatives are jet Venturi scrubbers, packed towers, or carbon-bed absorbers.

Because of energy cost increases, **coal fired boil-**

ers, primarily for steam, have been installed by a number of processors. Especially in the Midwest, tax incentives encourage intrastate use of coal suppliers.

Primary concerns with boilers revolve around ash particulate emissions and associated visual plumes. Boilers installed before 1972 are equipped with mechanical collectors; newer units use a variety of fluid bed technologies to maximize efficiency and to decrease emissions. Controls to meet current emission levels, which differ locally, also come into play.

Solid and Hazardous Wastes

Generating and handling solid and hazardous wastes have not constituted major problems in the industry although a number of significant sources of waste are causing increased concern (Table 8.3).

Various **bleaching clays** are used to purify and to remove color bodies from refined oils. These wastes contain 25 to 35% oil and may combust spontaneously, a problem for sanitary landfill disposal. Several methods can be used to overcome this problem; for instance, the model refinery discussed produces daily about 5,600 lb waste earth, of which 1,250 lb is oil.

Bleaching earth use is primarily a function of crude oil quality and press efficiency. Because problem recognition due to process and economic implications already is widespread, substantial opportunities to decrease amount of waste earth used through process control, simply for environmental purposes, probably will not arise. Certain brands and types of filter media are better suited for various crude mixtures and presses; however, materials being used are dictated by process conditions.

In the hydrogenation of oil, **Ni catalyst** is used. Because it can be recycled a number of times depending on the plant, waste generation rates differ. The model refinery generates about 220 lb spent catalyst/d.

Although the EPA has not yet designated Ni as hazardous, several states have, and the element likely soon will be treated in this manner universally. Although opportunities may exist to decrease the volume of waste catalyst by reusing it through several hydrogenation batches, experts disagree on the benefits of such a procedure. The final measurement of waste catalyst can be made by measuring hydrogenation efficiency.

Table 8.3. Major solid waste sources

Source	Loss rate
Meal and grain solids	1–10 lb/1,000 bushels
Bleaching earth	5,600 lb/day
Waste catalyst	220 lb/day

Grain and meal solids are lost because their transport is highly mechanized, relying on conveyors, elevators, pneumatic systems, and related equipment. Losses tend to occur at transfer points along the conveyance system as well as at loading and unloading points, e.g., barge, rail car, and truck. Additionally, in cyclones, building dust collectors, and similar air emission control devices, losses of grain and meal solids occur, usually as a result of plugging and overflow.

Process Factors Affecting Waste Generation and Characteristics

Wastewater

The most important single factor affecting wastewater loading is the handling of **refinery soapstock**. Four methods for disposal or treatment are used routinely, viz., (1) acidulating soapstock for fatty acid value, (2) selling as raw soapstock on the open market, (3) spraying on meal as a fat additive (if a crush operation is present), and (4) partly neutralizing and dewatering soapstock.

Acidulation probably is the most misunderstood and maligned process in the entire fats and oils industry. The simplest aspect of acidulation design is that of producing acceptable-quality acid oil. The most difficult is minimizing the midphase and generally creating oil free wastewater. Thus, the facility must be designed properly with respect both to reaction kinetics and to mechanical aspects of acid/oil mixing, decanting, and midphase recovery. The second and third methods produce no wastes except those from handling losses but are not usually the most economical methods of dealing with soapstock. The fourth method is a recent innovation developed to proscribe water content of soapstock sold for acidulation elsewhere.

Although it should be a minor contributor to waste, **deodorization** can produce significant waste loads if the deodorizer has a poorly operated scrub cooler. The barometric recycling system should either have its own oil skimmer or operate on blowdown skimming. At times, an indirect heat exchange system is used to decrease odor problems developing in the greasy water tower. In any event, waste load should be no greater than deodorizer steam load, with about 500 mg/L FOG—the soluble oil fraction at steady-state recycle. Although several refiners are using polymer additions for enhancement, the economic benefit of such a procedure is questionable.

The waterwash centrifuge stage at times is susceptible to **oil breakover** due to back pressure control, and substantial quantities of oil can be involved. Few plants have a method, other than visual inspection, of monitoring or controlling the problem. A secondary gravity separator should be used in-line on the washwater stream to recycle the floatable refined oil directly instead of allowing it to downgrade as acidulated material.

Waste from **clean-up and handling losses** can be minimized if employees are well trained and wish to prevent waste. However, physical aspects, such as vacuum-pump seal water, which can make up a great percentage of total water flow if not recycled or otherwise minimized, should be considered.

To address the issue appropriately, a plantwide study of oil loss and wastewater generation points should be conducted. Subsequently, a cost-effectiveness analysis of potential operational and physical remedial measures can be conducted. Very few plants in which such procedures have been carried out have not gained many opportunities to reduce losses and costs.

Fruit and Vegetable Processing

Summary

Major waste-generation point sources associated with the industry include the washing steps for raw and processed produce, peeling and pitting practices, blanching, fluming the produce after blanching, sorting, and conveying the product within the plant.

Waste minimization begins with the establishment of a baseline, or benchmark, for each processing facility. Management should prioritize the major waste point sources and determine the appropriate strategies needed to decrease wastes.

Ideally, considerable waste reduction can be achieved if harvesting equipment permits additional stems, leaves, and culled materials to remain in the field during harvest. If crop washing, grading, and trimming can take place there, then additional soil and food residues will remain at the farm. Realistically, most such wastes are being handled at vegetable and fruit processing plant sites, where primary waste-management strategies are water conservation. The industry has adopted a number of practices evidencing heightened sensitivity to this need.

Incorporating appropriate handling systems into the processing environment can minimize waste. One such approach is to decrease volume in the discharge. A second approach is to decrease organic load by preventing fruits from coming in contact with water. Several water conservation and waste prevention techniques are available by which to decrease water volume. A number of waste treatment methods are available to make fruit processing wastewater suitable for discharge. Solid wastes from fruit processing operations are returned to the land, as well. Drying operation can remove excess water from wastes. Another alternative is to devise new processes for using fruit processing solid wastes. Recovered solids usually have nutrient values useful in animal feed rations. Thus, it is a common waste handling practice to find drying operations in place to handle these separated, wasted food solids.

Introduction

The fruit and vegetable processing industries may be described as consisting of two segments—fresh pack and processing (Carawan et al., 1979c). The former collects crops and field packs them into lug boxes or bulk bins for shipment to a produce finishing plant. Crops are cooled to preserve integrity and fumigated or treated to control insect infestation or microbial disease development. The processing segment, or *packers*, includes all unit operations extending the shelf life of food being processed and adds value through produce modification to satisfy market niches.

The fresh pack segment of the industry shares unit operations with the processing segment. These operations are the sorting/trimming, washing, grading, and packing lines. But after the packing lines, additional unit operations may add to the waste generating scheme for the processing segment alone. Such additional operations may include combinations of peeling, stemming, snipping, pitting, trimming, chopping, and blanching. In some instances, the final product is dehydrated, e.g., chopped onions; in others, it is packaged and processed. Processing can include one treatment or a combination of several treatments, e.g., acidifying, brining, freezing, or cooking.

Major waste-generation point sources associated with the fruit and vegetable industry occur during crop harvesting and include the washing steps for raw and processed produce, peeling and pitting practices, blanching, fluming the produce after blanching, sorting, and conveying the product within the plant. Reducing size, coring, slicing, dicing, pureeing, and juicing process steps, as well as filling and sanitizing activities after processing, also contribute to the wastestream.

Economic and Social Impacts of the Processing and the Production Sectors

One of the best measures of an industry's impact on the economy is the use of income/employment multipliers (Connor, 1988; U.S. Department of Commerce, 1990). The average income multiplier for the food industry as a whole is 3.81. That is, for each $1 million invested in the labor force for processing food, another $2.81 million in generated income is infused into the supplier support base, e.g., vendors. But the income multiplier for the vegetable and fruit processing industries is only 1.7, a figure well below the food industries' average (Connor, 1988).

Another measure of an industry's impact on the economy is the multifactor associated with that industry's productivity. This measure is the rate of change in the use of labor, capital, material, and energy over a defined period and the influence of such a rate change on productivity. The vegetable and fruit processing industries have demonstrated a 0.5 multifactor over 30 yr (Connor, 1988).

Thus, it seems that the vegetable and fruit processing industries are mature and conservative. Clearly, they are an important component of the U.S. economy: review of the U.S. Department of Commerce's Bureau of Census (U.S. Department of Commerce, 1990) indicates that these industries contributed more than $30 billion to the economy in 1987. Table 8.4 summarizes Bureau of Census statistics derived from its 1987 Food Manufacturers Survey. The 1,629 processing plants represent jobs for 171,500 employees but also reflect a 70% decline in the number of plants, a decline occurring over the last 40 yr. These industries have increased by 40% the product value added to raw commodities and in 1 yr channeled more than an estimated 20.5 million t of processed food into the marketplace.

Tables 8.5 through 8.7 present the summarized statistical data for vegetable and fruit crops targeted for use by the processing sector, as reported by the USDA Statistical Reporting Service (SRS) (Census of Manufacturers, 1990). How these data relate to production inputs, processing outputs, and estimated losses and their value is summarized further in Table 8.8. The vegetable and fruit production sector contributed $30.7 billion to the U.S. economy and provided well in excess of 27.9 million t raw agriculture product to the processing sector.

The U.S. vegetable and fruit production and processing sectors continue to provide a safe, wholesome, nutritious, and reliable food source. Associated with production and processing activities are local jobs and thus a contribution to the economic base of the community.

Table 8.5. 1991 preliminary statistics for principal vegetable crops used for processing in the United States (U.S. Department of Agriculture's Statistical Reporting Service, Census of Manufacturers, 1987)

Principal vegetable crops for processing	Production acres harvested (thousands)	Production utilized (thousand t)	Value per ton ($)	Total value of crop (thousand $)
Bean, snap	233.4	775.8	174.40	135,327
Corn, sweet	542.3	3,380.7	71.60	241,926
Cucumber	103.8	622.8	208.50	129,856
Pea	332.7	478.1	258.60	123,630
Tomato	356.0	10,873.0	66.40	722,114
Total	1,568.2	16,130.4	NA[a]	1,352,853

[a]NA = not applicable.

Table 8.4. Economic impact of the fruit and vegetable industries based on 1987 estimated statistics (U.S. Department of Commerce, Bureau of Census, Food Manufacturers' Survey, Census of Manufacturers, 1987)

Industry identification	SIC[a] in the United States	Number	Employees (thousands)	Value added (million $)	Value shipped (million $)
Canned specialties	2032	211	24.5	2,652.4	5,350.1
Canned fruits and vegetables	2033	647	65.6	5,440.1	11,889.5
Dehydrated fruits, vegetables, and soups	2034	131	10.1	932.3	1,819.6
Pickles, sauces, and salad dressings	2035	382	21.5	2,544.8	5,050.3
Frozen fruits and vegetables	2037	258	49.8	2,986.8	6,606.2
Total	—	1,629	171.5	14,556.4	30,715.7

[a]SIC = Standard Industrial Classification.

Waste Characterization

Major wastewater characteristics to be considered for the vegetable and fruit processing industry are the wide ranges of wastewater volume and the concentrations of organic materials. Wastewater characteristics can be influenced by a number of factors such as the commodity processed, the process unit operations used, the daily-production performance level, and the seasonal variation, e.g., growing condition and crop age at harvest (Prior and Potgieter, 1981).

Table 8.6. **1991 preliminary statistics for secondary vegetable crops used for processing in the United States (U.S. Department of Agriculture's Statistical Reporting Service, Census of Manufacturers, 1987)**

Vegetable crop	Production acres harvested (thousands)	Production utilized (thousand t)	Value/t ($)	Total value of crop (thousand $)
Asparagus	91.8	43.8	955.00	41,865
Broccoli	113,000.0	101.1	392.00	39,584
Carrot	97.3	432.9	64.20	27,804
Cauliflower	64.1	45.4	496.00	22,473
Sweet potato	77.5	0.57	—[a]	—
Total	113,330.7	623.77	NA[b]	131,726[c]

[a]Not available.
[b]NA = not applicable.
[c]Estimated.

Table 8.7. **1991 preliminary statistics for principal fruit crops used for processing in the United States (U.S. Department of Agriculture's Statistical Reporting Service, Census of Manufacturers, 1987)**

Principal fruit crop for processing	Production utilized (thousand t)	Value/ton ($)	Total value of production (thousand $)
Apple	2,084.71	171.36	357,235.90
Apple	2,084.71	171.36	357,235.90
Cherry, sweet	75.72	668.00	50,580.96
Cherry, tart	93.0	570.32[a]	53,039.83[a]
Orange (1990 statistics)	6,759.56	206.00[a]	1,392,469.36[a]
Grapefruit (1990 statistics)	1,013.89	70.38[a]	71,353.76[a]
Apricot	7.17	407.00	29,161.55
Cranberry	487.60	361.07[a]	176,057.73[a]
Olive	54.0	633.00	34,182.00
Peach	636.85	316.00	201,244.60
Pear	0.44	306.00	13,464.00
Total	11,212.94	NA[b]	2,378,789.69

[a]Estimated.
[b]NA = not applicable.

Pollutant criteria of importance for vegetable and fruit products are BOD and TSS. The pH of wastewater can be important when lye peeling and cleaning-in-place operations are used. Table 8.9 presents historical data collected from analyses of raw wastewater discharged from the vegetable and fruit processing industry (Carawan et al., 1979c; Mulyk and Lamb, 1977; Soderquist, 1975; U.S. Environmental Protection Agency, 1971; Viraraghavan et al., 1983). Tables 8.10 and 8.11 present similar historical data derived from the USDA-SRS (U.S. Department of Commerce, 1990), which relate the weight of final canned product derived from 1 lb of raw product and the final frozen weight of product from the farm weight. When gross raw-produce weight input-data (27,967,110 t) are compared with gross processed weight output-data (20,540,000 t), an estimated loss of 26.6% occurs during postharvest handling, processing, and packaging. This loss, estimated at $138.14/t, represents more than $1 billion in waste.

When individual vegetable and fruit crops are examined in terms of waste streams generated, it is evident (Table 8.9) that cauliflower uses the highest H_2O/t product processed, at an average flow of 17,000 gal./t. Of the vegetable produce generating the highest organic BOD and TSS loadings, sweet and white potatoes contribute, respectively, an average BOD of 93 lb and 84 lb/t processed and an average TSS of 57 lb and 128 lb/t processed. Types of fruit produce that have high waste streams are apricots, cherries, peaches, and pears. The BOD strengths range from an average of 35 lb/t processed for peaches to 50 lb/t processed for pears. Pears also contribute the highest TSS/t processed, at an average discharge of 12 lb.

Preservation method, e.g., canning or freezing, can affect final product yield, and degree of raw produce weight lost is presented in Tables 8.10 and 8.11. For canned vegetables and fruit, whole corn, pumpkin, squash, citrus salad, grapefruit sections, and orange sections have the poorest yields, which correlate with the higher losses. Frozen vegetable produce generally has lower final yields and higher loss percentages than canned. Cut corn has the lowest yield and the associated highest produce loss of the vegetables studied. Frozen fruit produce has higher final product yields, with apples and pineapples at the lower end in this category.

As stated, the vegetable and fruit processing industry is mature and very conservative. Management has been reluctant to invest capital in new raw-material handling equipment designed to reduce waste stream. These investments usually occur as responses to regulatory compliance requirements for reducing pollutant discharges entering a tributary receiving stream or a publicly managed sewage-water collection system.

Process-Waste Point Sources

In the processing environment for vegetable and fruit material handling, heating, cooling, and packaging, there are six major contributing point sources for waste (Carawan et al., 1979c; Mulyk and Lamb, 1977; Soderquist, 1975; U.S. Environmental Protec-

Table 8.8. Estimated product losses for the fruit and vegetable processing industries in 1991

Production crop	Input production (thousand t)	Output processing (thousand t)	Output losses at 26.6% (t)	Estimated cost from losses (million $)
Principal vegetables	16,130.40	11,847.47	4,282.93	359.12
Secondary vegetables	623.77	458.04	165.73	34.99
Principal fruit	11,212.94	8,234.49	2,978.45	631.87
Production total	27,967.11	20,540.00	7,427.11	1,025.98

Table 8.9. Representative raw wastewater characteristics associated with typical vegetable and fruit raw products during processing (Carawan et al., 1979; Mulyk and Lamb, 1977; Soderquist, 1975; U.S. Environmental Protection Agency, 1971; Viraraghavan et al., 1983)

	Flow (1,000 gal./t)			BOD[a] (lb/t)			TSS[b] (lb/t)		
Crop	Min.[c]	Mean	Max.[d]	Min.	Mean	Max.	Min.	Mean	Max.
Vegetable product									
Asparagus	1.9	8.5	29.0	0.9	4.9	22	4.3	7.5	13
Bean, snap	1.3	4.2	11.2	1.6	15.0	81	0.8	6.1	46
Broccoli	4.1	92.0	21.0	5.8	20.0	61	4.6	17.0	61
Carrot	1.2	3.3	7.1	17.0	30.0	53	4.5	17.0	53
Cauliflower	12.0	17.0	24.0	5.5	16.0	36	2.8	7.8	22
Pea	1.9	5.4	14.0	16.0	38.0	87	3.8	11.0	38
Pickle	1.4	3.5	11.0	26.0	42.0	75	3.0	8.2	23
Potato, sweet	0.4	2.2	9.7	39.0	93.0	217	40.0	57.0	117
Potato, white	1.9	3.6	6.6	42.0	84.0	167	39.0	128.0	423
Spinach	3.2	8.8	23.0	5.7	14.0	31	1.8	6.1	21
Squash	1.1	6.0	22.0	—	20.0	—	—	14.0	—
Tomato, peeled	1.3	2.2	3.7	6.3	9.3	14	5.8	12.0	26
Tomato, product	1.1	1.6	2.4	2.2	4.7	9.7	5.6	10.0	19
Fruit product									
Apple	0.2	2.4	13.0	3.9	18.0	44	0.4	4.5	21
Apricot	2.5	5.6	14.0	18.0	40.0	80	5.0	9.9	19
Berry	1.8	3.5	9.1	11.0	19.0	40	1.4	7.1	22
Cherry	1.2	3.9	14.0	21.0	38.0	78	1.0	2.0	3.8
Citrus	0.3	3.0	9.3	0.9	9.6	26	0.7	3.7	14
Peach	1.4	3.0	6.3	17.0	35.0	70	3.4	8.6	21
Pear	1.6	3.6	7.7	19.0	50.0	125	3.6	12.0	33
Pineapple	2.6	2.7	3.8	13.0	25.0	45	5.2	9.1	17
Pumpkin	0.4	2.9	11.0	9.2	32.0	87	2.0	12.0	17

[a]BOD = biological oxidation demand.

[b]TSS = total suspended solids.

[c]Min. = minimum.

[d]Max. = maximum.

tion Agency, 1971; Viraraghavan et al., 1983). These sources are the following operations: (1) raw produce washing, grading, and trimming, (2) washing after steam/lye peeling and/or size reducing, (3) blanching and fluming, (4) filling, (5) sanitation/plant cleanup, and (6) processed product cooling. Plant management practice greatly influences process operation efficiency relative to final product yield and waste quantity generated (refer to Table 8.9 for industrial variability).

Waste Minimization

Waste minimization begins with the establishment of a baseline, or benchmark, for each processing facility (Carawan et al., 1979c). Measurements must be taken and analyses performed for defined point-source waste stream discharges and for total discharge from the facility. Such measurements as rate of water use, defined quantities of production throughput, actual quantification of discharge volumes over the course of production runs with correlated data for BOD and/or COD, pH, and TSS help establish the baseline.

After the current wastestream is characterized, efforts should be initiated by plant management to prioritize the major waste point sources and to determine the appropriate strategies needed to decrease these wastes. Successful strategies have been (1) the definition of waste control centers and the establishment of monitoring programs for them, (2) the institution of employee awareness programs and demonstrated management commitment to waste reduction, (3) the provision for employee training programs to decrease waste, and (4) the development of waste segregation practices, with the most appropriate waste-management options based on feasibility, economics, and compliance considerations.

Table 8.10. Vegetable and fruit-product yields and raw produce losses for common canning processing operations (U.S. Department of Commerce, 1989)

Canned product	Final product yield (lb)	Average losses (%)
Vegetable		
Asparagus	0.819	18.1
Bean, snap	1.404	A
Carrot	0.750	25.0
Corn, whole	0.394	60.6
Pea	1.353	A
Pickle	1.344	A
Potato, sweet	0.784	21.6
Potato, white	0.636	36.4
Pumpkin and squash	0.369	63.1
Spinach	1.110	A
Tomato	0.644	35.6
Fruit		
Apple	0.538	46.2
Applesauce	0.800	20.0
Apricot	1.440	B
Berry (average for all types)	1.500	B
Cherry, sweet—pitted	0.979	2.1
Cherry, tart—pitted	0.948	5.2
Cherry, unpitted	1.414	B
Citrus salad	0.477	52.3
Cranberry	2.580	B
Grapefruit sections	0.495	50.5
Orange sections	0.450	55.0
Peach, clingstone	1.196	B
Peach, freestone	0.979	2.1
Pear	1.000	B
Pineapple	0.585	41.5

A = Increase; liquid added.

B = Syrup added back.

Waste Management

Waste management practices are influenced by the nature of the waste stream generated, the site location of the processing plant, and the stringency of legislated discharge limitations (Carawan et al., 1979c; Loehr, 1974; Sistrunk, 1979; Tchobanoglous, 1976). Generally, these practices evolve as a result

Table 8.11. Vegetable and fruit-product yields and raw produce losses for common freezing operations (U.S. Department of Commerce, 1989)

Frozen product	Final product yield (lb)	Average losses (%)
Vegetable		
Asparagus	0.52	48
Bean, snap	0.85	15
Broccoli	0.75	25
Cauliflower	0.70	30
Corn, cut	0.27	73
Carrot	0.55	45
Pea	0.92	8
Potato, white	0.40	60
Potato, sweet	0.50	50
Spinach	0.70	30
Squash	0.55	45
Fruit		
Apple	0.60	40
Apricot	0.91	22
Berry, average	0.94	6
Cherry, sour	0.90	25
Cherry, sweet	0.85	15
Peach	0.80	33
Pineapple	0.625	50

of the immediacy of the regulatory environment. The goal of the initial stage is basic waste reduction and subsequent waste minimization; that of the final stage, monitoring and control.

Ideally, considerable waste reduction can be achieved if harvesting equipment permits additional stems, leaves, and culled materials to remain in the field during harvest. If crop washing, grading, and trimming can take place in the field, then additional soil and food residues will remain at the farm. Realistically, most such wastes are being handled at vegetable and fruit processing plant sites. Primary waste-management strategies used by this industry are water conservation (LaConde and Schmidt, 1976; Liptak, 1974; Mercer, 1971; Ralls et al., 1973; Robe, 1977; Smith, 1982) and waste-solids separation (Anonymous, 1980; Lindner, 1981; Sistrunk, 1985).

Water use by the vegetable and fruit processing industry is essential to the washing, heating, and cooling of food products. But the industry has adopted a number of practices evidencing heightened sensitivity to the need for water conservation:

1. use of air flotation units to remove suspended debris from raw crop materials;
2. recovery and reuse of process water throughout the processing plant (LaConde and Schmidt, 1976; Mercer, 1971; Robe, 1977; Smith, 1982; Tchobanoglous, 1976);
3. decrease of water volume use in peeling and pitting operations, as well as decrease of raw product losses (Smith, 1976);
4. separation of waste process streams at their sources, for potential by-product use (Anonymous, 1980);
5. countercurrent reuse of wash/flume/cooling waters (LaConde and Schmidt, 1976; Mercer, 1971; Robe, 1977; Smith, 1982; Tchobanoglous, 1976);
6. separation of low and high strength waste streams (Tchobanoglous, 1976);
7. installation of low-volume, high-pressure clean-up systems (Liptak, 1974);
8. conversion from water to steam blanching (Ralls et al., 1973); and
9. use of air cooling after blanching (Carawan et al., 1979c).

The waste-solids separation practice uses screens and settling basins as primary means of removing particulates from the process water stream. These recovered solids usually have nutrient values useful in animal feed rations (Lindner, 1981; Revel, 1982; Strolle, 1980). Thus, it is a common waste handling practice to find drying operations in place to handle these separated, wasted food solids. For example, in a number of vegetable and fruit processing operations wherein produce skin removal makes a major contribution to the wastestream and requires disposal, specifically designed material handling and processing schemes have been developed to convert these evident waste materials into dry granular or pelletized animal food. These by-products are transported in bulk to animal production facilities, where food value can be gained from an otherwise discarded material.

Innovative Opportunities

The major contributing factors to vegetable and fruit produce waste losses come from production. Such factors include insect and fungal damage, mechanical abuse during harvest, crop self-destruction mechanisms, and growing conditions. Therefore, if substantial improvement in waste reduction is to occur, it must do so at the crop production level. The most promising opportunities seem to exist in plant genetics programs incorporating insect and fungal resistance properties into specific plant gene pools by means of genetic engineering. Vegetable and fruit ripening processes also are being controlled through gene manipulation procedures. An example is the Flavr Savr tomato developed by Calgene. Another plant property being modified through genetic engineering is that of the plant's protective skin, which is being toughened to minimize crop bruising during mechanical harvest. Additional opportunities in plant breeding and genetic engineering are being explored.

At the processing plant, close attention must be paid both to raw produce materials moving rapidly through process operations and to material handling systems minimizing product abuse. Incorporating appropriate handling systems into the processing environment can minimize waste significantly.

Fruit Processing

Introduction

The fruit processing industry processes more than 12 million t of fruit annually, generating approximately 39 billion gal. of wastewater and 4.7 million t of solid residuals (Friend and Guralnik, 1954). This waste stream flow rate of 39 billion gal./yr is equivalent to 171 ft^3/sec. Canned, frozen, and fermented fruits are produced almost exclusively for domestic consumption and have a much greater retail value than raw products do. It thus is important for the industry's economic and social status that the costs of waste disposal and of environmental problems associated with fruit processing be managed properly. The four crops processed in the greatest quantities are citrus, apple, peach, and pear. These crops account for 89% of raw tonnage, 85% of wastewater, 75% of BOD, 88% of SS, and 95% of solid residuals.

Fruit Handling Processes

The initial preparation processes for canned, frozen, and fermented fruits are washing, sorting, trimming, peeling, pitting, cutting or slicing, inspecting, and grading. Unwanted and undesirable materials must be removed before the fruits undergo additional processing, but not all fruits are subjected to each step. For example, cherries and plums may be canned whole and unpeeled whereas apples, peaches, and pears must be peeled and either cored or pitted before being canned. Peeling can be done by hand or with machines, chemicals, or steam. After inspection and grading, the peeled fruits are conveyed mechanically or flumed to product handling equipment for processing (U.S. Department of Commerce, 1989).

The converted fruit handling processes are can filling, syrup adding, exhausting and sealing, thermoprocessing, can cooling, and storing. Processing equipment and plant floor usually are cleaned at the end of each shift and so constitute a final source of waste materials.

Amounts and Types of Waste

It is estimated that approximately 4.7 million tons of solid residuals and 39 billion gal. of waste water are generated annually in the United States by the fruit processing industry (Table 8.12). The four crops processed in the largest quantities are citrus, apple, peach, and pears. They account for 89% of raw tonnage, 85% of the wastewater, 75% of the BOD, 88% of the suspended solids (SS), and 95% of the solid residuals.

Physical and Chemical Composition of Wastes and Environmental Issues

Fruit processing wastes principally contain mostly biodegradable organic matter in both soluble and insoluble forms. The latter consists of peels, pits, cores, and trimmings. Fruit sugars and acids and spilled syrup from processing operations constitute the soluble solids in liquid wastes.

In general, fruit processing results in a liquid waste with about 10 times the BOD of domestic sewage. Table 8.13 presents volumes and characteristics of liquid wastes generated in the processing of a variety of fruits. The volumes and the strengths of liquid wastes differ greatly and depend on the type of fruit processed. Wastes generated in the processing of a given fruit differ considerably from sample to sample. Some differences in strength reflect differences in processing method used in individual plants.

Table 8.13. Strength of wastes from typical fruit-canning operations (U.S. Department of Health, Education and Welfare, 1962)

Fruit product	Waste volume (gal./case)	5-day BOD[a] (ppm)	Suspended solids (ppm)
Apple	25–40	1,680–5,530	300–600
Apricot	57–80	200–1,020	200–400
Cherry	12–40	700–2,100	200–600
Cranberry	10–20	500–2,250	100–250
Peach	45–60	1,200–2,800	450–750

[a]Biochemical oxygen demand.

Table 8.12. Wastes from canned and frozen fruits (Rose et al., 1971)

Fruit	Raw tons (1,000 t)	Waste water (10^4 gal./t)	Waste water (million gal.)	BOD[a] (lb/t)	BOD[a] (million lb)	Suspended solids (lb/t)	Suspended solids (million lb)	Solid residuals (lb/t)	Solid residuals (1,000 t)
Apple	1,000	5.0	5,000	40	40	5	5	600	320
Apricot	120	5.0	600	60	7	12	1	360	21
Cherry	190	2.0	400	20	4	6	1	300	27
Citrus	7,800	3.0	23,000	4	31	7	55	880	3,390
Peach	1,100	4.0	4,000	60	66	10	11	500	270
Pear	400	4.0	1,600	70	28	20	8	660	120
Pineapple	1,000	0.5	500	20	20	8	8	900	450
Other fruit	400	8.0	3,200	20	8	10	4	—	80
Total	12,250		38,700		200		90		4,680

[a]BOD = Biochemical oxygen demand.

Because of its high BOD and SS concentrations, fruit processing wastewater can pose a serious environmental problem when discharged into a stream. Microorganisms use the dissolved O_2 to metabolize organic compounds, thus depleting O_2 concentration to a point at which fish are killed. If O_2 depletion continues, anaerobic decomposition of wastes produces odor and stream discoloration.

Waste Management

A major concern of fruit processing plant managers in the United States is that of proper and economic management of liquid and solid wastes. Two important factors affecting cost of fruit processing wastewater disposal are volume, or hydraulic load, and strength, or organic load. One approach is to decrease the former in the discharge by minimizing the use of water whenever practicable. Any reductions in water volume will cause corresponding reductions in the amount of wastewater treated.

A second approach is to decrease organic load whenever possible by preventing fruits from coming in contact with water. This approach restricts organic load to relatively small quantities of water and thereby alleviates hydraulic overloads in treatment plants. It is more economical and efficient to treat concentrated than diluted wastewater. Furthermore, increasing the concentration of organic compounds in wastewater enhances the potential for by-product recovery.

Several water conservation and waste prevention techniques are available by which to decrease water volume. These include the use of high-pressure sprays for clean-up, the elimination of excessive overflow from washing and soaking tanks, the substitution of mechanical conveyors for flumes, the use of automatic shut-off valves on water hoses, the separation of can cooling water from composite wasteflow, and the recirculation of can cooling water. When can cooling water is not recirculated, it may be reused in caustic soda (NaOH) or in water peeling baths, in removal of NaOH after peeling, in primary wash of the raw material, in canning belt lubrication, and in plant cleanup operations (U.S. Department of Health, Education and Welfare, 1962).

A number of waste treatment methods are available to make fruit processing wastewater suitable for discharge. The most widely used processes include biological treatment, impoundment in storage lagoons, and land irrigation (Figures 8.2 and 8.3) (U.S. Environmental Protection Agency, 1977).

Solid wastes from fruit processing operations are returned to the land (Hudson, 1971). Costs range considerably for disposal of solid wastes on land and

Figures 8.2 and 8.3. **Tri Valley Growers' Los Banos plant, which primarily processes tomatoes, has established an 840 acre private grassland and wetland refuge adjacent to the plant. The surrounding land is very alkaline, so they are using water drained from the processing of tomatoes to irrigate 440 upland habitat acres planted in alfalfa and grasses attractive to mallards, gadwalls, cinnamon teal, northern harriers, pheasants, and other ground nesting birds. The wetland water comes from ground water. The plant is located along the Pacific Flyway, a transcontinental route used by migratory waterfowl. The Grassland Environmental Education Center on the site provides a place for a public and school education program cosponsored by the Grassland Water District and Resource Conservation. Additional assistance is provided by the California Waterfowl Association, Ducks Unlimited, and the U.S. Fish and Wildlife Service. Figure 8.2 shows the wetland adjacent to the plant and migrating shorebirds probing the mud for food. Figure 8.3 is an example of the protective wetland habitat for a shoveler and other species of waterfowl. Photographs courtesy of Tri Valley Growers, San Francisco, California.**

depend on the water content of waste materials, the distance that wastes must be transported, and the methods of delivery and of application (Hudson, 1971).

One promising approach to minimizing disposal costs and environmental problems is that of removing excess water from these wastes. The drying operation decreases not only volume and weight of waste material but also odor.

A number of drying processes, including freezing concentration, filtration, centrifugation, heat drying, and incineration, decrease the water content of solid wastes before disposal. The costs of additional dewatering equipment arise from fruit processing plant capital and maintenance and from treating filtrate or concentrate. Costs can be countered, however, by handling limited quantities of solid wastes so that environmental problems associated with disposal decrease.

Another processing alternative to current disposal methods is to devise new processes for using fruit processing solid wastes. For example, grape pomace resulting from the processing of grapes for either juice or wine can serve as a raw material for the potential production of ethanol, tartrate, grapeseed oil, anthocyanin, and dietary fiber, depending on the market value of the products and the cost of pomace management. As EPA regulations tighten, fruit processing plants will be forced to find new methods of using pomace.

To minimize disposal costs and environmental problems and to maximize output of food ingredients and other useful products from grape pomace, several technologies must be used, in this sequence (Hang, 1988):

1. Seeds must be removed from pomace for oil recovery.
2. Pomace, now without seeds, must be fermented to ethanol or to citric acid.
3. Anthocyanins and tartrates must be extracted from spent pomace.
4. The remainder must be decomposed anaerobically for CH_4 production.

Future Developments

Research developing new or modified processing procedures is needed to decrease pollution loads from fruit processing operations. New processes should be devised for processing fruit at the harvest location so as to decrease pollution load in fruit processing plants. As for unavoidable processing wastes, new fermentation methods should be developed to convert them into proteins, feeds, fuels, chemicals, and/or other valuable products with an accompanying decrease in pollution load. These products can be sold to offset waste treatment cost.

Dairy Processing Waste Management and Utilization

Summary

Generally, the extent of treatment required depends on the discharge limitations defined by municipal-sewer use ordinances or by state regulations regarding effluent discharge to surface water, ground water, and waterways.

Dairy wastewater treatment is, in fact, far more complex than municipal sewer treatment, especially when the activated sludge process or some modification thereof is used. Most dairy plant wastewaters are treated in activated sludge systems, biological filtration systems, or in a combination of secondary treatment systems. Considerable improvements in water and waste management remain important and realistic industry goals.

Biological oxidation has been the preferred method for treating dairy-food plant wastewaters. Alterative pretreatment or treatment systems recently developed include (1) chemical coagulation for the reduction of fats before treatment, as a method of protein coagulation; (2) electrocoagulation and electroflotation; (3) rotating biological contact; and (4) sequence batch activation.

Ultrafiltration now can be used instead of the biological separation of organic material from liquid substrate. Instead of using reverse-osmosis systems for tertiary waste treatment, some food plants use them to recycle internal liquid-wastestreams. The outflow from reverse-osmosis treatment can be of better quality than native water. The advantage of special functional or nutritive characteristics of protein concentrates could be exploited further, as could expanded use of lactose.

Introduction

The processing of dairy products often entails various unit operations. These generally include the receiving and the storing of raw materials, the processing of raw materials into finished products, the packing and the storing of finished goods, and a number of ancillary processes, e.g., heat transferring and cleaning, associated indirectly with processing and distributing.

Equipment and facilities for receiving, transporting, and storing raw materials are much the same throughout the industry. Bulk carriers unload products in receiving areas by means of flexible lines or dump material into hoppers connected to fixed lines subsequently transferred by pump to storage. Storage facilities can be of the refrigerator, vertical, or silo type, with storage tanks containing either liquid or dry products and ranging in volume from a few thousand gal. to one million gal. or more.

Milk, a perishable product made up of fat, protein, carbohydrates, salts, and vitamins, is an ideal food for microorganisms as well as for humans. Thus, it needs to be protected from contamination, and much of the efforts of the dairy industry are directed to this end. Milk and its by-products are processed according to approved procedures, on machinery normally run no longer than about 20 hr/d. Much equipment is dismantled daily. Systems may be cleaned in place or after having been taken apart. Automated cleaning systems, now predominant in the industry, require less labor but more water and cleaning chemicals than hand washing of dismantled equipment does.

Economic and Societal Importance

A thorough review of more than 5,000 U.S. dairy plants was made by Harper et al. (1971). They estimated that about 53 billion gal. of wastewater was being discharged from such plants, of which 31 billion gal. was being discharged into municipal treatment systems and the remainder directly into watercourses. The researchers identified typical characteristics of the wastestream from a milk processing plant as

1. BOD: 2,300 mg/L;
2. suspended solids (SS): 1,500 mg/L; and
3. Fats, oils, and grease (FOG): 700 mg/L.

According to Loehr (1974), 11% of plants in the United States processed 65% of milk supply. Generated wasteloads per plant ranged from 2,000 to 10,000 lb BOD/d, or a population equivalent of 20,000 to 100,000 people. Some 15 yr later, plant numbers are smaller, milk production has increased to almost 150 billion lb, and the problem of appropriate waste-management per site remains prominent.

Costs and Benefits of Managing Wastes

Industrial plants differ greatly in terms of the amount of waste that they discharge. Factors such as type of dairy product processed, e.g., ice cream, milk powder, or cheese, influence volume and nature of wastestream. Age of plant and degree of automation also affect waste quantity and quality, as do plant location and seasonal variation in product mix. If milk plant wastewater can be serviced by a large municipal treatment plant as in Chicago, New York, and San Francisco, then treatment costs are subject to minimum rates along with surcharge systems. In rural areas in which factories need to treat their own wastes, treatment required is influenced by size of the receiving stream and its classification, e.g., recreational. Each stream or watercourse has an assimilative capacity limit, which if exceeded can bring about serious ecological changes in the receiving stream.

Generally, the extent of treatment required depends on the discharge limitations defined by municipal-sewer use ordinance or by state regulations regarding effluent discharge to surface water, ground water, and waterway.

Whey

Whey is the watery part of milk separated from the coagulum of whole milk, cream, or skim milk. Sweet whey results from the manufacture of products principally by means of rennet type enzymes at a pH of approximately 5.6. Acid whey results from the manufacture of dairy products in which coagulum is formed by acidification in a pH range of approximately 5.1 and below. A dilute liquid containing lactose, proteins, minerals, and traces of fat, whey consists of approximately 6% total solids, of which 70% or greater is lactose. Most whey is generated during cheese production; some, during casein production. Figure 8.4 illustrates most of the available whey utilization systems. The cost of converting whey to a by-product may be unjustifiable economically.

Worldwide production of whey seems in the order of 90 million t, with cheese production increasing at a rate of approximately 3%/yr (Table 8.14). Full utilization of whey, even with new technology, is yet to be achieved; industry has been slow to adopt whey processing schemes even though ultrafiltration, for example, has been in use commercially since 1972.

Although whey fractions, like protein concentrates, seem more profitably salable than whole dried whey does, the lactose permeate creates disposal problems

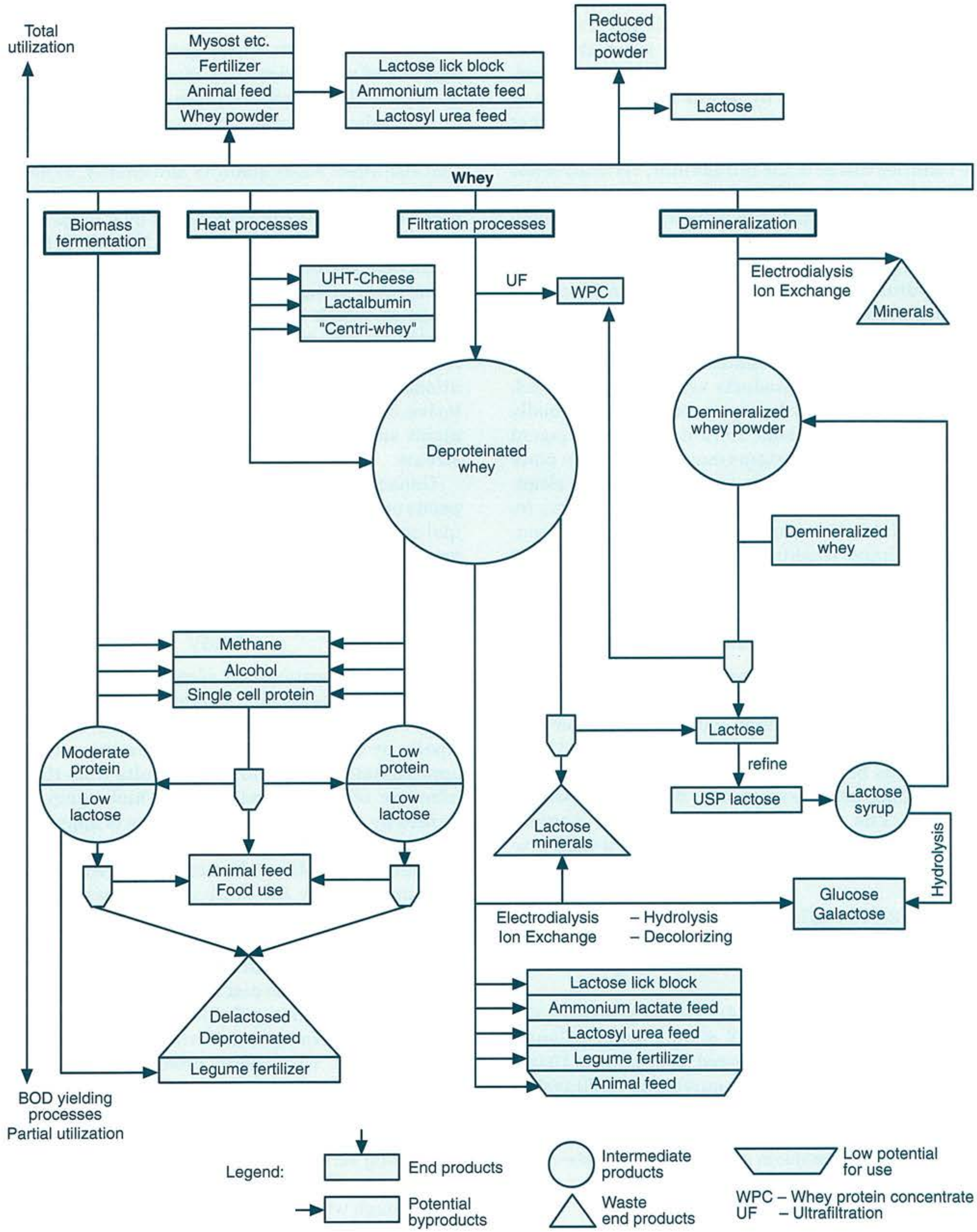

Figure 8.4. Whey utilization systems (Moller, 1981).

almost equivalent to those associated with raw whey. For the most part, little or no new technology for producing additional whey products has been created in the last several years although such technology is needed to move whey fractions into the general marketplace. The advantage of special functional or nutritive characteristics of protein concentrates could be exploited further, as could expanded use of lactose.

Treatment Alternatives

Dairy processing wastewaters are generated during the pasteurization and the homogenization of fluid milk and the production of dairy products such as butter, ice cream, and cheese. Figure 8.5 is a flow sheet for dairy and milk processing plants. The principal constituents of these wastewaters are whole and processed milk, whey from cheese production, and cleaning compounds.

Because the BOD_5 of whole milk is approximately 100,000 mg/L, the oxygen demand of these wastewaters normally is substantially greater than that of domestic sewage. A survey of 50 plants reported values for the BOD_5 of dairy processing wastewater that range from 400 to 9,440 mg/L, with average values ranging from 940 to 4,790 mg/L (Harper et al., 1971). The three milk constituents primarily responsible for the great oxygen demand of these wastewaters are lactose, protein, and fat.

It is a common misconception that the biological treatment of dairy processing wastewater is simple compared with that of municipal wastewaters. As industry experiences have demonstrated, dairy wastewater treatment is, in fact, far more complex, especially when the activated sludge process or some modification thereof is used. Harper and Blaisdell (1971) found in their analysis of 20 dairy processing wastewater treatment plants that greater than 20% of the time the efficiency of such facilities was less than 70%.

Although the low SS concentration of the flows obviates primary treatment, the variability of flows, as well as the characteristics of dairy processing wastewaters, has made consistently high levels of treatment efficiency exceedingly difficult to achieve.

Before being discarded into a stream, dairy wastewaters must undergo a series of treatment steps. Whether effluents must undergo all steps specified by local, state, and national agencies depends on the nature and the composition of the effluent and on whether it subsequently is to be treated on-site or discharged into the city sewer system. Figure 8.6 illustrates three commonly used methods. Most dairy plant wastewaters are treated in activated sludge systems, biological filtration systems, or in a combination of secondary treatment systems.

Because of the diversity of products handled in the dairy products industry, *milk equivalence* has been used to relate actual production of various commodities to a common denominator—namely, raw milk. Most current waste-characterization studies in the dairy industry use milk equivalence to relate water usage and process effluent loadings to plant throughput. A summary of conversion factors relating actual product to its milk equivalent appears in Table 8.15.

Table 8.14. Global cheese production (1,000 metric tons) in 1980 (Zall, 1984)

Country	1980
Australia	149
Canada	177
Czechoslovakia	109
EEC[a]	3,451
Hungary	38
Japan	66
New Zealand	99
Other countries	2,454
Other western Europe[b]	522
Poland	297
USA	1,800
USSR	678
Total world	9,841

[a]European Economic Community (EEC) included Belgium, Denmark, France, Germany, Irish Republic, Italy, Luxembourg, Netherlands, United Kingdom.

[b]Includes Austria, Finland, Norway, Spain, Sweden, Switzerland.

Table 8.15. Summary of conversion factors relating actual product to milk equivalents (Environmental Protection Service Canada, 1979)

One-pound product	Milk equivalent (lb)
Butter	21.30
Whole milk cheese	9.90
Evaporated milk	2.10
Condensed milk	2.40
Whole milk powder	13.50
Cottage cheese	7.12
Nonfat dry milk	12.50
Whey	1.10
Dry whey	17.60
Whey cream butter	40.70
Dry butter milk	249.00
Ice cream[a]	2.67

[a]One gal. ice cream weighs 5.4 lb.

Water use in the dairy products industry depends on plant complexity and water-management practice. Process wasteloads also differ considerably and are influenced greatly by the extent to which the plant controls raw material and product losses. Raw wasteloads for the American dairy industry are summarized, by commodity segment, in Table 8.16.

Milk product losses typically range from 0.5% in large, technologically advanced plants to greater than 2.5% in small, old plants. Given redoubled effort by management, water usage in most plants could be decreased to approximately 0.50 L/kg milk equivalent processed; effluent organic loads, to approximately 0.5 kg BOD/1,000 kg milk equivalent processed. Considerable improvements in water and waste management remain important and realistic industry goals.

Common Treatment Systems

Biological oxidation has been the preferred method for treating dairy-food plant wastewaters. These methods include the activated sludge process and its variations, e.g., trickling filters, aerated lagoons, and even anaerobic digestion systems. Spray irrigation has been an important disposal method for dairy wastewaters when land is sufficient and climate mild.

The activated sludge and the trickling filter systems were first used in England in 1914 (Ardern and Lockett, 1915) and in 1893 (Metcalf and Eddie, Inc., 1979), respectively. Although they have remained the most popular methods for treating dairy wastewaters, preferences differ. In the United Kingdom, the predominant method of treating dairy wastewaters is alternating double filtration; in the United States, activating sludge (Harper et al., 1971; Muers, 1968;

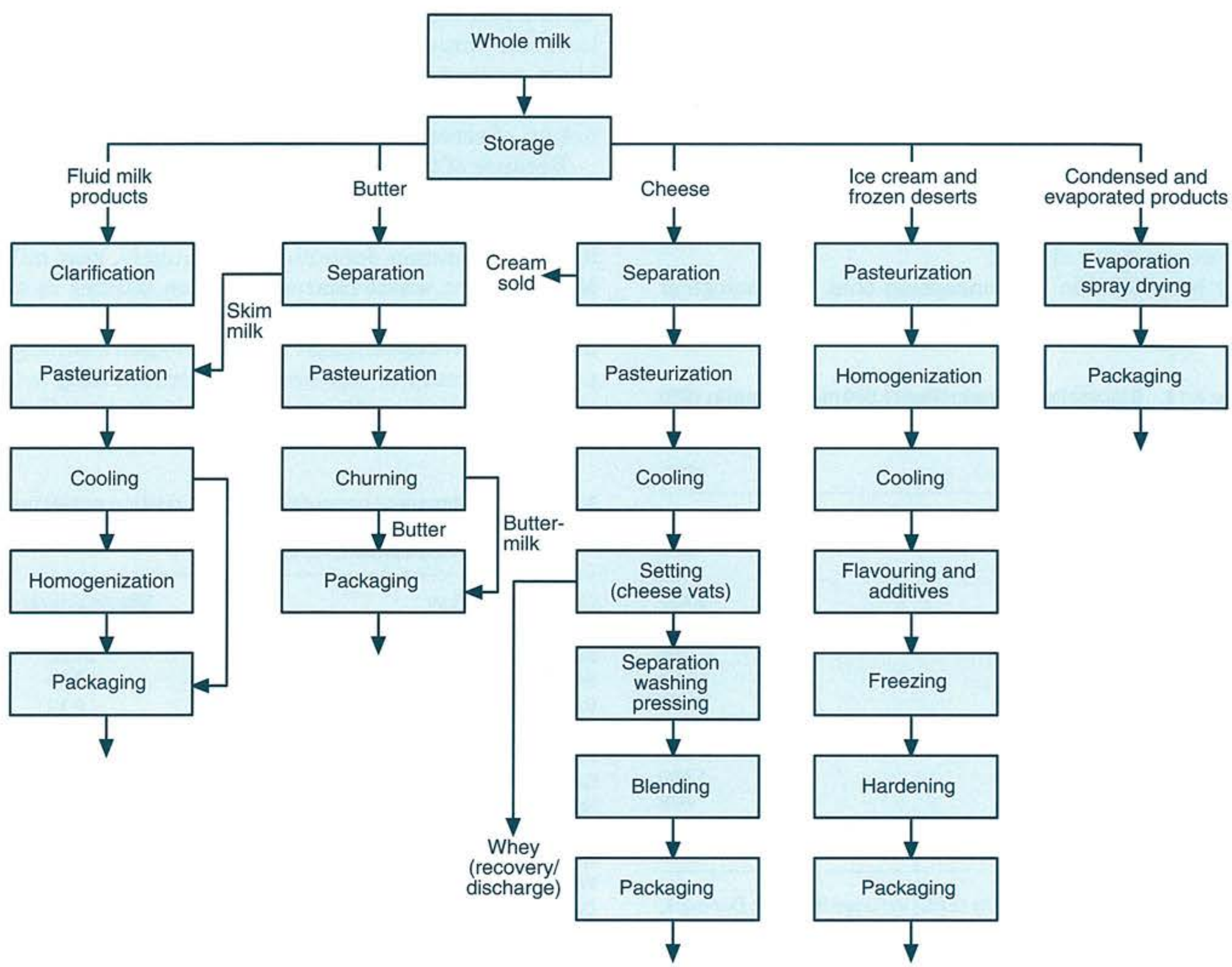

Figure 8.5. Flow sheet for dairy and milk processing plants (Carawan et al., 1979b).

Table 8.16. Summary of American dairy and milk processing plant effluent characteristics (Harper and Blaisdell, 1971)

Products	No. of plants	Waste vol. coefficient[a] Range	Waste vol. coefficient[a] Average	BOD coefficient[b] Range	BOD coefficient[b] Average
Milk	6	0.10–5.40	3.25	0.20–7.80	4.20
Cheese	3	1.63–5.70	3.14	1.00–3.50	2.04
Ice cream	6	0.80–5.60	2.80	1.90–20.40	5.76
Condensed milk	2	1.00–3.30	2.10	0.20–13.30	7.60
Butter	1		0.80		0.85
Powder	2	1.50–5.90	3.70	0.02–4.60	2.27
Cottage cheese	3	0.80–12.40	6.00	1.30–71.20[c]	34.00
Cottage cheese and milk	19	0.05–7.20	1.84	0.70–8.60[c]	3.47
Cottage cheese, ice cream, and milk	9	1.40–3.90	2.52	2.30–12.90	6.37
Mixed products	5	0.80–4.60	2.34	0.90–6.95	3.09
Overall	56	0.10–12.40	2.43	0.20–71.20	5.85

[a]Volume: kg wastewater/kg milk (or milk equivalent) processed.

[b]Biochemical oxygen demand (BOD): kg BOD/1,000 kg milk (or milk equivalent) processed.

[c]Whey included; whey excluded from all other operations manufacturing cottage cheese.

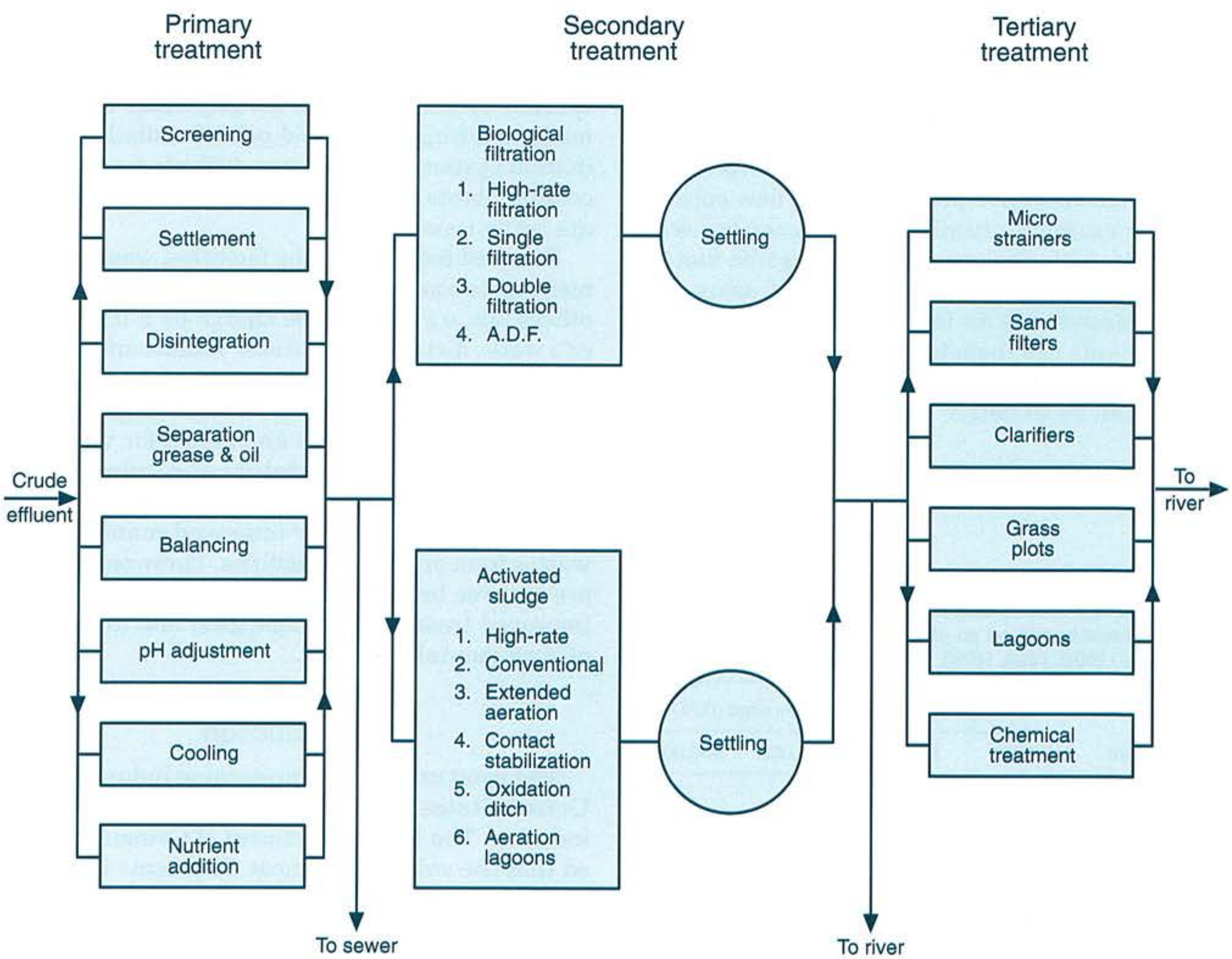

Figure 8.6. Possible treatment steps for dairy-food plant wastewaters (Carawan et al., 1979b).

Wheatland, 1960).

Alternative pretreatment or treatment systems recently developed include

1. chemical coagulation for the reduction of fats before treatment, as a method of protein coagulation;
2. electrocoagulation and electroflotation;
3. rotating biological contact; and
4. sequence batch activation.

Whether the effluent is treated on-site or is discharged depends on the receiving body of water's ability to accommodate wasteload.

Costs to treat effluents from dairy factories are provided in Table 8.17. Of interest is the difference between activated sludge and spray irrigation treatments, as well as the difference between wastewater volumes. Clearly, the cost of applying waste to land does not affect volume. Table 8.18 provides an overview of the advantages and the disadvantages of select parameters of treatment systems.

Innovations

In recent years, technological innovations with membrane systems have provided many new opportunities. For example, ultrafiltration now can be used instead of the biological separation of organic material from liquid substrate. And instead of using reverse-osmosis systems for tertiary waste treatment, some food plants use them to recycle internal liquid-wastestreams. The outflow from reverse-osmosis treatment can be of better quality than the native water.

Table 8.17. Capital and operating annual costs in cents/1,000 gal.[a] effluent based on an effluent concentration of 2,000 mg/1 BOD_5 (Zall, 1979)

	Milk equivalent processed by plant (GPD[b])			
Type of treatment	50,000	100,000	250,000	500,000
Activated sludge	351	198	114	81
Trickling filter	288	177	101	75
Aerated lagoon	175	101	57	42
Spray irrigation	140	140	140	140
Ridge and furrow	35	35	35	35

[a]Based on 1972 dollars: estimate upwards about 50%.

[b]GPD = gal. per day.

Meat and Poultry Processing-Waste Management and Utilization

Summary

Most meat and poultry products are recovered somehow by the processing industry. Blood, feathers, and bone usually are processed into meal products for animal feed. Similarly, meat scraps unsuitable for processing into food products are sold or given to rendering facilities for processing into animal and pet foods.

The characteristics of solid wastes and of wastewaters from a processing plant depend on plant processes determined according to initial product and final product, water consumption pattern, in-plant screening, and cleanup procedures. Four major areas of concern dominate the meat and poultry processing industries, namely, sludge management, ammonia control, inadequate pretreatment facilities, and regulatory limits. Heightened federal and state concern over surface and ground water quality has made renewing of national pollution discharge elimination system permits very difficult for many processing plants. And in some states, no new permits are being issued.

For most food processing facilities, waste management costs come in many forms, some avoidable and others not, e.g., water use charge by a municipality or a water district; wastewater volume and pollutant load surcharges and fines by a municipality; capital and operational costs for a waste storage and treatment systems; and fines and levies for violation of federal, state, and local statues or regulation.

Opportunities exist within the meat and poultry processing industries for improved management of wastes from processing facilities. These opportunities are of three broad types: (1) waste management, (2) improved treatment technologies, and (3) corporate environmental advocacy.

Introduction

The meat and poultry processing industries in the United States together make up a \$75.6 billion/yr industry. The U.S. Department of Commerce reported that the value of red meat shipments for 1988 totaled \$46.8 billion. Respective poultry and processed red meat shipments totaled \$12.6 billion and \$16.2 billion for that year (Food Engineering, 1989).

Table 8.19 provides a breakdown, by category and

Table 8.18. Advantages and disadvantages of treatment systems utilized in the dairy industry

Treatment system	Advantages	Disadvantages
Activated sludge (AS)	Good BOD[a] reduction Good operating flexibility Good resistance to shock loads Minimum load requirements	Substantial capital investment High operating cost Continuous supervision requirements Upset to shock loads Sludge disposal problems Very temperature sensitive
Trickling filters (TF)	Good BOD reduction Good resistance to shock loads Less operating cost than AS	Substantial capital investment High operating cost Continuous supervision requirements Long acclimation period after shock loads Ponding of trickling filters Significant land requirements Sludge disposal problems Performance drop with temperature drop
Aerated lagoon (AL)	Good BOD reduction Good resistance to shock loads Low capital cost Less supervision required than AS or TF Fewer sludge problems than with AS or TF	Large land requirements High power cost Performance drop with temperature drop
Stabilization ponds (SP)	Suitable as a pretreatment system Prevents shock loads to preceding treatment systems Good resistance to shock loads Low capital cost Low operating cost Fewer sludge problems than with AS and TF	BOD reduction below that of AS, TF, and AL Algae growth Large land requirements Insect problems Odors Ordinances restricting location
Irrigation	100% treatment efficiency Low operating cost No sludge problems (except for ridge and furrow) Suitable for whey disposal	Amount of land required and, in some instances, distance from dairies Surface runoff Ponding Seepage to ground water supplies Health hazards to animals Soil-clogging and compaction Vegetation damage Insect propagation Odors Spray carry-over Maintenance problems—clogged nozzles, freeze up, and the requirement that lines be relocated to allow 'rest periods' Cold water surface icing Sludge build-up (ridge and furrow only) State ordinances limiting location
Combined systems	Good BOD reduction Good shock resistance Good operating flexibility	High capital costs High operating costs Significant land requirements Constant supervision requirements Sludge disposal problems

[a]BOD = biochemical oxygen demand.

by Standard Industrial Classification (SIC) code, of the number of meat and poultry processing plants in the United States. Most red meat processing plants are located in the Midwest; most poultry processing plants, in the Southeast and the Mid-Atlantic. Processing of prepared meats, including canned cooked products, luncheon meats, hot dogs, bacons, stews, and other ready-to-eat meat products, has expanded rapidly in recent years. Table 8.20 breaks down the number of animals slaughtered in the United States in 1987.

Figure 8.7 shows that a shift has occurred in meat and poultry consumption patterns in the United States during the last 5 yr. Poultry meat consumption has increased 17.2% for chicken and 39.7% for turkey while beef consumption has decreased 11.3%. Total per capita meat and poultry consumption increased 2.9% from 1985 to 1989 (Food Engineering, 1989).

Amounts and Types of Waste and By-Products

Figure 8.8 is a mass flow diagram for broiler processing. A mass flow diagram for beef slaughtering appears in Figure 8.9. Both diagrams indicate the major sources of waste within an operation, including those listed in Table 8.21.

Most products are recovered somehow by the industry. Blood, feathers, and bone usually are processed into a meal product for animal feed. Similarly, meat scraps unsuitable for processing into food products are sold or given to rendering facilities for processing into animal and pet foods. The ultimate characteristics of solid materials and wastewaters generated by these source areas in a plant and unrecovered for another use differ greatly and are affected by

1. animal size and type,
2. processing level,
3. conveyance means,
4. processing water use, and
5. cleanup and housekeeping procedures.

Table 8.19. Number of U.S. plants involved in poultry and red meat processing (U.S. Department of Agriculture, 1988)

Category	SIC[a] code	Number of plants
Meat packing	2011–	617
Prepared meats	2013–	814
Poultry processing	2016–	243
Prepared poultry and egg products	2017–	253
Total plants		1,927

[a]SIC = Standard Industrial Classification.

Table 8.20. Meat animals processed in the United States during 1987 (U.S. Department of Agriculture, 1988)

Animal category	Slaughtered weight (1,000 lb)	Number (1,000 head)
Beef[a]		
Cattle	38,386,808	35,646.9
Calves	699,644	2,814.7
Pork	20,060,447	81,080.8
Sheep	618,670	5,199.6
Chicken		
Young, cut up	8,697,617	4,971,470.0
Young, further processing	3,420,568	
Mature, cut up	9,815	197,925.0
Mature, further processing	660,505	
Turkey		
Cut up	1,360,857	—
Whole, further processing	1,068,465	—
Other, further processing	1,658,579	—
Other poultry		
Further processing	384,759	—
Cut up	25,042	—

[a]1988 figures.

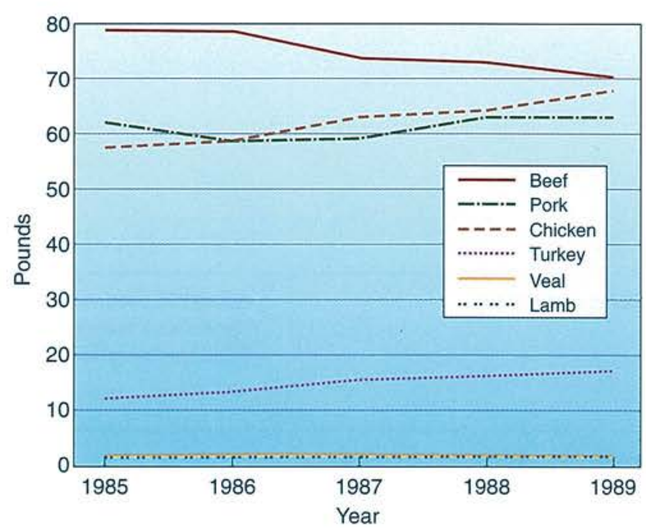

Figure 8.7. Per capita meat and poultry consumption in the United States

Table 8.21. Waste products from poultry and meat processing operations

Process area	Waste material
Holding pens, dock	Manure, animal hair, feathers, grit, dead animals (dead on arrival)
Slaughter	Blood and other body fluids
Cleaning	Feathers, skin, bone, and hide materials
Trimming and evisceration	Trim scrap, offal, paunch material
Inspection	Contaminated and rejected product
Further processing	Meat scrap, bone material
Cooling and storage	Contaminated ice, damaged product
Prepared food	Additives (sauces, batters, spices), oils and greases (from cooking), damaged product

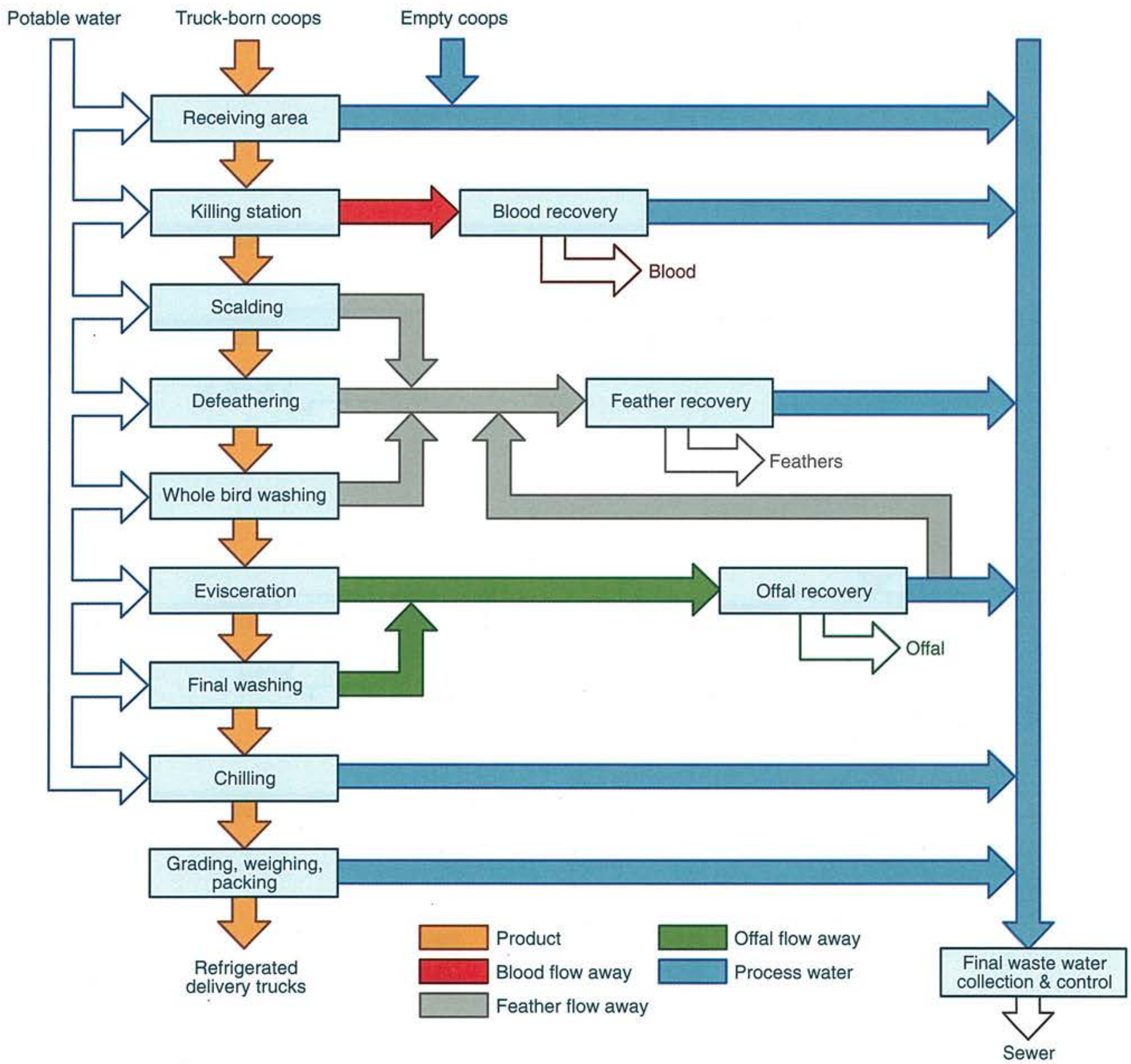

Figure 8.8. Process flow diagram for poultry processing operation

Animal Size and Type

Water use for broiler processing typically ranges from 3.5 to 10.0 gal./bird; for turkeys, 11 to 23 gal./bird. Flow rates of 350 gal./animal have been reported (Stebor et. al., 1989) for beef slaughtering plants. Rooney and Wu (1981) noted changes in water use in beef slaughtering from 458 to 187 gal./head after water conservation measures were adopted. Similar water use numbers appear in the examples in Table 8.22, together with pollutant contributions by animal type.

Processing Level

Modern meat and poultry processing facilities use a variety of processes, which usually entail a form of slaughter and processing of fresh product. Further

Table 8.22. Water consumption and pollutant contributions for beef, turkey, and broiler processing

Animal type	Pollutant contribution (lb/1,000 animals) BOD$_5$[a]	TSS[b]	FOG[c]	Water (gal./animal)	Source
Beef	6,710	6,860	440	350.0	Stebor et al., 1989
Turkey	170	260	60	26.0	Sheldon et al., 1989
Broiler	49	57	8	5.8	Valentine et al., 1988

[a]BOD$_5$ = five day biochemical oxygen demand.
[b]TSS = total suspended solids.
[c]FOG = fats, oils, and grease.

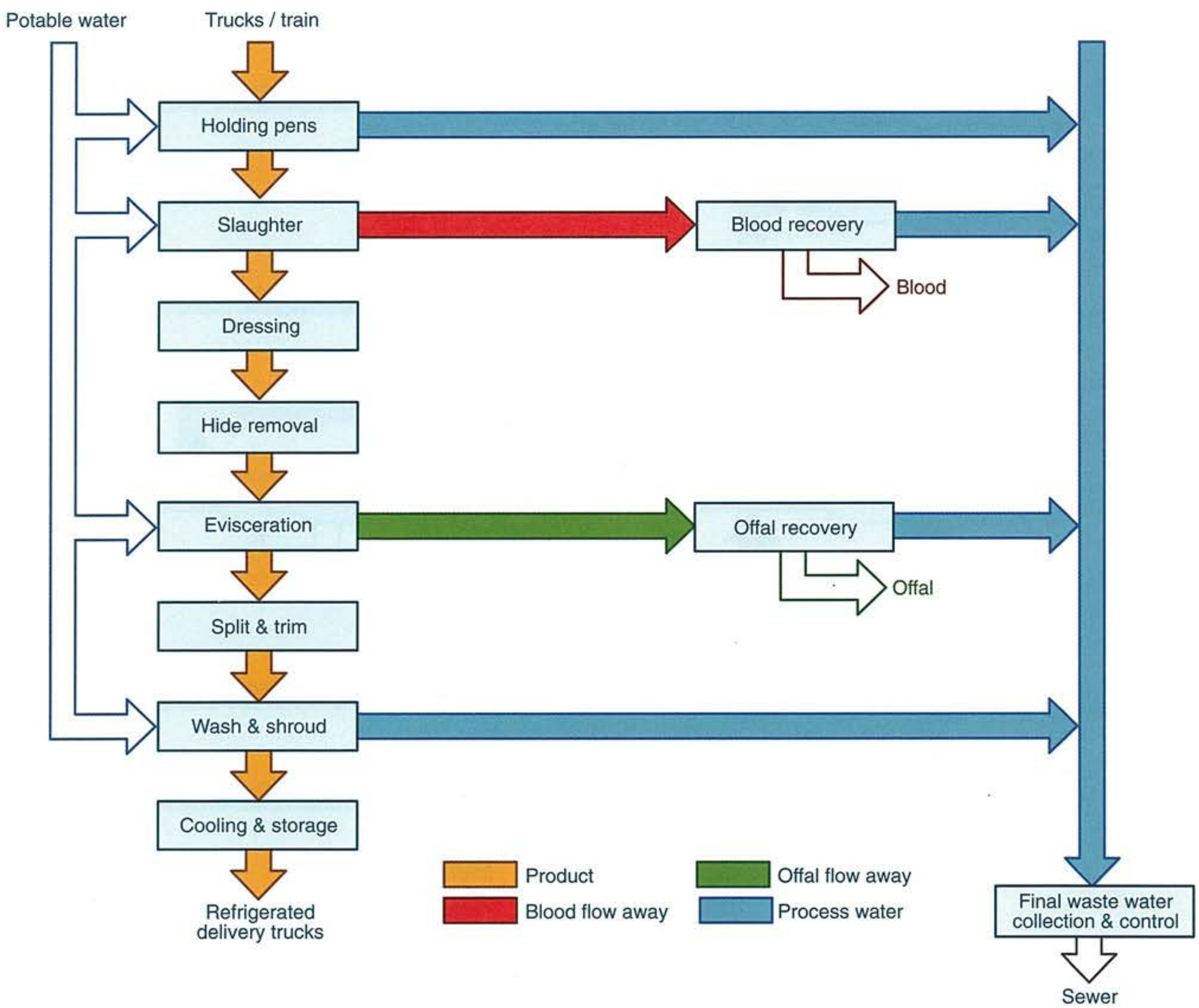

Figure 8.9. Process flow diagram for beef slaughtering operation.

processing for packaging requires segregating and processing of specific carcass portions such as breasts and wings in poultry operations, hams and hocks in pork operations, and roasts and steaks in beef operations. Many operations continue with the processing of lesser-quality cuts into mechanically deboned meat used for hot dogs and franks. Other facilities are equipped with batter and cooking facilities for the preparation of specialty items. Cooking facilities tend to produce greater quantities of oils and grease/lb of product processed than slaughtering plants do. Many slaughtering plants also may have processing capabilities for hide cleaning and curing, tripe producing, and by-product rendering.

Conveyance Means

Methods of operation and of waste material handling determine the characteristics of solid materials or wastewaters discharged by a plant. Conveyors and large bucket devices are used to transfer other solid waste products for eventual use or disposal. In most instances, materials are sent to rendering plants for processing into pet food and livestock feed.

The most common means of conveyance from a plant are flumes or troughs, which carry material away from production areas. Although water used in this device usually is screened to remove large materials, wastewater contains high concentrations of soluble and particulate materials that must be treated on-site and/or by a publicly owned treatment work (POTW).

Clean-up and Housekeeping

Another stream of wastewater comes from clean-up procedures occurring both during a processing shift and as a separate shift afterwards. Scrap materials unrecovered during processing shifts are recovered or washed down drains into wastewater lines. Products remaining inside and near processing equipment are removed by means of high-pressure hoses and detergents. These detergents and cleaners represent a BOD_5 of 0.65 lb BOD_5/lb of substance (Carawan, 1979a) and may upset biological wastewater treatment systems.

Additionally, manure and paunch contents accumulate in and near plant holding and killing areas. Much of these materials is recovered or washed from processing room floors or holding lots. As much as 65 to 80 lb of paunch material is removed from each head of beef during processing (Blanc et. al., 1983). Animal hair, feathers, and grit typically are included with this material.

Process Water Usage

Wastewater also is generated as part of the waste processing itself. Water is used for chilling, scalding, can retorting, washing, cleaning, and waste conveying. For example, poultry processing uses approximately 3.5 to 7.0 gal. H_2O/bird of 4 lb average weight. All broiler processing plants are required to have a scalder overflow rate of 0.25 gal./bird and a chiller overflow rate of 0.50 gal./bird. In many instances, this water is used in the plant for the transport of feathers and offal from the processing area. Carawan et al. (1974), studying a broiler processing plant, reported that processing accounted for 76% of the water load, with 13% used in cleanup and 12% in downtime.

Beef processing water usage, primarily from carcass washing and process clean-up, has been reported in the range of 150 to 450 gal./animal processed (Stebor et al., 1987). An estimated 500 million gal./d (MGD) of wastewater is generated by U.S. slaughtering and meat processing operations alone (Blanc et al., 1983). Carawan (1989) estimated that, as a general rule, meat processors use roughly 1 gal. H_2O/lb of processed hamburger meat.

Physical and Chemical Composition of Wastes and Environmental Issues

The characteristics of solid wastes and of wastewaters from a processing plant depend on plant processes determined according to initial product and final product, water consumption pattern, in-plant screening, and cleanup procedure. Characterizing the compositions of wastes and of wastewaters from processes differing not only from plant to plant but also from day to day therefore is difficult.

Wastewaters from a processing plant should be characterized thoroughly to determine what steps are necessary to remain in compliance with local, state, and federal environmental ordinances. Table 8.23 illustrates representative wastewater characteristics from a variety of meat and poultry processing facilities.

Of particular interest are the pollutant variables BOD_5, TSS, and FOG. As can be seen in Table 8.23, these characteristics differ from plant to plant for the reasons outlined and must be evaluated for waste reduction, resource recovery, and treatment option opportunities. Four major areas of concern dominate the meat and poultry processing industries, namely, (1) sludge management, (2) ammonia control, (3) inadequate pretreatment facilities, and (4) regulatory limits.

Sludge Management

At meat and poultry processing plants, most pretreatment systems, including most DAF and systems clarifiers, aerated and anaerobic lagoons, produce skimmings or sludges. The most commonly used DAF systems produce skimmings materials with high oil and fat contents. Depending on the type of chemicals used in the DAF, this material can be handled according to a number of methods, including (1) land application, (2) rendering, and (3) landfill.

Land Application

Of these three methods, land application is used most frequently. In most states, a special permit is required. The major problems and limitations of land application include (1) the availability of suitable land in terms of soil type, contour, climate, etc.; (2) the potential for ground water contamination due to high water table, overapplication, and poor management; (3) the nuisance complaints due to odor and flies; and (4) the issuing of permits (Carr et al., 1988; Jones and Petitout, 1989). In most instances, these problems can be minimized through appropriate management practices, including careful selection of site, incorporation of material into the soil immediately after application, maintenance of buffer zones along populated areas, and improved characterization of applied wastes. Nitrification of ammonia into nitrate has been a problem with the application of many meat and poultry processing DAF skimmings (Westerman et al., 1988). Poor accounting practices lead to overapplication and eventually to leaching to ground water.

Recent changes in sludge regulations regarding the application of municipal and industrial sludges, whose heavy-metal concentrations are of keen interest, can cause additional problems. Although these concentrations rarely are the limiting factor in land application of most sludges and skimmings produced by the meat and poultry industries, these materials must not be categorized with municipal sludges. Data from Pancorbo and Barnhart (1989), however, indicated high concentrations of bacteria in untreated DAF poultry sludges, evidence raising questions about the safety of direct land application without a form of stabilization.

Table 8.23. Representative meat and poultry processing plant discharge characteristics and treatment methods

	Plant discharge characteristic							
Wastewater source	Volume (MGD[a])	NH_4-N[b] (mg/L)	FOG[c] (mg/L)	BOD_5[d] (mg/L)	COD[e] (mg/L)	TSS[f] (mg/L)	Method of treatment[g]	Source
Poultry processing	0.25	—[h]	3,300	2,070	—	4,400[1]	sc, daf, anl, ael, poll, irr	White, 1988
Poultry processing	0.70	9	169	1,016	2,478	1,177	sc, daf, sldew, dd, act, clar, poll, chl	Ross et al., 1988
Turkey processing	0.40	—	93	704	1,112	270	sc, sew	Merka et al., 1987
Turkey processing	0.80	—	253	706	1,552	281	sc, daf, sew	Sheldon et al., 1989
Beef slaughterhouse	0.80	76	150	2,300	6,350	2,350	and, clar, sidew, sew	Stebor et al., 1987
Beef/swine slaughterhouse	3.00	30	230	820	1,540	520	daf, anl, act, filt, chl, dchl, dd	Totzke, 1987
Sausage processing	0.30	—	5,000	1,200	—	600	daf, sbr, sew	Norcross, 1988
Hamburger processing	0.04	—	1,900	4,900	—	4,500	daf, sew	Mikula et al., 1989

[a]MGD = million gal./day.

[b]NH_4-N = ammonium nitrogen.

[c]FOG = fats, oils, and grease.

[d]BOD_5 = five-day biochemical oxygen demand.

[e]COD = chemical oxygen demand.

[f]TSS = total suspended solids.

[g]Legend:

act	activated sludge	daf	dissolved air flotation	sbr	sequencing batch reactor
ael	aerobic lagoon	dchl	dechlorination	sc	screening
anl	anaerobic lagoon	dd	direct discharge into receiving stream	sew	sewer to POTW
and	anaerobic digester	filt	filtration	sidew	sludge dewatering
chl	chlorination	irr	irrigation		
clar	clarifier	poll	polishing pond		

[h]Not available.

Rendering

Rendering frequently is used to process DAF skimmings into animal feed and other products. A processor usually handles this by means of either an on-site rendering facility or an outside renderer, who also may accept plant meat scrap and offal. Potential problems with rendering DAF skimmings include

1. chemicals—most available for use as flocculants and coagulants in DAF systems are not approved by the USDA as suitable for use in rendered feed products;
2. water content—most skimmings come, at 90 to 95% moisture content, from DAF systems and, because of the high energy needed to evaporate the water, often must be dewatered to 70 to 80% moisture content before being accepted by rendering plants; and
3. product freshness—rancidity affects many DAF skimmings held at warm ambient temperatures for longer than 1 d.

Landfilling

For years, landfills have been used as depositories for relatively small quantities of sludge and skimming. Because of concerns about ground water contamination, states and municipalities recently have tightened restrictions on the types and the quantities of sludges allowed in landfills. Often, material must be dry enough to be considered *bladeable*, a somewhat nebulous parameter designed to decrease the potential for contamination due to leaching into ground water around the landfill site. Many landfills reject such material under all circumstances.

Because of the costs associated with their handling and disposal, such materials are the focus of many processors who are considering techniques, e.g., belt pressing, centrifuging, and thermal decanting, to remove at least 50% of water content (Steele and West, 1989; Walsh and Valentine, 1989).

Ammonia Control

Typically, the blood protein present in most waste waters is converted into N and ammonia by most wastewater pretreatment systems. Animal manures from holding areas and paunch materials from processing can add to this N load. The ammonia concentration of most such wastewaters tends to exceed limits set by National Pollutant Discharge Elimination System (NPDES) permits and by municipal surcharge requirements. Moreover, limits constantly are being revised downward. Such problems should encourage improved blood-recovery practices in plants. Additionally, several technologies are available for ammonia control, including ammonia stripping, land application, deep-ditch aeration, and breakpoint chlorination (Griggs, 1989; Harper et al., 1989). All these options are expensive, and land application requires extensive permitting and adequate land area. In some instances, discharge of ammonia into the air around the plant may be regulated by a municipal or a state agency.

Inadequate Pretreatment Facilities

Inadequate pretreatment facilities are common at meat and poultry processing facilities. Wastewater volumes and characteristics change, equipment ages, and regulations are revised or expanded. Process changes at many plants have led to changes in wastewater volumes and therefore to the development of characteristics different from those specified by original design criteria. Examples include increased line speeds at poultry processing plants and additional cooking processes at beef slaughtering plants. Because of these changes, systems are unable to operate at or near optimal efficiency. Moreover, most system managers use either daily or weekly sampling of influent and effluent to determine system efficiency, and performance therefore is inadequate during much of the operating time.

Many operational pretreatment systems were installed more than 15 yr ago and are nearing the end of their design lifetime. Changing environmental regulations also have led to the need for system upgrades, as with the installation of sludge dewatering systems to satisfy revised landfill requirements for sludge depositions, or the addition of chemicals to DAF systems to satisfy increasingly stringent sewer discharge limits on TDS.

Regulatory Limits

Increasingly costly surcharges, stringent municipal pollutant limits, and restrictive NPDES permits have made some pretreatment facilities obsolete. Obsolescence usually occurs when the municipality must improve the efficiency of its own wastewater treatment facilities to meet state and federal guidelines.

Heightened federal and state concern over surface and ground water quality has made NPDES permitting renewal very difficult for many processing plants. In some states, no new permits are being issued. Ammonia in wastewater has become a weighty problem for all industries, for which limits on discharge of ammonia and other noxious gases to the air may become increasingly problematic. The EPA's recent changes in regulations regarding land application of municipal and industrial sludges may restrict management of food processing sludge and skimming.

Costs and Benefits of Managing Wastes

For most food processing facilities, waste management costs come in many forms, some avoidable and others not:

1. water use charges by a municipality or a water district;
2. wastewater volume and pollutant load surcharges and fines by a municipality;
3 capital and operational costs for a waste storage and treatment system; and
4. fines and levies for violation of federal, state, and local statutes or regulations.

Water and wastewater charges by municipalities have increased markedly in the last 5 yr. Carawan (1989) noted from the results of a study of 120 municipalities that water costs from 1986 to 1988 increased 24% in Los Angeles and 34% in New York and were expected to increase fivefold during the next 5 to 10 yr. Similar increases are occurring in smaller cities. Valentine and Merka (1989) noted that sewer charges in 10 medium-sized Georgia cities increased 42% during the last 3 yr, namely from $1.65 to $2.36/1,000 gal. These costs will continue to rise as POTWs continue to be strained by growing population and industry, maturing system equipment, and increasing federal pressure to implement industrial pretreatment programs.

The costs of operating and designing waste treatment systems differ considerably from plant to plant. These costs likely will rise as municipal discharge limits become increasingly strict and surcharge costs rise. Valentine et al. (1988) determined that the amortized capital and operating costs for treating 1 million gal./d of wastewater from a poultry processing facility would run from $820 to $2,200/d, depending on the costs of chemicals, sludge disposal, and labor. Sludge management costs range from $0.03 to $0.05/gal. for transportation and from $0.05 to $0.08/gal. for land application. Other sludge management costs include those for dewatering and storing.

Lastly, plants in violation of federal, state, or local environmental statutes can be fined heavily. These fines can be either *event fines* (such as those for fish kills), which depend on the impact to the affected stream, or *daily fines*, which must be paid until a problem is resolved. In extreme cases, fines will be followed by a show cause hearing in court, and if infractions continue, a court can order plant closure.

Increased Use and Minimization of Wastes by Altering Management Practices

Opportunities exist within the meat and poultry processing industries for improved management of wastes from processing facilities. These opportunities are of three broad types: (1) waste management, which involves waste water reduction, waste recycling, and material segregation and handling; (2) improved treatment technologies, which can incorporate system upgrades, new processes, and refined systems; and (3) corporate environmental advocacy, which can promote public relations, management focus, regulatory activism, and education.

Waste Management

Wastewater Reduction

The amount of wastewater generated by the industries can be decreased largely through changes in cleanup practice (Carawan et al., 1979b). Water use can be minimized by means of commercially available high-pressure, restricted flow hoses, which can be fit with automatic shutoffs to prevent water loss during inactivity. Many materials can be handled mechanically. For example, flour and other dry material can be vacuumed from the floor; augers and conveyors can be used to transport scrap meat and viscera.

Recycling

Chiller and scalder water is reused in most poultry processing plants for flushing water to remove offal and feathers. Reconditioning of chiller overflow through the use of filtration and ultraviolet irradiation has been recommended (Sheldon and Carawan, 1988). Limits to use include the potential of bacterial contamination by coliforms or by *Escherichia coli*. Recycling is limited by the characteristics of the waste stream and by the potential for contamination of food products.

Material Segregation

To the extent possible, blood and other recoverable material currently is segregated and recovered. Blood alone contributes more than 1,000,000 mg BOD_5/L and is a primary factor in the amounts of ammonia enerated in wastewater and sludge leaving the plant. Because individual plant processes generate wastestreams with highly variable characteristics, it may be beneficial to pretreat concentrated wastestreams before mixing them with more dilute wastestreams.

Material Handling

Dry vacuums and other physical methods of solid material removal are available and in use in several plants. But methods often are more labor intensive than water transport.

Improved Treatment-Technologies

System Upgrades

Although many pretreatment and treatment technologies have matured, distinct areas for improvement exist. Most common methods for wastewater treatment in this industry appear in Table 8.23. Dissolved air flotation performance can be improved if a variety of chemicals is added, flow equalized; compressed gases, e.g., gas or bubble size, modified; and skimmings removed (Zimmerman and Jacquez, 1980). Treatment efficiency of anaerobic lagoons can be improved if a flexible cover is added. Moreover, biogas production, once considered a nuisance, is being considered seriously as a usable by-product of anaerobic treatment (Walsh et al., 1988).

New Processes

Although most "new" waste treatment processes actually are variations on existing technologies, innovative technologies are emerging. Anaerobic packed bed and sludge bed treatment systems offer increased organic loading capabilities for wastewaters generally considered too dilute for certain traditional anaerobic treatment methods (Totzke, 1988). And catalytic combustion technologies converting high-moisture food wastes into usable energy are emerging (Butner et al., 1988).

New Control Systems

Common to all technologies is the need to monitor and to control waste characteristics and process functions. New sensors should be developed to allow online characterization of solid-waste materials and wastewaters. Monitoring helps process controllers determine the efficiency of in-plant processes and the effectiveness of waste reduction efforts. Computerized process control is being implemented on many biological treatment systems (Stover and Downs, 1989).

Corporate Environmental Advocacy

Public Relations

Especially in regard to environmental issues such as waste management, all food processing companies must maintain a wholesome corporate image. Merely being within regulatory compliance may be insufficient: for instance, a plant emitting offensive odors may be perceived as producing an unwholesome product.

Enlightened Management

It is incumbent on processing facility managers at all levels to recognize the importance of waste management and to consider it a primary objective. The entire organization should be aware of the importance of sound environmental policy and the consequences of environmental noncompliance. Without this focus, a company's environmental policy will be ineffective and subject to lapses in implementation.

Regulatory Activism

Regulatory requirements often are established at a local or a municipal level and frequently are based on guidelines provided by state or federal government. Many such requirements, e.g., maximum surcharge limits for oil and grease, are subject to public review and comment. Similar forums of public review and comment are provided for state and federal regulatory initiatives. Affected processing facilities should participate in these forums and make their concerns and interests clear.

Education

Education ties in with the previous three points by providing managers and other employees with sufficient information and incentive to carry out corporate environmental policy. For example, a plan to implement water conservation measures must be accompanied by an educational program to ensure that employees understand their role in making the measure a success, their reward if it succeeds, and their liability if it fails.

Innovation Opportunities

A variety of techniques and technologies recently have been developed to improve waste management within the meat and poultry processing industries. As illustrated in Table 8.24, many are modifications or improvements of traditional methods. Although management techniques and technologies are being improved, a number of related problems must be solved. And in their solution lie opportunities for innovation through research and development during the coming decade.

Table 8.24. Technology innovations and current problems

Technology	Recent advances	Current problems
Dissolved air flotation	Chemical addition Chemical selection Electroflotation Air/gas dissolution	Sludge disposal
Water reduction	High pressure nozzle Employee training Dry vacuuming Drain restrictions	Management limitations
Water recycling	UV irradiation, filtration, ozonation	Bacterial contamination
Refeeding	Fermented paunch material	Palatability Bacterial contamination
Aerobic	Sequencing batch reactors Activated sludge Total barrier oxidation ditch Sludge composting	Odor control Filamentous growth control Power requirements Sludge disposal
Anaerobic	Packed bed reactors Sludge bed reactors Covered lagoons	Oil and grease fouling Thermal requirements Start-up requirements
Land application	Sludge injection Spray irrigation	Crop utilization Odor control Runoff control Nitrate levels
Ammonia control	Air stripping Breakpoint chlorination Biological removal Selective ion exchange	Odor/emissions control Energy requirements Cost
Sludge dewatering	Screw press Belt press Thermal dewatering Centrifuge Electro-osmosis	Chemical requirements Fouling Energy requirements

9 Seafood Waste Management and Utilization

Summary

The solid wastes generated from seafood processing are as varied in composition as the species themselves are. Currently, the industry operates under effluent limitation guidelines attained by best conventional control technology (BCT), which the EPA considers equivalent to the best practical control technology currently available.

How seafood waste is disposed of depends on species, plant location, processing method, and processor options. Digestion of fish waste by proteolytic enzymes is a promising old technology that may constitute an alternative means of handling waste. Disposal alternatives such as landfilling and ocean dumping are becoming increasingly burdensome because of transportation costs and tipping fees; consequently, the industry must look to other, less costly options that may result in secondary products with income generating potential. Total utilization, which ultimately would solve the waste problem, will factor prominently in industrial development during the 1990s. The motivation for total utilization most likely will be economics, not regulation.

Although seafood meals are a positive step toward total utilization, they are not the complete answer. Numerous potential applications of chitin exist, but potential users have been reluctant to commit capital, and potential suppliers to invest in production facilities without known markets. Several seafood industry processing practices use significant amounts of water, and the potential exists to capture and to concentrate this water fraction and to use it as a natural flavoring agent. Fish fertilizer is becoming economically and environmentally desirable to crop growers. Additionally, because it contains a high concentration of a red pigment desirable in certain species, waste generated from crustaceans can be used in the formulation of aquaculture feed.

Introduction

The term *seafood* is a generic description for a large industry whose diversity often is overlooked by those not closely associated with the industry. More than 3,000 commercial species of seafood are estimated to exist. Because more than 250 of these are available in the United States (Martin et al., 1978; Otwell, 1986), U.S. consumers have many choices. Moreover, because many species share edibility characteristics and therefore one species may have a texture, appearance, and taste very similar to that of another, when one species is unavailable or overpriced, knowledgeable consumers can purchase substitutions.

Diversity within the seafood industry has its downside. Equipment and processes suitable for one species often are unsuitable for another. Consequently, mechanization within the industry has advanced neither as far nor as rapidly as it has in other muscle-protein food industries. Furthermore, handling and shelf life characteristics differ significantly among species: some freeze well, others do not; some can be maintained 2 wk under refrigeration, others only 1 wk.

The diversity evidenced in the seafood industry's processes and products also can be viewed in terms of the volume of waste generated, its composition, and its handling. Volume of waste generated for specific products depends on industry size and on species yield characteristics.

Yield

Species yield is fairly complex in that it depends on animal size, product form, and cutter skill. For example, blue crab yields generally are between 10 and 15% with 85 to 90% waste whereas fillets from whole cod represent about 47% of total weight. The edible portions of other species are as follows: salmon, 64%; perch, 33%; shrimp, 30 to 40%; scallop, 10 to 18%; and oyster, 11 to 17% (Waterman, 1975).

Waste Composition

The solid wastes generated from seafood processing are as varied in composition as are the species themselves. For example, the compositions of finfish waste (species unknown) and of crab waste (blue crabs) appear in Table 9.1 (Fontenot et al., 1982).

Waste Disposal

How seafood waste is disposed of depends on species, plant location, processing method, and processor options. Disposal options used by various segments of the seafood industry are

1. meal (fish meal, crab meal, and others),
2. pet food,
3. rendering,
4. composting,
5. landfilling,
6. ocean dumping, and
7. bait.

Although incomplete, the list does illustrate available options and methods for handling most solid wastes generated by the seafood processing industry.

Total Utilization

At the University of Florida Sea Grant Program's conference on *Seafood Waste Management in the 1980s*, Pigott (1981) challenged the industry to think about waste and waste disposal in terms of total utilization. He also encouraged the industry to consider waste a secondary raw material. Total utilization, which ultimately would solve the waste problem, will factor prominently in industrial development during the 1990s.

Currently, the industry operates under effluent limitation guidelines attained by best conventional control technology (BCT), which the EPA considers equivalent to the best practical control technology currently available (Anderson, pers. com., 1989). With respect to the seafood industry, the BCT is screening—although the tuna and seafood processing industries in remote areas of Alaska are exceptions to this rule. The BCT in tuna processing includes air flotation; however, and in remote areas of Alaska screening is not required. According to the EPA, the rationale for these two exceptions is the fact that air flotation was an established practice within the tuna processing industry before the guidelines were implemented and that therefore this level of technology already was attainable. As for the remote areas of Alaska, screening would result in an accumulation of solids impractical to dispose of except through direct overboard discharge.

The motivation for total utilization most likely will be economics, not regulation. As indicated, yields depend on species and differ greatly; notwithstanding, the edible portions of most currently marketed species represent less than 50% of harvest weight. When the magnitude of seafood harvested is considered, the volume of waste generated is enormous. Disposal alternatives such as landfilling and ocean dumping, which formerly tended to divert attention from the problem, are becoming increasingly burdensome expenditures because of transportation costs and tipping fees. Consequently, the industry must look to other, less costly options that may result in secondary products with income generating potential. Additionally, in some areas, environmental concern about ocean dumping is growing, and pressure to abandon the practice can be expected. Citing problems with noxious odors and pests such as flies and rodents, as well as longer-term concerns such as ground water contamination, some communities have prohibited seafood wastes in landfills.

Secondary seafood products such as meals generate revenue but compete in extremely volatile mar-

Table 9.1. Composition of seafood wastes in percentage of dry matter (Fontenot et al., 1982)

Kind of waste	Dry matter	Soluble carbohydrates	Protein	Acid detergent fiber	Ash	Calcium	Phosphorus	Magnesium
Fish	26.35	1.96	60.37	0.03	27.97	7.30	4.18	0.23
Crab	40.18	3.74	44.14	0.18	34.48	34.48	1.76	0.11

kets in which price is dictated by that of other feed proteins, e.g., soybean meal. And because of the high-moisture content of fish solids, huge amounts of energy are required to dehydrate the product to acceptable moisture levels; thus, manufacturing cost increases significantly over other feed proteins. Furthermore, if quality meal is to be produced, raw materials must be fresh. Less-than-fresh fish produce inferior meal (low protein content) and create odor problems during dehydration. In some areas, fishing seasons are relatively short but intense. During these seasons, meal plant capacities often are exceeded, necessitating alternative disposal means. Disposal costs therefore remain. The long downtime subsequent to these short operating seasons can be expensive from the standpoint of equipment maintenance. Although seafood meals are a positive step toward total utilization, they are not the complete answer.

Alternatives

Chitin and Chitosan

A relatively difficult seafood waste to handle is that derived from crustacean species such as crab. These animals typically yield very little, produce significant waste, and have a great shell content. Their shell is composed of the carbohydrate polymer, *chitin*. Use of chitin and its derivatives, e.g., chitosan, has been studied and discussed for many years. Numerous potential applications exist, e.g., in (1) ion exchange and chelation, (2) coagulation, (3) film and fiber, and (4) medicine (absorbable sutures and wound healing accelerators).

According to a report published by the Massachusetts Institute of Technology (Ashford, 1977), a key problem in commerce has been that potential users have been reluctant to commit capital to develop chitin applications because the supply has been uncertain and the costs have been high for experimental quantities. In turn, potential suppliers have been reluctant to invest in production facilities in the absence of known markets. Currently, one commercial production facility operates in the United States.

Flavor Extracts

Several seafood industry processing practices use significant amounts of water and as a result produce great flows of waste water. For example, certain segments of the clam industry use a retort heat shocking process to facilitate mechanical shucking. The result is a juice by-product that constitutes a serious disposal problem for clam processors (Burnette et al., 1983). Retort cooking of blue crab also results in a significant water loss (20%) from the crabs. In these processes, as in others, the potential exists to capture and to concentrate this water fraction and to use it as a natural flavoring agent. Burnette et al. (1983) and Joh and Hood (1979) have worked with clam processing waste and have developed commercial applications. The authors are aware of at least one clam plant that collects and concentrates clam juice and markets it to flavor manufacturers. Before this, the juice was part of plant wastestream and contributed to BOD and to solids fractions.

Fertilizers

Although fish and their by-products have been used as fertilizer for centuries, a scientific understanding of the real value and the specific properties of fish by-products as fertilizer still is being sought. Until the 1940s, the American menhaden industry depended greatly on sale of fish scrap as fertilizer, without knowing precisely why it helped field and garden crops. Subsequently, the aggressive marketing of economical, petroleum derived chemical fertilizers, combined with wartime demand for the protein content of fish scrap as stock and broiler feed supplements, nearly dismantled the production and use of fish fertilizers. Now, 50 yr later, as petroleum prices increase and source countries destabilize, fish fertilizer is becoming economically and environmentally desirable to crop growers (Aung and Flick, 1980).

Composting

Another area receiving increased attention is the use of fish wastes as composting material. If handled properly, composting offers a clean method of waste disposal, generating no leachate and very little odor. Fish wastes produce an odorless organic-N-rich soil amendment with market potential for home gardeners, highway departments, and others. Composting materials may include wastes not acceptable for rendering, such as those of dogfish or shellfish processing. But composting is not without problems: it is a rather imprecise technology relying greatly on operator experience and is a biological process proceeding most efficiently at warm temperature. Although the process generates internal heat, some protection from cold environmental conditions may be required in northern climates (Goldhor and Regenstein, 1988).

Fish Protein Hydrolysis

Digestion of fish waste by proteolytic enzymes is a promising old technology that may constitute an alternative means of handling waste. The basic operation uses such enzymes to digest proteins and to liquify wastes. Processing technologies used may range from the simple to the complex, depending on digestion control, hydrolysate component-separation, and end-product stabilization methods. Goldhor and Regenstein (1988) identified the unique combination of advantages gained when proteins are digested and wastes liquefied by means of specific hydrolysates:

1. palatability enhancement for a wide range of monogastric species;
2. improved digestibility for very young animals;
3. absence of antigenic reactions in the immature gut;
4. high solubility;
5. choice of oil content;
6. choice of wet, semimoist, or dry product forms;
7. choice of peptide size range;
8. extremely high protein content;
9. low ash content; and
10. sprayability.

Although commercial hydrolysate plants operate in the United States, the technology is much more prevalent in Europe.

Pigments

Waste generated from crustaceans such as crabs and crawfish contains a high concentration of an orange-red pigment known as *astaxanthin*. The pigment, located in the shell fraction, can be extracted from waste during the making of meal. Because the pigment can be used in feed formulation and produces the red coloration so desirable in certain species, the aquaculture industry is one of its prime markets.

10 Economic Considerations in Managing Food Processing Waste

Summary

Food processing is an essential manufacturing sector in the U.S. economy. Generally, it performs well—providing inexpensive, safe, nutritious food—and maintains a high productivity-growth rate. Like other U.S. industries, it increasingly participates in a global marketplace. In the last two decades, food processing firms, like most other U.S. manufacturers, have reduced their outputs of pollutants. At the same time, a new emphasis has been placed on converting wastes to marketable by-products. Indeed, there remains a considerable quantity of waste with the potential to enhance world food supplies. But uneconomic recycling should be avoided in that it wastes resources potentially more beneficial elsewhere.

Improved waste-recycling is possible through continued technological development. Improvement also can be induced by scarcity or by high-priced raw materials for which food processing by-products can substitute. Additionally, a number of institutional mechanisms can encourage recycling and environmental enhancement.

Introduction

Economics offers insight into society's choices regarding the use of waste from agricultural production processes and the control of water pollution from these sources. In that all forms of environmental degradation are related to the scale of economic activity, the extent of waste generation and pollution is determined fundamentally by decisions regarding production and consumption. Additionally, for a given level of economic activity, society can choose from among a number of techniques to decrease pollution and can institute policies to encourage adoption of technologies converting waste into resources.

The discussion of economic considerations that is presented in this chapter characterizes the importance of the U.S. food processing and manufacturing industry to the national economy. The magnitude of waste generated by this industry and the importance of recycling also are considered. The last section of the chapter reviews several options for controlling pollution and for providing incentives for using waste as a resource. The general theme of the final section is that society has the ability to affect waste generation and pollution by establishing "rules of the game" for an industry. Because the problems associated with waste and with pollution can be either exacerbated or mitigated by social institutions, their development is as important as or possibly more important than technological development. That is, although current technologies often constitute the means by which to improve waste utilization, society has not yet provided the necessary economic incentives for their use.

Importance of Food Processing and Manufacturing

Food processing is a basic and essential industry, taking raw food materials—vegetable, animal, and marine—and molding them into products found on grocery shelves and served in restaurants. Chemical, biological, and mechanical processes are used to convert relatively bulky and inedible food materials produced at various times of the year and literally in all parts of the world into palatable, storable, convenient, and nutritious food products.

The economic functions performed by food processors and manufacturers are those of providing place, form, and time utility to consumers. Consider the cans of soup, boxes of cereal, cartons of milk, packages of hamburger, bags of vegetables, loaves of bread, and so forth in any shopping cart. Each product is available to the consumer after raw materials have followed a complex path from the farm gate, through transportation and processing networks, to storage facilities in which temperature and condition prevent quality deterioration, and finally to a processing location where basic ingredients are transformed into products most popular among consumers. The product subsequently is transported through distribution networks to wholesalers, retailers, and ultimately consumers. Each link in this chain requires businesses to combine capital, labor, and technology to produce a product demanded by the next link. All business people involved must assemble adequate financing, bear risk, anticipate market demand, adopt low-cost production techniques, and supervise labor.

The food and fiber industry is immense, providing approximately 18% of U.S. private-sector employment, e.g., in farming, processing, wholesaling, and retailing. More than 14 million jobs are attributable directly to the food and fiber system, one of the nation's largest employers (Connor, 1988).

Food processing is an important segment of this system, employing 1.6 million workers, or about 2% of all those in the private sector. To express its relative size in another way, food processing is one of the largest manufacturing industries in the country, accounting for 8% of all jobs in the manufacturing sector (Connor, 1988).

The U.S. food system, including basic agricultural commodities and manufactured products, is a major component of foreign trade, accounting for 12% of all U.S. exports in 1988 (Food and Agricultural Organization, 1989). Manufactured food products rank third in terms of value among all U.S. export product classes.

Recent problems for all manufacturers have included decreased market share due to competition from low-cost imports. The increasing market share of foreign manufacturers has been attributed to these circumstances abroad:

1. improved labor-productivity,
2. rapidly adopted new technologies,
3. new capital investments, and
4. fewer and less stringent regulations.

The food processing industry has not been immune from these larger forces. Since 1982, there has been a trade deficit in processed food. From 1981 to 1990, the annual dollar volume of U.S. processed food exports increased from $13.0 billion to $18.5 billion while that of imports rose from about $10.5 billion to $20.9 billion (Connor, 1988; U.S. Department of Agriculture, 1992). United States food processors increasingly supply foreign food markets with local products processed by affiliates rather than by U.S. exporters. In 1992, sales of processed food from U.S. affiliates were $89 billion, four times the value of processed food exports. This gap between foreign affiliate sales and U.S. exports more than doubled between 1982 and 1992 (U.S. Department of Agriculture, 1994a). Although the volumes of processed food exports and imports are, in a sense, modest, constituting only 4% of total industry shipments, these recent trends reinforce the message that markets are global, industries are not insular, and foreign competition is a reality as in other U.S. manufacturing industries.

The end product of the U.S. food processing industry typically is nutritious, safe, and inexpensive. Some would take issue with this claim, but from a historical and geographic perspective, most U.S. consumers enjoy food products unparalleled in cost or quality.

Households in the United States allocate only 11% of their personal consumption expenditures to food and beverages, and this percentage has been decreasing continually for several decades (U.S. Department of Agriculture, 1994a). Most of this decline can be attributed to productivity growth within the entire food and fiber system, especially on farms and in food processing companies.

The food processing industry has had one of the highest productivity growth rates of any sector of the economy (Kendrick and Grossman, 1980). Factors causing this growth are technological improvements; capital investments; human capital improvements, e.g., education; cost advantages gained from construction of large plants; and improved worker-health and -safety. Additionally, the industry supplies consumers with products of increasing variety and convenience.

Pollution from Food Processing and the Food System

Like firms in other U.S. industries, food processing firms face regulatory pressure to improve the treatment of waste and the quality of effluent delivered to streams, rivers, and lakes. The Federal Water Pollution Control Act of 1972 (P.L. 92 500) and the Clean Water Act of 1977 (P.L. 95 217), cornerstone pieces of legislation that changed the course of methods for both private and public sectors, addressed the environmental impacts of firms and communities, and made a concerted effort to enhance environmental quality.

The most visible form of pollution emanates from a sewer, an industrial discharge pipe, or other point source. The EPA classifies the discharge pipes of food processing plants as *point sources*, the same classification received by pollutants from fertilizer factories, agricultural chemical manufacturing plants, other industrial sources, and municipal-wastewater treatment plants. But another type of pollutant, i.e., *nonpoint sources*, is responsible for much of the water pollution in the United States. Nonpoint pollution comes from diffuse sources: agricultural land, forests, urban streets, and construction sites. Agriculture accounts for the largest part of nonpoint pollution, and diffuse runoff from farms and ranches is quite extensive relative to the total loadings from several important pollutants. As great as 98% of all SS and 75% of TDS in the nation's waterways originate on agricultural land. Similarly, agricultural nonpoint source pollution accounts for as great as 90% of BOD (Clark et al., 1985).

Thus, the food and fiber system, broadly defined, is the major source of many water pollutants in the United States. The food processing industry is thought to be a minor contributor. Although food processing firms generate by-products as they wash, grind, cut, mix, cook, and transform raw food products, incentives exist for firms to recycle most of these by-products. The adage that the only thing lost from a pig after it leaves a slaughterhouse is the squeal may overstate, but most food processing plants do reclaim by-products because it is profitable to do so. Little information exists about industrial responsibility for specific water pollutants. The EPA estimates that industries decreased their discharges by 70% or greater between 1972 and 1977 (U.S. Environmental Protection Agency, 1984). On the whole, industries have been more successful than have municipalities or farms in reducing discharges into surface waters. Provisions of the 1990 Farm Bill and Clean Water Act revisions will stem nonpoint sources of pollution somewhat.

Although pollutants such as pesticides may be washed into streams during food processing, their potential impact on surface water is difficult to characterize with precision. Similarly, waste lagoons and water impoundments may threaten ground water supplies. When the EPA inventoried industrial impoundments in 1983, greater than 70% were located over permeable soil structures permitting leaching to underground aquifers. Additionally, nearly one-third of these sites were within one mile of a water supply well. The extent to which these lagoons actually degraded ground water is unknown.

Environmental Quality

The economic benefits of improved environmental quality are defined by comparing individual well-being before and after an environmental quality change. The economic value of an environmental quality change is the amount of money that individuals would be willing to pay to have clean water versus unclean water (Crutchfield et al., 1995). Benefits typically are characterized as *use values*, or the value an individual places on an environmental resource that he or she consumes directly or uses, and *nonuse values*, or the value an individual places on the existence of a resource even though he or she does not use it directly. Examples of economic benefits of improved water quality include (1) use value such as recreation (swimming, boating, fishing), drinking water, irrigation, decreased ditch or reservoir dredging, property, wildlife habitat, and aesthetics; and (2) nonuse value such as stewardship for future generations and improved water quality for others.

The benefits of improved waste-management and pollution control are difficult to measure. Some benefits, e.g., improved fish-catches and recreational opportunities, can be measured with a degree of accuracy although estimation techniques can be rather costly. When the benefits of improved water-quality are not exchanged on markets, however, prices and other information relative to market performance will not account for the benefits accurately. For example, the measurement of improved aesthetics associated with cleaning up streams is imprecise.

Several approaches have been used to estimate nonmarket benefits. One approach is to measure individual "revealed preference" for environmental services. Examples of revealed preferences are (1) the additional travel costs boaters willingly incur as they use a distant but clean lake rather than a close but dirty one, (2) household expenditures on bottled water as a substitute for polluted tap water, and (3) differences in the market value of houses on lakes with variations in water quality. The more direct, *contingent valuation* method asks a sample of people to value environmental quality after being presented with a hypothetical situation. How much, for example, would a respondent be willing to pay to improve a lake's water quality and the usability of its water?

Crutchfield et al. (1995) reviewed numerous studies estimating the benefits of improving water quality. For example, Russell and Vaughn (1982) estimated the national recreational fishing benefits of controlling water pollution to be $300 million to $966 million/yr (1982 dollars). Carson and Mitchell (1993) asked 800 respondents to indicate their willingness to pay for various levels of water quality. National benefits of improving surface water quality from "nonboatable" to "swimmable" were $29 billion/yr, or $240/household (1990 dollars). Schultz and Lindsay (1990) estimated the willingness to pay for ground water protection to be $129/household/yr.

Direct costs are incurred by industries complying with environmental regulations. Viewed broadly, economic costs include those related to the economic adjustments necessitated by pollution control. Pollution control measures may decrease output in polluting industries and thereby cause unemployment and international trade loss, as well as increased administrative and legal cost, project delay, and diminished efficiency. From a social viewpoint, the costs of environmental enhancement could be much higher than just the investment and the operating costs of pollution control technology.

From 1973 to 1992, pollution control investment by the private sector was between 0.28 and 0.46% of gross domestic product. Investment since probably has declined somewhat. Investment in pollution control equipment was largest from 1974 to 1976, constituting greater than 0.40% of gross domestic product, as firms complied with environmental regulations mandated by the 1972 Federal Water Pollution Control Act. But comparing these expenditures with those in other countries is difficult. A Congressional Budget Office (CBO) report estimated that from 1975 to 1979, the U.S. private sector spent 0.40% of gross national product while Canadian firms spent 0.05%; Japanese, 0.52%; and West German, 0.18%. The international competitiveness of some U.S. firms may have been affected by environmental regulations (U.S. Congress, 1985), but private-sector pollution control costs seem comparable among the four developed countries responsible for the largest share of export markets.

The CBO also estimated the effects of pollution control expenditures on private-sector productivity. Productivity measures private-sector output per unit input. If pollution control expenditures add little to measurable economic output, then productivity can be impaired. From 1967 to 1982, private-sector productivity grew from 1.0 to 2.25% annually. That is, technological innovations and improvements in human capital enabled the United States to produce more goods with the same land, labor, and capital inputs. This productivity growth rate is estimated by the CBO to be 0.28% lower with pollution control regulations than without. The magnitude of this loss is small and suggests that environmental regulation has caused no substantial losses in private-sector efficiency.

Of course, some industries may be affected more than others. In a study of the surface mining industry, Ro and Forster (1984) examined the effect of pollution control on Ohio coal industry output and employment. They also investigated the economic impact on the region as pollution control effects rippled through the economy. The researchers estimated that industry output and employment declined approximately 8%, a sizable decline whose magnitude likely dwarfed that in the food processing industry. Economic effects in the regional economy as a whole, however, seemed relatively minor, with regional output and employment declining by less than 1%. The researchers' conclusion was that the "economic impacts of pollution control are minor on the regional economy as a whole. The negative environmental impact of this industry can be controlled at a rather modest cost to the region's economy" (Ro and Forster, 1984, p. 186). Undoubtedly, the same could be said of controlling both waste from and negative environmental effects of the food processing industry.

Recycling Food Industry Waste

Wastes have been characterized as "resources out of place." In fact, food processing waste generally is either a potential feed ingredient for farm animal or pet food or a potential nutrient source for crops. For example, in cereal processing firms such as breweries, distilleries, and mills, by-products are not wasted but marketed as livestock feed ingredients. Similarly, in meat processing firms, poor-quality meat-by-products can be converted to better-quality human food-products by means of breakdown and recombination of by-product components. Other by-products such as stomachs, intestines, and fish wastes are converted to pet foods. Finally, poor-quality effluent may be used on cropland as a nutrient source.

But not all food processing waste is recycled. Tolan (1983) and Singer (1980) estimate that food wasted from the first stages of processing to the point of consumption may be as much as 25% of total food supply on an energy basis. Pimentel and Pimentel (1983) argue that an adequate future food supply will depend on shrinking food waste and facilitating resource recycling.

Improving Waste Utilization

The idea of a social imperative to recycle waste products as food or as nutrient resources should be rejected. If such use is uneconomical, that is, if costs exceed benefits, then society is ill served by recycling. In a sense, uneconomical recycling efforts only wastes or abuses other resources (Wilson and Brigstocke, 1983).

Intensity of waste recycling efforts depends on available technologies, prices of alternatives to by-products, and political institutions. Technology rarely is a limiting factor in food waste recycling (Wilson and Brigstocke, 1983). Although there are immense quantities of discarded or underutilized waste, economic considerations usually makes recycling impractical. Of course, technologies are evolving, and continued development of resource recovery techniques is essential if waste utilization is to improve.

Prices of alternative by-products help explain the extent of waste recycling efforts throughout an industry. For example, most animal-feed manufacturers use least-cost feed formulations, and composition of feed mixes depends greatly on the relative prices of feed ingredients. By-products such as fish meal, bone meal, and distillers' dry grain are used commonly as feed ingredients and readily substitute for other ingredients as sources of protein, energy, and other feed requirements. Demand for these by-products is determined primarily according to relative price. Interest in agricultural waste as a source of energy waxes when fossil fuel prices are high and wanes when they are low. Recycled wastes are valued in markets, and the incentive for their reuse depends on their ability to substitute for other raw materials.

Role of Institutions

Institutions can provide incentives for recycling and for controlling pollution. Laws can be passed, and regulations enforced. In the past, regulation has been the most used mechanism for encouraging changes in waste use. But other potentially more efficient mechanisms such as fiscal instruments exist (Baumol and Oates, 1975). Charges can be assessed for pollutants entering streams, polluted industrial effluent flowing to municipal treatment plants, or wastes dumped in landfills. Subsidies can be provided for by-product use, as in the case of federal tax subsidies for ethanol users. Markets for by-products such as composted animal manures in home gardening can be developed. Public institutions can develop new technologies and encourage their adoption in the private sector, as the Land Grant University system has done through its agricultural experiment stations and its extension service programs in rural education.

One institutional arrangement potentially decreasing the cost of pollution control is the joint treatment of domestic and food-processing-plant wastewaters (Rossi et al., 1979). In many rural communities, wastewater treatment is mandated by federal legislation, but costs per capita are high because economies of scale are absent. Food processing plants located in or near these communities also face regulatory requirements, and their effluent may be treated at the plant or discharged into a municipal-waste treatment system.

Although required to provide joint treatment services if certain conditions are satisfied, municipalities have considerable latitude to encourage or to discourage joint treatment. For example, they have flexibility in the pricing of waste water treatment services and in the levying of use charges against the dischargers of industrial effluents. They also have flexibility in the establishment of both pretreatment requirements for and maximum concentrations of certain pollutants. When food processing waste is treated at municipal treatment facilities, user charges are an effective institutional mechanism for reducing pollutants (Hudson et al., 1981).

Combining municipal and food processing wastes may decrease treatment costs to both municipal users and food processing companies (Epp et al., 1982; Young, 1986). Substantial economies of scale in secondary wastewater treatment systems, e.g., activated sludge, trickling filter, or lagoon systems, may result in decreased per unit treatment costs when industries and communities treat wastes jointly. Potentially offsetting these cost savings are wastewater collection and transmission costs. Great distances between community treatment plants and food processing plants may cause the costs of transmission to offset the advantages of economies of size.

Some food processing waste may be combined with some forms of community solid waste and composted at a joint facility. For example, two communities in the state of Washington— Grandview and Prosser—are combining residential yard debris with food processing wastes such as apple pomace, grape skin, and cranberry residual (Riggle, 1989).

11 Conclusions

The food production system begins with *photosynthesis*, or the biochemical reaction occurring in the leaves of plants and combining carbon dioxide (CO_2) with H_2O to form organic matter (CH_2O) and O_2. The end products of this process are known as, among other things, grasses; hays; grains, e.g., wheat, barley, and corn; soybeans; fruits; vegetables; and trees. Some of these products are processed and packaged directly, e.g., fruits and vegetables; others are fed to animals to yield meats, eggs, milk, or wool. Waste products include the residues from production, for example, wheat straw and corn stubble left after harvest; the waste generated in a milking parlor or in a slaughterhouse; and the excess of inputs necessary for sustained production, such as fertilizers and weed and pest control chemicals.

The inputs discussed in this report were fertilizers and pesticides. Of the commonly used fertilizers, nitrate is of greatest concern because this very mobile element is contained with much difficulty in the root zone. Farming practices limiting the release of unwanted materials into the environment are being developed and introduced rapidly. Regulation of fertilizer use is being considered by Congress and well may be introduced soon.

A great number of pesticides are now in use. Few persist in the environment long enough to be considered pollutants; some, however, have a short half-life and can be hazardous if used improperly. Some of the old, high-volume herbicides are being detected in surface and ground waters, and an important research effort is under way to find means of eliminating such contamination. The problem of how to deal with pesticides remains one of the greatest challenges to agriculture, for these chemicals ensure production stability. The number and the variety of chemicals are great because the number of insects and diseases is great and changing constantly.

Long-term stability of the food production enterprise in harmony with environmental health and quality demands ongoing investment in research and development. One reason that approximately 80% of all cultivated land in the United States is devoted to only four plant species is that these are the most stable to produce under given climatic conditions. Realism about society's dependence on a stable food production system, a stability that can be ensured only through the ability to prevent disastrous crop loss due to diseases or insects, is essential. The annual research investment in the production end of the system should be increased; today, research investment in crop protection is less than 1% of the value of product received by farmers.

Waste produced during food processing consists almost entirely of organic matter, and water is being used to wash away unneeded or unrecoverable organics. Waste streams occur at mill processing plants, slaughterhouses, oil processing plants, and other locales. Although these streams impose a burden on waste treatment facilities, they rarely present a health problem. Industry contributes its share of processing costs. Industrial waste streams are well described and quantified, being regulated under the Clean Water and Clean Air Acts. Increasingly, products contained in the wastestream are being recovered and used.

Maintaining the stability of the food production enterprise will continue to require an investment in research and development. Plant production systems in harmony with the environment will be required. How pests will be controlled is unclear, but biological controls will be part of management systems.

Appendix A: Symbols and Abbreviations

μg	microgram
a.	acre
acre-in.	acre-inch
BOD	biochemical oxygen demand
BTU	British thermal units
°C	degrees Centigrade
C	carbon
Ca	calcium
Cd	cadmium
Cl	chlorine
Cl^{-1}	chloride
cm	centimeter
COD	chemical oxygen demand
Cu	copper
d	day
°F	degrees Fahrenheit
Fe	iron
ft	feet
gal.	gallon
H_2O	water
ha	hectare
hp	horsepower
hr	hour
in.	inch
K	potassium
K_2O	potash
kg	kilogram
L	liter
lb	pound
m	meter
mg	milligram
Mg	magnesium
Mg ha^{-1}	megagram per hectare
MGD	million gallons per day
min	minute
mm	millimeter
mmhos	millimhos
Mn	manganese
Mo	Molybdenum
mo	month
N	nitrogen
Na	sodium
NH_3-N	ammonia nitrogen
NH_4-N	ammonium nitrogen
O	oxygen
P	phosphorus
P_2O_5	phosphate
ppm	parts per million
PWD-1	*Bacillus licheniformis*
S	sulfur
sec	second
SIC	standard industrial classification
SOM	soil organic matter
t	metric ton
TKN	total Kjeldahl
TS	total solids
wk	week
yr	year
Zn	zinc

Appendix B: Acronyms

ARS	Agricultural Research Service
ASAE	American Society of Agricultural Engineers
BCT	best conventional-control technology
BMP	best management practices
BOD	biochemical oxygen demand
BOD_5	five-day biochemical oxygen demand
CAST	Council for Agricultural Science and Technology
CBO	Congressional Budget Office
CCFA	California Cattle Feeders Association
COD	chemical oxygen demand
DAF	dissolved air flotation
EPA	U.S. Environmental Protection Agency
FOG	fats, oils, and grease
HI	Harvest Index
MWPS	Midwest Plan Service
NPDES	national pollutant discharge elimination system
NRCS	Natural Resource Conservation Service
POTW	publicly owned treatment work
SCS	Soil Conservation Service
SRS	Statistical Reporting Service
SS	suspended solids
TDS	total dissolved solids
TKN	total Kjeldahl nitrogen
TSP	total suspended particulate
TSS	total suspended solids
TNRCC	Texas Natural Resource Conservation Commission
USDA	U.S. Department of Agriculture

Appendix C: Glossary

Active organic N. Nitrogen in soil dominated by the microbial population and by organic soil amendments.

Aerobic bacteria. Microorganisms active in the presence of free oxygen.

Anaerobic bacteria. Microorganisms active in the absence of free oxygen.

Agricultural liming material. A material whose calcium and magnesium compounds are capable of neutralizing soil acidity.

Astaxanthin. An orange-red pigment located in the shell fraction of waste generated from crustaceans such as crabs and crawfish.

Biosolids. Sludges that are products of biological wastewater treatment processes.

Bladeability. Parameter designed to decrease the potential for contamination due to leaching into ground water around a landfill site.

Chitin. The carbohydrate polymer composing the shell of crustaceans.

Composting. The microbial breakdown of organic wastes into stable, unobjectionable, and safe humuslike materials spreadable on land.

Conventional tillage. Use of a moldboard plow to turn the soil to a depth of 4 to 10 inches. Also known as *clean culture*.

Daily fine. Fine levied for polluting, which must be paid until the problem is resolved.

Effervescence. Bubbles of biogas.

Event fine. Fine levied for polluting, the size of which depends on impact to the affected body.

Facultative bacteria. Microorganisms active under both aerobic and anaerobic conditions.

Feedlot. A concentrated animal feeding facility; usually fenced or enclosed otherwise.

Fluidized bed processing. Processing raw waste material on a bed of hot-air jets, to dry and to cook poultry by-product wastes into feed ingredients.

Food processing wastes. Solid and liquid residues of the food production system.

Freeboard. Indicator of space between highest water level and top of water impoundment structure.

Harvest Index. The mass of harvested or usable plant product as a fraction of total plant biomass produced per unit land area (or per plant); a measure of crop residue.

Inorganic N. Nitrogen in the nitrate (NO_3^-) or ammonium (NH_4^+) forms.

Keratinaceous. Of or relating to a scleroprotein principally constituting the hair, nails, epidermis, horny tissue, and tooth enamel organic matrix.

Mesophilic. Reproducing, metabolizing, and growing most readily in the temperature range 40 to 100°F, or 5 to 37°C.

Milk equivalence. Relates actual production of various commodities to a common denominator, i.e., raw milk.

Nonpoint source. Diffuse emitter of pollution, e.g., construction sites or urban streets.

No-till culture. A farming practice whereby the soil surface is undisturbed by tillage and seeding is done by equipment designed to cut through residues and the soil surface to place the seed at the correct depth for germination.

Old organic N. Nitrogen that is centuries old, accumulated as the soil developed, and resists mineralization. Also known as *humus*.

Packers. The processing segment of the fruit and vegetable industry.

Pesticide. "Any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any insects, rodents, nematodes, fungi, or weeds, or any other forms of life declared to be pests; and any substance or mixture of substances intended for use as a plant regulator, defoliant, or desiccant." (Federal Insecticide, Fungicide, and Rodenticide Act)

Photosynthesis. The biochemical reaction occurring in the leaves of plants or in certain microorganisms living in freshwater lakes and streams or in oceans.

Point source. Specific emitter of pollution, e.g., discharge pipes of food processing plants.

PM-10. The median aerodynamic particle size of 10 microns.

Psychrophilic anaerobic digestion. Methanogenesis at temperatures approaching 0°C.

Psychrophilic. Reproducing, metabolizing, and growing readily in the temperature range < 40°F, or < 5°C.

PWD-1. *Bacillus licheniformis.*

Stable organic N. Nitrogen that is maintained at a given level when the agrosystem is managed properly.

Sward. Grassy surface of land.

Thermophilic. Reproducing, metabolizing, and growing most readily in the temperature range 100 to 150°F, or 37 to 65°C.

Tilth. Physical condition of the soil.

Whey. The watery part of milk separated from the coagulum of whole milk, cream, or skim milk.

Literature Cited

Ackerman, S. E. and T. L. Richard. 1990. Composting mortality from cage layer flocks. Pp. 31–37. *Proceedings of the National Poultry Waste Management Symposium*, Raleigh, North Carolina, October 3–4, 1990.

Adams, F. 1984. (Ed.). *Soil Acidity and Liming*. Agronomy Series No. 12. American Society of Agronomy, Madison, Wisconsin. 380 pp.

Alexander, M. 1961. *Soil Microbiology*. John Wiley & Sons, New York.

Algeo, J. W., C. J. Elam, A. Martinez, and T. Westing. 1972. *Feedlot air, water and soil analysis: Bulletin D, How to control feedlot pollution*. California Cattle Feeders Association, Bakersfield. 75 pp.

American Society of Agricultural Engineers. 1993a. *Manure Production and Characteristics*. Pp. 530–532. Standards, D384–1. American Society of Agricultural Engineers, St. Joseph, Michigan.

American Society of Agricultural Engineers. 1993b. *Design of Anaerobic Lagoons for Animal Waste Management*. Pp. 543–546. Standards, EP403.2. American Society of Agricultural Engineers, St. Joseph, Michigan.

Anderson, D. 1989. Personal communication. U.S. Environmental Protection Agency, Washington, D.C.

Anderson, L. 1990. Commercial composting of poultry manure. Pp. 130–143. *Proceedings of the National Poultry Waste Management Symposium*, Raleigh, North Carolina, October 3–4, 1990.

Anonymous. 1980. Rotating drum screen for liquids/solids separation. *Effluent Water Treat. J. (G.B.)* 20:343.

Arave, C. W., D. C. Dobson, M. J. Arambel, R. L. Boman, and J. B. Gilbert, Jr. 1985. Value of a masking agent or feed flavor in enhancing preference for concentrate with added processed chicken excreta. *J. Dairy Sci.* (Suppl. 1):159.

Arave, C. W., D. C. Dobson, M. J. Arambel, D. Purcell, and J. L. Walters. 1990a. The effect of poultry waste feeding on intake, body weight, and milk yield of Holstein cows. *J. Dairy Sci.* 73:129.

Arave, C. W., D. C. Dobson, N. J. Stenquist, and J. L. Walters. 1990b. Caged layer waste as a supplement to grass hay for beef steers and heifers. Vol. 41. *Proceedings of the Western Section*. American Society of Animal Science, Champaign, Illinois.

Arave, C. W., D. C. Dobson, J. B. Walters, B. J. Gilbert, Jr., and M. J. Arambel. 1988. Effect of added processed poultry waste on dairy heifer's preference for concentrates. *J. Dairy Sci.* 71:3021–3025.

Archibald, S. O. and C. K. Winter. 1990. Pesticides in our food. In C. K. Winter, J. N. Seiber, and C. F. Nuckton (Eds.). Ch. 1. In *Chemicals in the Human Food Chain*. Van Nostrand Reinhold, New York, New York. 276 pp.

Ardern, E. and W. T. Lockett. 1915. Experiments on the oxidation of sewage without the aid of filters. *J. Soc. Chem. Ind.* 34:767.

Arrington, R. M. and C. E. Pachek. 1981. Soil nutrient content of manures in an arid climate. Pp. 150–152. *Livestock Waste: A Renewable Resource. Proceedings of the Fourth International Symposium on Livestock Waste, 1980*. American Society of Agricultural Engineers, St. Joseph, Michigan.

Asghari, M. and R. G. Hanson. 1984. Climate, management and N effect on corn leaf N, yield and grain N. *Agron. J.* 76:911–916.

Ashford, N. A. 1977. *Industrial prospects for chitin and protein from shellfish wastes*. Report No. MITSG 77–3. Massachusetts Institute of Technology Sea Grant Program, Massachusetts Institute of Technology, Cambridge.

Aspelin, A. L. 1994. *Pesticide industry sales and usage. 1992 and 1993 market estimates*. U.S. Environmental Protection Agency, Washington, D.C.

Aung, L. H. and G. J. Flick. 1980. *Fish solubles as a fertilizer for growing plants*. VPI–SG–80–09. Sea Grant College Program, Virginia Polytechnic Institute and State University, Blacksburg.

Bachman, L. J. 1984. *Nitrate in the Columbia Aquifer, Central Delmarva Peninsula, Maryland*. Report No. 84–4322. U.S. Geological Survey, Towson, Maryland.

Balesdent, J., G. H. Wagner, and A. Mariotti. 1988. Soil organic matter turnover in long-term field experiments as revealed by carbon–13 natural abundance. *Soil Sci. Soc. Am. J.* 52:118–124.

Balsari, P. and E. Bozza. 1988. Fertilizers and biogas recovery installation of a slurry lagoon. Pp. 71–80. *Agricultural Waste Management and Environmental Protection: Proceedings of the Fourth International Symposium of the CIEC*.

Bar, J. C. 1991. Personal communication. Chief Executive Officer, National Milk Producers Federation.

Barber, S. A. 1984a. Liming materials and practices. Pp. 171–210. In F. Adams (Ed.). *Soil Acidity and Liming*. Agronomy series no. 12. American Society of Agronomy, Madison, Wisconsin. 380 pp.

Barber, S. A. 1984b. *Soil Nutrient Bioavailability*. John Wiley & Sons, New York.

Barker, J. C. 1983. *Lagoon design and management for livestock waste treatment and storage*. EBAE 103–83. Biological and Agricultural Engineering Department, North Carolina State University, Raleigh. 10 pp.

Barker, J. C. and L. B. Driggers. 1981. Design criteria for alternative swine flushing systems. Pp. 367–370, 374. *Livestock Waste: A Renewable Resource*. American Society of Agricultural Engineers, St. Joseph, Michigan.

Barker, J. C. and L. B. Driggers. 1985. Pit recharge system for managing swine underfloor manure pits. Pp. 575–581. *Agricultural Waste Management and Utilization*. SP 13–85. American Society of Agricultural Engineers, St. Joseph, Michigan.

Barker, J. C. and H. R. Williams. 1991. *Greene County animal mortality collection ramp*. EBAE 186–93. Biological and Agricultural Engineering Department, North Carolina State University, Raleigh. 2 pp.

Barker, J. C. and J. P. Zublena. 1995. *Livestock manure nutrient assessment in North Carolina*. Pp. 98–106. Proceedings of the Seventh International Symposium on Agricultural and Food Processing Wastes. American Society of Agricultural Engineers, St. Joseph, Michigan.

Barker, J. C., F. J. Humenik, M. R. Overcash, and S. W. Tedder. 1983. *Evaluating swine drylot runoff impact on a coastal plain* *stream*. EPA–600/2–83–079. U.S. Environmental Protection Agency, Ada, Oklahoma. 89 pp.

Barker, J. C., P. W. Westerman, and L. M. Safley. 1988. Lagoon design and management for layer waste treatment and storage. Pp. 26–33. *Proceedings of the National Poultry Waste Management Symposium*, Columbus, Ohio, April 18–19, 1988.

Barrington, S. F. and P. J. Jutras. 1983. *Soil sealing by manure in various soil types*. Paper 83–4571. American Society of Agricultural Engineers, St. Joseph, Michigan. 28 pp.

Barrington, S. F. and C. A. Madramootoo. 1989. Investigating seal formation from manure infiltration into soils. *Trans. Am. Soc. Agric. Eng.* 32:851–856.

Barth, C. L. 1985. The rational design standard for anaerobic livestock lagoons. Pp. 638–647. *Agricultural Waste Utilization and Management*. ASAE Publ. 13–85. American Society of Agricultural Engineers, St. Joseph, Michigan.

Barth, C. L., J. Brock, and R. Stovall. 1990. Waste and resource management for a 720,000-layer complex. Pp. 33–40. *Proceedings of the Sixth International Symposium on Agricultural and Food Processing Wastes*, Chicago, Illinois, December 17–18, 1990.

Battacharya, A. N. and J. F. Fontenot. 1965. Utilization of different levels of poultry litter nitrogen by sheep. *J. Anim. Sci.* 24:1174–1178.

Battacharya, A. N. and J. F. Fontenot. 1966. Protein and energy value of peanut hull and wood shaving poultry litter. *J. Anim. Sci.* 25:367–371.

Battacharya, A. N. and J. C. Taylor. 1975. Recycling animal waste as a feedstuff: A review. *J. Anim. Sci.* 41:1438–1457.

Baumol, W. and W. Oates. 1975. *The Theory of Environmental Policy*. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Blake, J. P. and J. O. Donald. 1992. An on-farm fermentation system for dead poultry disposal. *Poult. Sci.* 71:51 (abstr.).

Blake, J. P., M. E. Cook, and C. C. Miller. 1990. Dry extrusion of offal, feathers, and dead birds. *Proceedings of the Midwest Poultry Federation Meetings*, Minneapolis, Minnesota, February 1990.

Blanc, F. C., J. C. O'Shaughnessy, and S. H. Corr. 1983. Treatment of beef slaughtering and processing wastewaters using rotating biological contactors. Pp. 133–1140. *Proceedings of the 38th Industrial Waste Conference*. Ann Arbor Science Publishers, Ann Arbor, Michigan.

Blevins, K. 1990. A simple dead-bird composter. Pp. 50–51. *Proceedings of the National Poultry Waste Management Symposium*, Raleigh, North Carolina, October 3–4, 1990.

Bragg, D. B., M. C. Kwok, H. S. Saben, and W. D. Kitts. 1975. Nutritive value of biological waste following degradation by thermophilic microorganisms. *Poult. Sci.* 54:1736.

Brodie, H. L. and G. L. Smith. 1991. *Calibrating manure spreaders*. FS–419. Cooperative Extension Service, University of Maryland, College Park. 8 pp.

Bugbee, G. J. and C. R. Frink. 1989. Composted waste as a peat substitute in peat-lite media. *Hortscience* 24:625–627.

Bulletin of the International Dairy Federation (IDF). 1989. *The World Dairy Situation*. The International Dairy Federation, Brussels, Belgium.

Burnette, J. A., G. J. Flick, J. R. Miles, R. L. Ory, A. J. St. Angelo, and H. P. Dupuy. 1983. Characterization and utilization of ocean quahog (*Artica islandica*) clam juice as a liquid and dehydrated flavoring agent. *J. Food Sci.* 48:353.

Burns, J. C., L. D. King, and P. W. Westerman. 1990. Long-term swine lagoon effluent applications on coastal Bermuda grass: 1. Yield, quality, and element removal. *J. Environ. Qual.* 19:749–756.

Burton, D. L. and E. G. Beauchamp. 1986. Nitrogen losses from swine housings. *Agric. Wastes* 15:59–74.

Butchbaker, A. F. 1973. Feedlot runoff disposal on grass or crops. *Great Plains beef cattle feeding handbook*. L–1053. GPE–7521. Texas Agricultural Extension Service, Texas A&M University, College Station. 4 pp.

Butner, R. S., E. G. Baker, D. C. Elliot, and L. J. Sealok. 1988. A thermocatalytic process for the gasification of high-moisture food processing wastes. *Proceedings of the 1988 Food Processing Waste Conference*. Georgia Technology Research Institute, Atlanta.

Cai, T., O. C. Pancorbo, H. M. Barnhart, J. E. Sander, and W. C. Merka. 1994. Chemical and microbiological characteristics of poultry processing by-products, wastes, and poultry carcass during lactic acid fermentation. *J. Appl. Poult. Res.* 3:49-60.

Carawan, R. E. 1989. Water conservation and waste reduction for the poultry processing industries. *Proceedings of the Clean Water Act and the Poultry Industries*. Washington, D.C.

Carawan, R. E., J. V. Chambers, and R. R. Zall. 1979a. *Water and wastewater management in food processing*. Extension Special Report No. AM–18D. (Poultry spin off manual). North Carolina Agricultural Extension Service, Raleigh.

Carawan, R. E., J. V. Chambers, and R. R. Zall. 1979b. *Water and wastewater management in food processing*. Extension Special Report No. AM–18J. (Wastewater treatment spin off manual). North Carolina Agricultural Extension Service, Raleigh.

Carawan, R. E., J. V. Chambers, R. R. Zall, and R. H. Wilkowske. 1979c. Fruit and vegetable commodities spin off manual. Manual Series on *Water and wastewater management in food processing*. Set of 15. Extension Special Report No. AM–18E. North Carolina State University, Raleigh.

Carawan, R. E., W. M. Crosswhite, J. A. Macon, and B. K. Hawkins. 1974. *Water and waste management in poultry processing*. EPA–660/2–74–031. Office of Research and Development, U.S. Environmental Protection Agency, Washington, D.C.

Carr, L. E. 1988. Utilization of poultry solid waste on crops. Pp. 133–140. *Proceedings of the National Poultry Waste Management Symposium*, Columbus, Ohio, April 18–19, 1988.

Carr, L. E., R. C. Moore, W. C. Merka, and F. D. Schales. 1988. Land disposal of dissolved air flotation sludge from poultry processing. *Trans. Am. Soc. Agric. Eng.* 31:463.

Carson, R. T. and R. Mitchell. 1993. The value of clean water: The public's willingness to pay for boatable, fishable, and swimmable water quality. *Water Resour. Res.* 29:2445–2454.

Carter, T. A. 1990. Personal communication. Department of Poultry Science, North Carolina State University, Raleigh.

Casada, M. E. and L. M. Safley. 1990. *Global methane emissions from livestock and poultry manure*. Project Report. EPA Assistance Agreement CX–816200–01–0. U.S. Environmental Protection Agency, Washington, D.C. 124 pp.

Caswell, L. F., J. P. Fontenot, and K. E. Webb, Jr. 1978. Fermentation and utilization of broiler litter ensiled at different moisture levels. *J. Anim. Sci.* 46:547–561.

Chandler, J. A., S. K. Hermes, and K. D. Smith. 1983. A low cost 75–kW covered lagoon biogas system. *Energy From Biomass and Wastes VII Conference*, Lake Buena Vista, Florida. 23 pp.

Clark, E. H., J. A. Haverkamp, and W. Chapman. 1985. *Eroding soils, the off-farm impacts*. Conservation Foundation, Washington, D.C.

Clark, R. N. 1975. Seepage beneath feedyard runoff catchments. Pp. 289–296. *Managing Livestock Wastes: Proceedings of the Third International Symposium on Livestock Wastes*. American Society of Agricultural Engineers, St. Joseph, Michigan.

Clark, R. N., C. B. Gilbertson, and H. R. Duke. 1975a. Quantity and quality of beef feedyard runoff in the Great Plains. Pp. 429–431. *Managing Livestock Wastes: Proceedings of the Third International Symposium on Livestock Wastes*. American Society of Agricultural Engineers, St. Joseph, Michigan.

Clark, R. N., A. D. Schneider, and B. A. Stewart. 1975b. Analysis of runoff from southern Great Plains feedlots. *Trans. Am. Soc. Agric. Eng.* 15:319–322.

Collins, E. R. 1990a. *Ammonia emissions from a large swine production complex.* Paper No. 904519. American Society of Agricultural Engineers, St. Joseph, Michigan. 8 pp.

Collins, E. R. 1990b. Lagoon treatment for poultry wastes. Pp. 266–277. *Proceedings of the National Poultry Waste Management Symposium*, Raleigh, North Carolina, October 3–4, 1990.

Collins, E. R., T. G. Ciravolo, D. L. Hallock, D. C. Martens, H. R. Thomas, and E. T. Kornegay. 1975. Effect of anaerobic swine lagoons on ground water quality in high water table soils. Pp. 303–305, 313. *Managing Livestock Wastes: Proceedings of the Third International Symposium on Livestock Wastes*. American Society of Agricultural Engineers, St. Joseph, Michigan.

Connor, D. E., J. P. Blake, and J. O. Donald. 1991. *Microbiological safety of composted poultry farm mortalities*. Paper No. 914053. American Society of Agricultural Engineers, St. Joseph, Michigan. 11 pp.

Connor, J. M. 1988. Differences in value added in Part II: Size, growth, and contribution of individual food processing industries. *Food Processing, an Industrial Powerhouse in Transition.* Lexington Books, Lexington, Massachusetts.

Converse, J. C., G. W. Evans, K. L. Robinson, W. Gibbons, and M. Gibbons. 1981. Methane production from a large-size on-farm digester for poultry manure. Pp. 122–124. *Livestock Waste: A Renewable Resource*. American Society of Agricultural Engineers, St. Joseph, Michigan.

Council for Agricultural Science and Technology. 1980. *Organic and conventional farming compared*. Report No. 84. Council for Agricultural Science and Technology, Ames, Iowa.

Council for Agricultural Science and Technology. 1988. *Effective use of water in irrigated agriculture*. Report No. 113. Council for Agricultural Science and Technology, Ames, Iowa.

Council for Agricultural Science and Technology. 1994. *Pesticides in surface and ground water*. Issue Paper No. 2. Council for Agricultural Science and Technology, Ames, Iowa.

Cronce, R. C., D. E. Baker, and R. G. Meyers. 1990. Evaluation of the pollution effects of animal manure spread on land. Pp. 424–433. *Proceedings of the Sixth International Symposium on Agricultural and Food Processing Wastes*, Chicago, Illinois, December 17–18, 1990.

Cross, D. L. and B. F. Jenny. 1976. Turkey litter silage in rations for dairy heifers. *J. Dairy Sci.* 59:919–923.

Crutchfield, S. R., P. Feather, and D. Hellerstein. 1995. *The benefits of protecting rural water quality*. Agricultural Economic Report No. 701. Economic Research Service, U.S. Department of Agriculture, Washington, D.C. 27 pp.

Cullimore, D. R., A. Maule, and N. Mansuy. 1985. Ambient temperature methanogenesis for pig manure waste lagoons: Thermal gradient incubator studies. *Agric. Wastes* 12:147–157.

Cullinson, A. E., H. C. McCampbell, A. C. Cunningham, R. S. Lowrey, E. P. Warren, B. D. McLendon, and D. H. Sherwood. 1976. Use of poultry manures in steer finishing rations. *J. Anim. Sci.* 42:219–228.

de Bartoldi, M., G. Vallini, and A. Pera. 1984. Technological aspects of composting including modeling and bacteriology. Pp. 27–41. In J. K. R. Gasser (Ed.). *Composting of Agricultural and Other Wastes*. Elsevier Science Publishing Company, Inc., New York.

deGraft-Hanson, J. A., E. C. Naber, J. F. Stephens, and O. C. Thompson. 1990. The microbiology and safety of cage layer manure rapidly composted in a closed system with various carbon sources. Pp. 25–32. *Proceedings of the Sixth International Symposium on Agricultural and Food Processing Wastes*, Chicago, Illinois, December 17–18, 1990.

deMooy, C. J., J. Pesek, and E. Spaldon. 1973. Mineral nutrition. Ch. 9. In B. E. Caldwell (Ed.). *Soybeans: Improvement, Production, and Uses*. Agronomy Monograph 16. American Society of Agronomy, Madison, Wisconsin.

Dobbins, D. N. 1988. *Lactobacillus* fermentation: A method of disposal/utilization of carcasses or toxic chemicals. Pp. 76–80. *Proceedings of the National Poultry Waste Management Symposium*, Columbus, Ohio, April 18–19, 1988.

Dobson, S. H. 1975. Personal communication. Crop Science Department, North Carolina State University, Raleigh.

Donald, J. O. and J. P. Blake. 1990a. Dead poultry composter construction. Pp. 38–44. *Proceedings of the National Poultry Waste Management Symposium*, Raleigh, North Carolina, October 3–4, 1990.

Donald, J. O. and J. P. Blake. 1990b. *Installation and use of incinerators*. Circular DTP 11/90–014. Cooperative Extension Service, Auburn University, Auburn, Alabama. 2 pp.

Donald, J. O., C. C. Mitchell, and C. H. Gilliam. 1990. *Dead poultry composting*. Circular ANR–558. Alabama Cooperative Extension Service, Auburn University, Auburn.

Donham, K. J., J. Yeggy, and R. R. Dague. 1985. Chemical and physical parameters of liquid manure from swine confinement facilities: Health implications for workers, swine and the environment. *Agric. Wastes* 14:97–113.

Driggers, L. B. 1987. *Ventilation of swine buildings*. AG–132. North Carolina Agricultural Extension Service, Raleigh. 15 pp.

Drummond, J. G., S. E. Curtis, J. Simon, and H. W. Morton. 1980. Effects of aerial ammonia on the growth and health of young pigs. *J. Anim. Sci.* 50:1085.

Dutton, H. E., Jr. 1990. Composting dead chickens—Dutton Farm demonstration. Pp. 45–49. *Proceedings of the National Poultry Waste Management Symposium*, Raleigh, North Carolina, October 3–4, 1990.

Eaken, J. H. 1972. Food and fertilizer. Ch. 1. In *The Fertilizer Handbook*. The Fertilizer Institute, Washington, D.C.

Economic Report of the President. 1987. P. 260. U.S. Government Printing Office, Washington, D.C.

Elam, C. J., J. W. Algeo, T. Westing, and L. Hokit. 1971. *Measurement and control of feedlot particulate matter: Bulletin C, How to control feedlot pollution*. California Cattle Feeders Association, Bakersville. 30 pp.

Elliott, L. F., T. M. McCalla, L. N. Mielke, and T. A. Travis. 1972. Ammonium, nitrate and total nitrogen in the soil water of feedlot and field soil profiles. *Appl. Microbiol.* 23:810–813.

Environmental Protection Service Canada. 1979. *Economic and technical review report*. EPS 3–WP–29–3. Environmental Protection Service Canada, Ottawa, Ontario.

Epp, D. J., C. E. Young, and D. Rossi. 1982. Benefits from joint treatment of municipal and poultry processing wastewater. *Water Resour. Res.* 18:1587–1590.

Epstein, E., J. E. Alpert, and C. C. Calvert. 1978. Alternative uses of excess crop residues. Ch. 13. In W. R. Oschwald (Ed.). *Crop Residue Management Systems.* Special Publication 31. American Society of Agronomy, Madison, Wisconsin.

Evans, E., E. T. Moran, G. K. Macleod, and E. M. Turner, Jr. 1978a. Laying hen excreta as a ruminant feedstuff. II. Preservation and acceptability of wet excreta for sheep. *J. Anim. Sci.* 46:527–540.

Evans, E., E. T. Moran, Jr., and J. P. Walker. 1978b. Laying hen excreta as a ruminant feedstuff. I. Influence of practical extremes in diet, waste management procedure and state of production on composition. *J. Anim. Sci.* 46:520–526.

Evans, R. O., P. W. Westerman, and M. R. Overcash. 1984. Subsurface drainage water quality from land application of swine lagoon effluent. *Trans. Am. Soc. Agric. Eng.* 27:473–480.

Ferket, P. R. 1990. Personal communication. Department of Poultry Science, North Carolina State University, Raleigh.

Ferket, P. R. 1991. Technological advances could make extrusion an economically feasible alternative to pelleting. *Feedstuffs* 66(4):1, 20–22.

Ferket, P. R. and F. T. Jones. 1992. Drying equipment shows promise for feed, poultry industries. *Feedstuffs* 64:15–16, 25.

Ferket, P. R., J. L. Grimes, and C. M. Williams. 1995. Utilization of poultry and sweet potato waste products as value-added feedstuffs for animals. *Proceedings of the Fifth Annual Research Symposium*, North Carolina Institute of Nutrition, Chappel Hill. In press.

Fischer, J. R., E. L. Iannotti, and D. M Sievers. 1981. Anaerobic digestion of manure from swine fed on various diets. *Agric. Wastes* 3:301–214.

Flipot, P., M. McNiven, and J. D. Summers. 1975. Poultry wastes as a feedstuff for sheep. *Can. J. Anim. Sci.* 55:291–296.

Fontenot, J. P. 1988. Utilizing poultry wastes in ruminant feeding. Pp. 52–64. *Proceedings of the National Poultry Waste Management Symposium*, Columbus, Ohio, April 18–19, 1988.

Fontenot, J. P. and K. E. Webb, Jr. 1975. Health aspects of recycling animal wastes by feeding. *J. Anim. Sci.* 40:1267.

Fontenot, J. P., G. J. Flick, and V. G. Allen. 1982. *Utilization of seafood waste as ruminant feed.* Annual Project Report. Sea Grant College Program, Virginia Polytechnic Institute and State University, Blacksburg.

Food and Agriculture Organization. 1985. Water quality for agriculture. Pp. 34–35. *Irrigation and drainage.* Paper 29, Revision 1. Food and Agriculture Organization of the United Nations, Rome, Italy.

Food and Agriculture Organization. 1989. *FAO trade yearbook.* Food and Agriculture Organization of the United Nations, Rome, Italy.

Food Engineering. 1986. *1986 directory of U.S. food and beverage plants.* Chilton Company, Radnor, Pennsylvania.

Food Engineering. 1989. State of the food industry: Meat and poultry. P. 92. *Food Engineering.* June 1989. Chilton Company, Radnor, Pennsylvania.

Friend, J. H. and D. B. Guralnik (Eds.). 1954. *Webster's New World Dictionary of the American Language, College Edition.* The World Publishing Company, Cleveland, Ohio.

Fronning, G. W. and D. Bergquist. 1990. Utilization of inedible eggshells and technical egg white using extrusion technology. *Poult. Sci.* 69:2051-2053. Research note.

Fulhage, C. D. 1991. Personal communication. University of Missouri, Columbia.

Galler, W. S. and C. B. Davey. 1971. High rate poultry manure composting with sawdust. Pp. 158–162. *Proceedings of the International Symposium on Livestock Wastes*, American Society of Agricultural Engineers, St Joseph, Michigan, December 1971.

Gerken, J. 1990. Utilization of poultry waste by feeding cattle. Pp. 115–122. *Proceedings of the National Poultry Waste Management Symposium*, Raleigh, North Carolina, October 3–4, 1990.

Gersberg, R. M., B. V. Elkins, and C. R. Goldman. 1984. Use of artificial wetlands to remove nitrogen from wastewater. *J. Water Pollut. Control Fed.* 56:152–156.

Gilbertson, C. B., R. N. Clark, J. C. Hye, and N. P. Swanson. 1980. Runoff control for livestock feedlots: State of the art. *Trans. Am. Soc. Agric. Eng.* 23:1207–1212.

Gilbertson, C. B., J. A. Nienaber, J. L. Gartrung, J. R. Ellis, and W. E. Splinter. 1979a. Runoff control comparisons for commercial beef feedlots. *Trans. Am. Soc. Agric. Eng.* 22:842–849.

Gilbertson, C. B., F. A. Nordstadt, A. C. Mathers, R. F. Holt, A. P. Garnett, T. M. McCalla, C. A. Onstad, and R. A. Young. 1979b. Animal waste utilization on cropland and pastureland: A manual for evaluating agronomic and environmental effects. Pp. 32–34. Report No. URR–6. U.S. Department of Agriculture, Science and Education Administration, Hyattsville, Maryland.

Gilbertson, C. B., J. C. Nye, R. N. Clark, and N. P. Swanson. 1981. *Controlling runoff from feedlots—A state of the art.* Agricultural Information Bulletin 441. U.S. Department of Agriculture, Agricultural Research Service, Washington, D.C. 19 pp.

Goering, H. K. and L. W. Smith. 1977. Composition of the corn plant ensiled with excreta or nitrogen supplements and its effect on growing weather. *J. Anim. Sci.* 44:452–461.

Goldhor, S. H. and J. M. Regenstein. 1988. U.S. fishery byproducts: A selective update and review. *Feedstuffs* May 16:14.

Goldhor, S. and H. Regenstein. 1991. *Improving the profitability of fin fish processing waste.* Pp. 1-42. New York Sea Grant Institute, New York.

Goodrich, P. R. and E. J. Monke. 1980. Movement of pollutant phosphorus in saturated soils. Pp. 325–328. *Livestock Waste Management and Pollution Abatement.* American Society of Agricultural Engineers, St. Joseph, Michigan.

Graves, C. R. and J. F. Bradley. 1988. Management of wheat straw in wheat-soybean cropping systems. *Tennessee Farm and Home Science* 145:8–9.

Griggs, W. E. 1989. Damned if you do and damned if you don't, an ammonia discharge at a rendering plant. *Proceedings, 1989 Food Processing Waste Conference.* Georgia Technology Research Institute, Atlanta.

Hammer, D. A. (Ed.). 1989. *Constructed Wetlands for Wastewater Treatment: Municipal, Industrial, and Agricultural.* Lewis Publishers, Inc., Chelsea, Michigan.

Hang, Y. D. 1988. Recovery of food ingredients from grape pomace. *Process Biochem.* 23:2–4.

Hansen, R. C. and K. M. Mancl. 1988. *Modern composting—a natural way to recycle.* Pp. 1–7. Bulletin 792. Agdex 400/720. Ohio Agricultural Research and Development Center, The Ohio State University, Columbus.

Hansen, R. C., H. M. Keener, and H. A. J. Hoitink. 1988. *Poultry manure composting: System design.* Paper No. 88–4049. American Society of Agricultural Engineers, St. Joseph, Michigan.

Hansen, R. C., H. M. Keener, and H. A. J. Hoitink. 1989. *Poultry manure composting design guidelines for ammonia.* Paper No. 89–4075. American Society of Agricultural Engineers, St. Joseph, Michigan.

Haque, A. K. M. A., J. J. Lyons, and J. M. Vandepopuliere. 1991. Extrusion processing of broiler starter diets containing ground whole hens, poultry by-product meal, or ground feathers. *Poult. Sci.* 70:234–240.

Hardison, J. R. 1960. Disease control in forage seed production. Pp. 96–106. *Advances in Agronomy.* Vol. XII. Academic Press, Inc., San Diego, California.

Harmon, B. W., J. P. Fontenot, and K. E. Webb, Jr. 1974. Effect of processing method of broiler litter on nitrogen utilization by lambs. *J. Anim. Sci.* 39:942–946.

Harmon, B. W., J. P. Fontenot, and K. E. Webb, Jr. 1975a. Ensiled broiler litter and corn forage. I. Fermentation characteristics. *J. Anim. Sci.* 40:144–155.

Harmon, B. W., J. P. Fontenot, and K. E. Webb, Jr. 1975b. Ensiled broiler litter and corn forage. II. Digestibility, nitrogen utilization, and palatability by sheep. *J. Anim. Sci.* 40:156–160.

Harper, W. J. and J. L. Blaisdell. 1971. State-of-the-art of dairy food plant wastes and waste treatment. Pp. 509–545. *Second Food Wastes Symposium Proceedings, National Symposium on Food Processing Wastes*. Pacific Northwest Water Laboratory, U.S. Environmental Protection Agency, Denver, Colorado.

Harper, W. J., J. L. Blaisdell, and J. C. Grosskoff. 1971. *Dairy food plant wastes and waste treatment practices*. EPA Report No. 12060 EGU 03/71. Ohio State University, Columbus.

Harper, S. R., R. Wallace, T. D. Shadburn, T. L. King, J. N. Mullis, and J. T. Cook. 1989. *Ammonia stripping and chlorination for nitrogen removal from poultry processing wastewater*. Final Report. Project N 400–950. Environmental Sciences and Technology Division, Georgia Technology Research Institute, Atlanta.

Hashimoto, A. G. 1983. Thermophilic and mesophilic anaerobic fermentation of swine manure. *Agric. Wastes* 6:175–191.

Hassan, T. E. and J. L. Heath. 1987. Chemical and nutritive characteristics of fish silage produced by biological fermentation. *Biol. Wastes* 10:187.

Hauck, B. W. 1990. Processing changes for the 1990's. What should we prepare for? *Proceedings of the 33rd Annual Pet Food Institute Conference*, Kansas City, Missouri, September 12–13, 1990.

Hauge, A. K. M. A., J. J. Lyons, and J. M. Vandepopuliere. 1987. Utilization of ground whole hens in broiler diets. *Poult. Sci.* 66:110.

Henry, S. T. and R. K. White. 1990. Composting broiler litter—Effects of two management systems. Pp. 1–9. *Proceedings of the Sixth International Symposium on Agricultural and Food Processing Wastes*, Chicago, Illinois, December 18–19, 1990.

Hileman, L. H. 1967. *The fertilizer value of broiler litter*. Agricultural Experiment Station Report Series 158. University of Arkansas, Fayetteville.

Hill, D. T. 1984. Methane productivity of the major animal waste types. *Trans. Am. Soc. Agric. Eng.* 27:530–534.

Hill, D. T., J. P. Bolte, and T. J. Prince. 1985. Thermophilic anaerobic digestion of screened-flushed swine waste. *Trans. Am. Soc. Agric. Eng.* 29:229–234.

Hill, D. T., T. J. Prince, and J. J. Maddox. 1984. *Biomass utilization for energy production and refeeding in confinement swine production facilities*. Completion Report. USDOE Grant No. DE—FG05–81ER10265. U.S. Department of Energy, Washington, D.C.

Hoban, T. J. 1991. Personal communication. Department of Sociology, Anthropology and Social Work, North Carolina State University, Raleigh.

Hoban, T. J. and W. B. Clifford. 1995. *Livestock and Poultry Producers' Waste Management Practices nad Attitudes in North Carolina in Animal Waste and the Land-Water Interface.* Pp. 441–448. Lewis Publishers, Inc., Chelsea, Michigan.

Hobson, P. N., S. Bonsfield, and R. Summers. 1981. *Methane Production From Agricultural and Industrial Wastes*. Halstead Press, New York.

Hockmuth, G. 1990. Personal communication. University of Florida, Gainesville.

Hoitink, H. A. J. and P. C. Fahy. 1986. Basis for the control of soilborne pathogens with composts. *Annu. Rev. Phytopathol.* 24:94–114.

Homer-Dixon, T. F., J. H. Boutwell, and G. W. Rathjens. 1993. Environmental change and violent conflict. *Sci. Amer.* February 1993:38–45.

Huang, J. J. H., J. C. H. Shih, and S. C. Steinsberger. 1981. The potential of biological methane generation from chicken manure. *Biotechnol. Bioeng.* 23:2307–2314.

Huang, J. J. H., J. C. H. Shih, and S. C. Steinsberger. 1982. Poultry waste digester, from the laboratory to the farm. Pp. 376–383. In Z. F. Vogt (Ed.). *Energy Conservation and Use of Renewable Energies in the Bio-Industries.* Pergamon Press, Elmsford, New York.

Hudson, H. T. 1971. Solid waste management in the food processing industry. *Proceedings of the Second National Symposium of Food Processing Wastes*, Oregon State University, Corvallis.

Hudson, J. F., E. E. Lake, and D. S. Grossman. 1981. *Pollution Pricing.* Lexington Books, Lexington, Massachusetts.

Huffman, R. L. and P. W. Westerman. 1991. *Seepage and electromagnetic terrain conductivity around new swine lagoons.* ASAE Paper No. 914016. American Society of Agricultural Engineers, St. Joseph, Michigan. 15 pp.

Jantrania, A. R. and R. K. White. 1985. High-solids anaerobic fermentation of poultry manure. Pp. 73–80. In *Agricultural Waste Utilization and Management*. American Society of Agricultural Engineers, St. Joseph, Michigan.

Jenkinson, D. S. and J. H. Rayner. 1977. The turnover of soil organic matter in some of the Rothamsted classical experiments. *Soil Sci.* 123:298–305.

Joh, Y. and L. F. Hood. 1979. Preparation and properties of dehydrated clam flavor from clam processing wash water. *J. Food Sci.* 44:1612.

Jones, B. W. and G. Petitout. 1989. In-house sludge management for poultry waste utilizing land application: A case study. *Proceedings of the 1989 Food Processing Waste Conference.* Georgia Technology Research Institute, Atlanta.

Kendrick, J. W. and E. S. Grossman. 1980. *Productivity in the United States: Trends and Cycles.* The Johns Hopkins University Press, Baltimore, Maryland.

King, L. D., J. C. Burns, and P. W. Westerman. 1990. Long-term swine lagoon effluent applications on coastal Bermuda grass: II. Effect on nutrient accumulation in soil. *J. Environ. Qual.* 19:756–760.

Klausner, S. D. and R. W. Guest. 1981. Influence of NH_3 conservation from dairy manure on the yield of corn. *J. Agron.* 73:720–723.

Koelsch, R. K., E. E. Fabian, R. W. Guest, and J. K. Campbell. 1990. *Anaerobic digesters for dairy farms*. Extension Bulletin 458. Agricultural and Biological Engineering Department, Cornell University, Ithaca, New York. 68 pp.

Kwak, W. J., J. P. Fontenot, and H. H. Henbeis. 1989. Nutrient utilization from broiler litter processed by different methods. P. 54. Report No. 8. Virginia Agriculture Experiment Station. *Anim. Sci. Res.*

LaConde, K. V. and C. J. Schmidt. 1976. In-plant control technology for the fruit and vegetables processing industry. EPA–600/2–76–304. *Proceedings of the Seventh National Symposium on Food Processing Wastes*, Atlanta, Georgia, April 7 to 9, 1976.

Large, E. C. 1954. Growth stages in cereals: Illustration of the Feekes scale. *Plant Path.* 3:128–129.

Lee, M. R. and J. C. H. Shih. 1988. Effects of anaerobic digestion on the oocysts of protozoan *Eimeria tenella*. *Appl. Environ. Microbiol.* 54:2335–2341.

Lee, C. G., P. R. Ferket, and J. C. H. Shih. 1991. Improvement of feather digestibility by bacterial keratinase as a feed additive. *Fed. Am. Soc. Exper. Biol. J.* 5:A596.

Legg, T. D., J. J. Fletcher, and K. W. Easter. 1989. Nitrogen budget and economic efficiency: A case study of southeastern Minnesota. *J. Prod. Agric.* 2:110–116.

Lehman, O. R. and R. N. Clark. 1975. Effect of cattle feedyard runoff on soil infiltration rates. *J. Environ. Qual.* 4:437–439.

Lehman, O. R., B. A. Stewart, and A. C. Mathers. 1970. *Seepage of Feedyard Runoff Water Impounded in Playas.* MP-944. Texas Agricultural Experiment Station, Texas A&M University, College Station, Texas. 7 pp.

Liebhardt, W. C., C. Colt, and J. Tupin. 1979. Nitrate and ammonia concentrations of ground water resulting from poultry manure applications. *J. Environ. Qual.* 8:211–213.

Lin, X., C. G. Lee, E. S. Casale, and J. C. H. Shih. 1992. Purification and characterization of a keratinase from feather-degrading *Bacillus licheniformis* strain. *Appl. Environ. Microbiol.* 58:3272-3275.

Lindemann, E. R., J. M. Sweeten, and J. P. Burt. 1985. Sludge removal from dairy lagoons. Pp. 653–659. In *Agricultural Waste Utilization and Management: Proceedings of the Fifth International Symposium on Agricultural Wastes*. American Society of Agricultural Engineers, St. Joseph, Michigan.

Lindner, P. 1981. Precipitation of proteins from potato juice with bentonite. *J. Sci. Food Agric.* 32:1177.

Liptak, B. G. 1974. *Food Processing Waste. Environmental Engineer's Handbook.* Vol. I. Chilton Book Company, Radnor, Pennsylvania.

Loehr, R. C. 1974. Agricultural waste management, problems, processes, approaches. *Proceedings of the 1974 Cornell Agricultural Waste Management Conference*, Syracuse, New York, March 1974.

Logan, T. J. and A. L. Page (Eds.). 1989. Peer review of the proposed EPA standards for the disposal of sewage sludge (40 CFR, Parts 257 and 503). Unpublished manuscript. Scientific Research Service Technical Committee W–170, U.S. Department of Agriculture. Washington, D.C.

Logsdon, G. 1989. Compost stops pathogens. *Biocycle* 29:28.

Loudon, T. L., D. D. Jones, J. B. Petersen, L. F. Barker, M. F. Brugger, J. C. Converse, C. D. Fulhage, J. A. Lindley, S. W. Melvin, H. C. Person, R. D. Schultes, and R. K. White. 1993. *Livestock Waste Facilities Handbook*. Pp. 2.1–2.2, 5.1–5.9. MWPS–18. 3nd ed. Midwest Plan Service, Iowa State University, Ames.

Maddox, J. J. and J. B. Kingsley. 1989. Waste treatment for confined swine with an integrated artificial wetland and aquaculture system. Pp. 191–200. In D. A. Hammer (Ed.). *Constructed Wetlands for Wastewater Treatment*. Lewis Publishers, Inc., Chelsea, Michigan.

Magdoff, F. 1991. Understanding the Magdoff pre-sidedress nitrate test for corn. *J. Prod. Agric.* 4:297–305.

Malone, G. W. 1990. Carcass preservation systems—acid preservation and proteolytic yeast. Pp. 52–68. *Proceedings of the National Poultry Waste Management Symposium*, Raleigh, North Carolina, October 3–4, 1990.

Malone, G. W. 1992. Fermentation of mortality. Pp. 49-55. *Proceedings of the National Poultry Waste Management Symposium.*

Marois, J. J. 1990. Personal communication. Department of Plant Pathology, University of California, Davis.

Martin, R. E., R. J. H. Gray, and M. D. Pierson. 1978. Quality assessment of fresh fish and the role of the naturally occurring microflora. *Food Technol.* 32:188.

Mathers, A. C. and B. A. Stewart. 1971. Crop production and soil analysis as affected by application of cattle feedlot waste. Pp. 229–231, 234. *Livestock Waste Management: Proceedings of the Second International Symposium on Livestock Wastes*. American Society of Agricultural Engineers, St. Joseph, Michigan.

Mathers, A. C. and B. A. Stewart. 1984. Manure effects on crop yields and soil properties. *Trans. Am. Soc. Agric. Eng.* 27:1022–1026.

Mathers, A. C., B. A. Stewart, and J. D. Thomas. 1975. Residual and annual rate effects of manure on grain sorghum yields. *Managing Livestock Wastes: Proceedings of the Third International Symposium on Livestock Wastes*. American Society of Agricultural Engineers, St. Joseph, Michigan.

Mathers, A. C., J. D. Thomas, B. A. Stewart, and J. E. Herring. 1980. Manure and inorganic fertilizer effects on sorghum and sunflower growth on iron-deficient soil. *Agron. J.* 72:1025–1029.

McCalla, T. M., J. R. Peterson, and C. Lue-Hing. 1977. Properties of agricultural and municipal wastes. Ch. 2. In L. F. Elliott and F. J. Stevenson (Eds.). *Soils for Management of Organic Wastes and Waste Waters.* American Society of Agronomy, Madison, Wisconsin.

McCaskey, T. A. and J. B. Martin. 1988. Evaluation of a process for improved quality and microbial safety of broiler litter. *Biological Wastes* 25:209–218.

McCaskey, T. A., B. G. Ruffin, J. O. Donald, and C. O. Iniguez. 1987. Effect of heat on crude protein content of deep stack processed broiler litter. *J. Dairy Sci.* 70:205.

McCaskey, T. A., A. H. Stephenson, C. G. Iniguez, and B. G. Ruffin. 1988a. Factors affecting nutrient quality of deep stack processed broiler litter. *J. Dairy Sci.* 71:276.

McCaskey, T. A., A. H. Stephenson, and B. G. Ruffin. 1988b. Effects of management practices on composition and feed value of broiler litter. *J. Dairy Sci.* 71:224.

McCaskey, T. A., A. H. Stephenson, and B. G. Ruffin. 1989. Nutrient composition and microbial safety of pellet-processed broiler litter. *J. Dairy Sci.* 72:441.

Mengel, K. and E. A. Kirkby. 1987. *Principles of Plant Nutrition.* 4th ed. International Potash Institute, Bern, Switzerland.

Mentzer, J. R., J. R. Foley, N. J. Moeller, and W. M. Dillon. 1969. *Handling dairy manure with conventional equipment.* Purdue University Cooperative Extension Service Bulletin ID–74. Purdue University, West Lafayette, Indiana.

Menzel, R. D., E. D. Rhoades, A. E. Olness, and S. J. Smith. 1978. Variability of annual nutrient and sediment discharges in runoff from Oklahoma cropland and rangeland. *J. Environ. Qual.* 7:401–406.

Mercer, W. A. 1971. Conservation and recycling of water and other materials. EPA Report No. 12060 EDK 08/71. *Food Industry Week Conference. Proceedings of the Waste Management and Pollution Control Conference*, National Canners Association, Berkeley, California, August 1971.

Merka, W. C., F. A. Gardner, J. H. Denton, and P. L. Wang. 1987. Characteristics of waste water discharged by two turkey processing plants over diurnal periods. *Proceedings of the 1987 Food Processing Waste Conference*. Georgia Technology Research Institute, Atlanta.

Metcalf and Eddy, Inc. 1979. *Wastewater Engineering: Treatment, Disposal, Reuse.* 2nd ed. McGraw-Hill, New York.

Midwest Plan Service. 1983. *Swine housing and equipment handbook.* MWPS–8. Iowa State University, Ames.

Midwest Plan Service. 1985. *Livestock waste facilities handbook.* MWPS–18, Iowa State University, Ames.

Mielke, L. N. and A. P. Mazurak. 1976. Infiltration of water on a cattle feedlot. *Trans. Am. Soc. Agric. Eng.* 19:341–344.

Mielke, L. N., N. P. Swanson, and T. M. McCalla. 1974. Soil profile conditions of cattle feedlots. *J. Environ. Qual.* 13:14–17.

Mikula, W. J., J. W. Tarantino, R. J. DeLorenzo, T. A. Seeler, and R. J. Kukenberger. 1989. Pretreatment of ice cream manufacturing wastewaters: A case study. *Proceedings of the 1989 Food Processing Waste Conference*. Georgia Technology Research Institute, Atlanta.

Milkfacts. 1990. Milk Industry Federation, Washington, D.C.

Miller, B. F. 1984. Extruding hatchery waste. *Poult. Sci.* 43:1284–1286.

Miner, J. R. and R. C. Stroh. 1976. Controlling feedlot surface odor emission rates by application of commercial products. *Trans. Am. Soc. Agric. Eng.* 19:533–538.

Moller, H. W. 1981. *Whey utilization systems.* Presented at the

American Cultured Dairy Products Institute, San Antonio, Texas.

Moore, J. A., R. O. Hegg, D. C. Scholz, and E. Strauman. 1975. Settling solids in animal waste slurries. *Trans. Am. Soc. Agric. Eng.* 18:694–698.

Moore, K. C., S. K. Taylor, R. K. Rudel, G. M. Ehlmann, and D. L. Pfost. 1988. *1987 Missouri farm service custom rates*. University of Missouri Extension Agricultural Guide 302. University of Missouri, Columbia.

Moran, E. T., J. D. Summers, and S. J. Klinger. 1966. Keratin as a source of protein for the growing chick. 1. Amino acid imbalance as the cause for inferior performance of feather meal and the implication of disulphide bonding in raw feathers as the reason for poor digestibility. *Poult. Sci.* 45:1257–1266.

Morrison, S. R., P. Vohra, W. L. Shupe, and B. J. Mills. 1981. *Livestock Wastes: A Renewable Resource*. Proceedings of the American Society of Agricultural Engineers, St. Joseph, Michigan.

Morrow, W. M. and P. R. Ferket. 1993. The disposal of dead pigs: A review. *Swine Health Prod.* 1(3):7–13.

Muehling, A. J. 1989. Pit recharge waste management systems—an update. Pp. 52–58. *Proceedings of the 1989 Livestock Waste Management Conference*, University of Illinois, Urbana-Champaign, March 21, 1989.

Muers, M. M. 1968. *Water Pollut. Control Fed.* 67:644.

Mulford, F. R., J. G. Kantzes, V. A. Bandez, J. A. Axley, and L. E. Carr. 1987. *Wheat Management Studies Utilizing Poultry Manure and Commercial Fertilizer as the Nitrogen Source in Wheat Production*. Pp. 1–2. University of Maryland Extension Circular. Popular Hill Field Day, Popular Hill Research Farm, Quantico, Maryland.

Mulyk, P. A. and A. Lamb. 1977. Inventory of the fruit and vegetable processing industry in Canada—A report for Environment Canada, Environmental Protection Service, Ottawa, Ontario.

Murphy, D. W. 1988. Composting as a dead bird disposal method. *Poult. Sci.* 67:124.

Murphy, D. W. 1990. Disease transfer studies in a dead bird composter. Pp. 25–27. *Proceedings of the National Poultry Waste Management Symposium*, Raleigh, North Carolina, October 3–4, 1990.

Murphy, D. W. and T. S. Handwerker. 1988. Preliminary investigations of composting as a method of dead bird disposal. Pp. 65–72. *Proceedings of the National Poultry Waste Management Symposium*, Columbus, Ohio, April 18–19, 1988.

Murphy, D. W. and S. A. Silbert. 1990. Carcass preservation systems—lactic fermentation. Pp. 56-63. *Proceedings of the National Poultry Waste Management Symposium.*

Murphy, D. W., O. P. Thomas, and S. A. Silbert. 1990. Lactic acid fermentation of whole broiler carcasses. *Poult. Sci.* 69:98.

Naber, E. C. 1985. The refeeding of cage layer manure subjected to aerobic fermentation. Pp. 182–190. *Proceedings of the Fifth International Symposium on Agricultural Wastes*. American Society of Agricultural Engineers, St. Joseph, Michigan.

Naber, E. C., J. A. deGraft-Hanson, J. F. Stephens, and O. C. Thompson. 1990. The feeding value for broiler chicks of caged layer manure rapidly composted in a closed system with various carbon sources. Pp. 204–211. *Proceedings of the Sixth International Symposium on Agricultural and Food Processing Wastes*, Chicago, Illinois, December 17–18, 1990.

National Research Council. 1983. *Underutilized Resources as Animal Feedstuffs*. National Academy Press, Washington, D.C.

National Research Council. 1989. *Irrigation-Induced Water Quality Problems*. National Academy Press, Washington, D.C.

Newton, G. L., C. V. Boorman, and O. M. Hale. 1980. Swine fecal solids as a feed ingredient for sows and steers. *J. Anim. Sci.* 51:134.

Norcross, K. 1988. SBR treatment of food process wastewater: Five (5) case studies. *Proceedings of the 1988 Food Processing Waste Conference*. Georgia Technology Research Institute, Atlanta.

Norstadt, F. A. and H. R. Duke. 1982. Stratified Profiles: Characteristics of simulated soils in a beef cattle feedlot. *Soil Sci. Soc. Am. J.* 46:827–823.

Novakovic, A. M. 1990. Personal communication. Department of Agricultural Economics, Cornell University, Ithaca, New York.

Oklahoma State University Department of Dairy Technology. 1971. Oklahoma State University, Norman.

Oschwald, W. R. 1978. *Crop residue management systems*. Special Publication 31. American Society of Agronomy, Madison, Wisconsin.

Otwell, W. S. 1986. Why is seafood quality less regulated than meat or poultry? Vol. 6, P. 3. In C. Jarman and D. Conner (Eds.). *Water Log*. Mississippi-Alabama Sea Grant Consortium, University of Mississippi, Mississippi State.

Overcash, M. R., F. J. Humenik, and J. R. Miner. 1983. Vol. 1. *Livestock Waste Management*. CRC Press, Inc., Boca Raton, Florida.

Paine, M. D. 1973. Chemical control of manure odor. *Great Plains beef cattle feeding handbook*. L–1188. Texas Agricultural Extension Service, Texas A&M University, College Station. 2pp.

Paine, M. D., N. Teter, and P. Guyer. 1976. Feedlot layout. *Great Plains beef cattle handbook*. GPE–5201. Cooperative Extension Service, Oklahoma State University, Stillwater. 6 pp.

Pancorbo, O. C. and H. M. Barnhart. 1989. Microbiological characterization of raw and treated poultry processing wastewater and sludge: Preliminary assessment of suitability for land application. *Proceedings of the 1989 Food Processing Waste Conference.* Georgia Technology Research Institute, Atlanta.

Papadopoulos, M. C. 1985. Processed chicken feathers as feedstuff for poultry and swine. A review. *Agric. Wastes* 14:275–290.

Papadopoulos, M. C., A. R. El Boushy, and A. E. Roodbeen. 1985. The effect of varying autoclaving conditions, and added sodium hydroxide on amino acid content and nitrogen characteristics of feather meal. *J. Sci. Food Agric.* 36:1219–1226.

Papadopoulos, M. C., A. R. El Boushy, A. E. Roodbeen, and E. H. Ketclaars. 1986. Effects of processing time and moisture content on amino acid composition and nitrogen characteristics of feather meal. *Anim. Feed Sci. Technol.* 14:279–290.

Parsons, J. and P. R. Ferket. 1991. Alternative dead bird disposal methods—central pickup and fermentation. Pp. 7–20. *Proceedings of the 1991 Poultry Supervisors Short Course*, North Carolina State University, Raleigh, April 10, 1991.

Pennsylvania Department of Environmental Resources. 1986. *Field application of manure: A supplement to Manure Management for Environmental Protection*. Document FA. Department of Environmental Resources, Commonwealth of Pennsylvania, Harrisburg. 13 pp.

Peters, J. A. and T. R. Blackwood. 1977. *Source assessment: Beef cattle feedlots*. Monsanto Research Corporation. EPA–6002–77–107. U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory, Research Triangle Park, North Carolina. 101 pp.

Phillips, R. L. 1981. Maps of runoff volumes from feedlots in the United States. Pp. 274–277. *Livestock Waste: A Renewable Resource. Proceedings of the Fourth International Symposium on Livestock Waste*. American Society of Agricultural Engineers, St. Joseph, Michigan.

Phillips, V. R., B. F. Pain, N. L. Warner, and C. R. Clarkson. 1988. Preliminary experiments to compare the odour and ammonia emissions after spreading pig slurry on land using three different methods. Pp. 151–152. *Engineering Advances for Agriculture and Food: Proceedings for the Jubilee Conference of the Institute of Agricultural Engineers*, Cambridge, England, September 12–18, 1988.

Pigott, G. M. 1981. Seafood waste management in the Northwest and Alaska. Report No. 40. In W. S. Otwell (Ed.). *Seafood Waste Management in the 1980s: Conference Proceedings.* Sea Grant College Program, University of Florida, Gainesville.

Pimentel, D. and M. Pimentel. 1983. World outlook for food. In D. A. Ledward, A. J. Taylor, and R. A. Lawrie (Eds.). *Upgrading Waste for Feeds and Food.* Butterworths, London.

Pos, J., R. G. Bell, and J. B. Robinson. 1971. Aerobic treatment of liquid and solid poultry manures. Pp. 220–224. *Proceedings of the International Symposium on Livestock Wastes.* American Society of Agricultural Engineers, St. Joseph, Michigan.

Pos, J., R. Eszes, and V. Pavlicik. 1985. Evaluation of two full-size mesophilic digesters processing swine manure. Pp. 81–90. *Agricultural Waste Utilization and Management.* American Society of Agricultural Engineers, St. Joseph, Michigan.

Power, J. F. and J. O. Legg. 1978. Effect of crop residues on the soil chemical environment and nutrient availability. Ch. 5. In W. R. Oschwald (Ed.). *Crop Residue Management Systems.* Special Publication 31. American Society of Agronomy, Madison, Wisconsin.

Powers, W. L., R. L. Herpich, L. S. Murphy, D. A. Whitney, H. L. Manages, and G. W. Wallingford. 1973. *Guidelines for land disposal of feedlot lagoon water.* C–485. Cooperative Extension Service, Kansas State University, Manhattan.

Pratt, P. F. and J. Z. Castellanos. 1981. Available nitrogen from animal manures. *Calif. Agric.* July–August 1981. P. 24.

Pratt, P. F. and R. M. Lippert. 1986. Residual available phosphorus in soils. *Calif. Agric.* March–April. Pp. 21–22.

Prince, T. J., D. T. Hill, and N. J. Van Dyke. 1983a. Effects of screen size and waste flow rate on the nutrient composition of screened swine waste solids for refeeding. *J. Anim. Sci.* 57:264.

Prince, T. J., D. T. Hill, N. J. Van Dyke, and R. D. Holmberg. 1983b. Economic value of raw swine waste and anaerobic digestion residue for refeeding to swine in waste utilization systems. Paper No. 83–4061. American Society of Agricultural Engineers, St. Joseph, Michigan.

Prior, B. A. and H. J. Potgieter. 1981. Composition of fruit and vegetable processing wastes. *Water Sanit. (S. Africa)* 7:3,155.

Ralls, J. W., H. D. Maagdenberg, N. L. Yacoub, M. E. Zinnecker, J. M. Reiman, H. D. Karnath, D. G. Homnick, and W. A. Mercer. 1973. In-plant hot-gas blanching of vegetables. 122 pp. *Proceedings of the 1973 Cornell Agricultural Waste Management Conference*, Syracuse, New York, March 1973.

Rand McNally Cosmopolitan World Atlas. 1978. P. 50. Rand McNally and Company, New York.

Reddell, D. L. 1974. Forage and grain production from land used for beef manure disposal. Pp. 464–483. *Proceedings and Management of Agricultural Wastes.* Cornell University, Ithaca, New York.

Reddell, D. L. and G. G. Wise. 1974. *Water quality of storm runoff from a Texas beef feedlot.* PR–3224. Texas Agricultural Experiment Station, College Station.

Reddy, K. R., R. Khaleel, M. R. Overcash, and P. W. Westerman. 1979a. A nonpoint source model for land areas receiving animal wastes: I. Mineralization of organic nitrogen. *Trans. Am. Soc. Agric. Eng.* 22:863–872.

Reddy, K. R., R. Khaleel, M. R. Overcash, and P.W. Westerman. 1979b. A nonpoint source model for land areas receiving animal wastes: II. Ammonia volatilization. *Trans. Am. Soc. Agric. Eng.* 22:1398–1405.

Reddy, K. R., M. R. Overcash, R. Khaleel, and P. W. Westerman. 1980. Phosphorus adsorption-desorption characteristics of two soils utilized for disposal of animal wastes. *J. Environ. Qual.* 9:86–92.

Reiser, M. 1991. Personal communication. Carolina By-Products.

Revel, J. L. 1982. Potato and corn by-products used as cattle feed. *Ind. Wastes (Chicago)* 28:3,27.

Reynolds, D. 1990. Microbiologic evaluation of dead bird meal. *Proceedings of the 1990 Midwest Poultry Federation Meetings*, Minneapolis, Minnesota, February 1990.

Riggle, D. 1989. Revival time for composting food industry wastes. *Biocycle* 30:35–37.

Ritter, W. F. 1980. *Chemical odor control of livestock wastes.* Paper No. 80–4059. American Society of Agricultural Engineers, St. Joseph, Michigan. 16 pp.

Ritter, W. F. 1990. Poultry manure as a nutrient source for crops in the mid-Atlantic states. Pp. 185–191. *Proceedings of the Sixth International Symposium on Agriculture and Food Processing Wastes*, Chicago, Illinois, December 17–18, 1990.

Ritter, W. F. and A. E. M. Chirnside. 1984. Impacts of land use on ground-water quality in southern Delaware. *Ground Water* 22:39–45.

Ritter, W. F. and J. R. Harris. 1988. *Impact of dead bird disposal on ground water quality.* Paper No. 882546. American Society of Agricultural Engineers, St. Joseph, Michigan. 22 pp.

Ritter, W. F., E. W. Walpole, and R. P. Eastburn. 1984. Effect of an anaerobic swine lagoon on ground water quality in Sussex County, Delaware. *Agric. Wastes.* 10:267–284.

Ro, Y. K. and D. L. Forster. 1984. Regional input-output analysis of an environmental regulation. *J. Econ. Dev.* 9:167–188.

Robbins, J. W. D., G. J. Kriz, and D. H. Howells. 1971. Quality of effluent from farm animal production sites. Livestock Waste Management and Pollution Abatement. *Proceedings of the International Symposium on Livestock Wastes.* Publ. Proceedings 271. American Society of Agricultural Engineers, St. Joseph, Michigan.

Robe, K. (Assoc. Ed.). 1977. Low cost, total recycling of wash water. *Food Processing-Marketing* 38:30.

Robertson, F. N. 1977. *The quality and potential problems of ground water in Sussex County, Delaware.* Technical Report. Water Resources Center, University of Delaware, Newark.

Robinson, F. E. 1973. Changes in seepage rates from an unlined cattle waste digestion pond. *Trans. Am. Soc. Agric. Eng.* 16:95–96.

Rogers, K. H., P. F. Breen, and A. J. Chick. 1991. Nitrogen removal in experimental wetland treatment systems: Evidence for the role of aquatic plants. *J. Water Pollut. Control Fed.* 63:934–941.

Rooney, M. C. and M. H. Wu. 1981. Joint treatment of meat-packing and municipal wastewater by full-scale AWT facilities. Pp. 301–310. *Proceedings of the 36th Industrial Waste Conference.* Ann Arbor Science Publishers, Ann Arbor, Michigan.

Rose, W. W., W. A. Merier, and A. Katsuyama. 1971. *Proceedings of the Second National Syrup Food Processing Wastes*, Oregon State University, Corvallis.

Ross, C. C., G. E. Valentine, and S. R. Harper. 1988. Pilot-scale anaerobic pre-treatment of poultry processing wastewaters. Paper 88–6008. American Society of Agricultural Engineers, St. Joseph, Michigan.

Rossi, D., C. E. Young, and D. J. Epp. 1979. The cost impact of joint treatment of domestic and poultry processing wastewaters. *Land Econ.* 55:444–449.

Russell, C. S. and W. Vaughn. 1982. The national recreational fishing benefits of water pollution control. *J. Environ. Econ. Manage.* 9:328–354.

Safley, L. M. and P. D. Lusk. 1990. *Low temperature anaerobic digester*. Project Report. Energy Division, North Carolina Department of Economic and Community Development, Raleigh. 14 pp.

Safley, L. M. and P. W. Westerman. 1990. Psychrophilic anaerobic digestion of animal manure: Proposed design methodology. *Biol. Wastes* 34:133–148.

Safley, L. M., J. C. Barker, T. A. Carter, C. D. Safley, S. L. Warren, P. W. Westerman, and J. P. Zublena. 1990. *Composting poultry litter—Economics and marketing potential of a renewable resource*. Report No. 8556122, 89–9P–1. Low-Input Sustainable Agriculture Program (Southern Region), University of Georgia, Athens. 278 pp.

Safley, L. M., J. C. Barker, and P. W. Westerman. 1992. Loss of nitrogen during sprinkler irrigation of swine lagoon liquid. *Bioresource Technol.* 40:7–15.

Safley, L. M., Jr., R. L. Vetter, and D. Smith. 1985. Managing a poultry manure anaerobic digester. Pp. 491–499. *Proceedings of the Fifth International Symposium on Agricultural Wastes*. American Society of Agricultural Engineers, St. Joseph, Michigan.

Safley, L. M., R. L. Vetter, and L. D. Smith. 1987. Management and operation of a fullscale poultry waste digester. *Poult. Sci.* 66:941–945.

Schuler, M. L., E. D. Roberts, D. W. Mitchell, F. Kargi, R. E. Austic, A. Henry, R. Vashon, and H. W. Seely. 1979. Process for the aerobic conversion of poultry manure into a high protein feedstuff. *Biotech. Bioeng.* 21:19–38.

Schulte, E. E. and L. M. Walsh. 1993. *Management of Wisconsin soils*. Cooperative Extension Publication A3588. 4th ed. University of Wisconsin Extension, Madison.

Schuman, G. E. and T. M. McCalla. 1975. Chemical characteristics of a feedlot soil profile. *Soil Sci.* 119:113–118.

Shafer, D. J. and J. B. Carey. 1994. Chemical preservation of whole broiler carcasses utilizing aqueous alkaline solutions. *Proceedings of the National Poultry Waste Management Symposium.*

Sheldon, B. W. and R. E. Carawan. 1988. Reconditioning of broiler overflow prechiller water using a combination of diatomaceous earth pressure leaf filtration and UV irradiation. *Proceedings of the 1988 Food Processing Waste Conference*. Georgia Technology Research Institute, Atlanta.

Sheldon, B. W., R. E. Carawan, W. C. Merka. 1989. Water use and waste water discharge patterns in a turkey processing plant. Pp. 72–74. *Proceedings of the Food Processing Waste Conference.* Georgia Institute of Technology, Atlanta, Georgia.

Shih, J. C. H. 1987a. From anaerobic digestion to holistic farming. Pp. 1–16, Vol. 2. In D. L. Wise (Ed.). *Bioenvironmental Systems*. CRC Press, Inc., Boca Raton, Florida.

Shih, J. C. H. 1987b. Ecological benefits of anaerobic digestion. *Poult. Sci.* 66:946–950.

Shih, J. C. H. 1988a. Anaerobic digestion of poultry waste and by-product utilization. Pp. 45–50. *Proceedings of the National Poultry Waste Management Symposium*, Columbus, Ohio, April 18–19.

Shih, J. C. H. 1988b. Pathogen control by anaerobic digestion. Anaerobic Digestion 88. In E. R. Hall and P. N. Dobson (Eds.). *Advances in Water Pollution Control*. Pergamon Press, Oxford, England.

Shih, J. C. H. 1993. Recent development in poultry waste digestion and feather utilization: A review. *Poult. Sci.* 72:1617-1620.

Shotts, E. B., Jr., R. E. Wooley, and J. A. Dickens. 1984. Antimicrobic effects of *Lactobacillus* fermentation on edible waste material contaminated with infected carcasses. *Am. J. Vet. Res.* 45:2467-2470.

Shultz, S. and B. Lindsay. 1990. The willingness to pay for groundwater protection. *Water Resour. Res.* 26:1869–1875.

Siebenmorgen, T. J., D. D. Schulte, and J. L. Ballard. 1988. Integration of a cogeneration system into a swine operation: I. Model development and system description. *Trans. Am. Soc. Agric. Eng.* 31:1556–1565.

Sims, J. T. 1987. Agronomic evaluation of poultry manure as a nitrogen source for conventional and no-tillage corn. *Agron. J.* 79:563–570.

Sims, J. T., D. Palmer, J. Scarborough, and R. Graeber. 1989. *Poultry manure management*. Bulletin 24. University of Delaware, Newark.

Singer, D. D. 1980. By-products and wastes in animal feeding. P. 71. In E. R. Orskov (Ed.). *Occasional publication no. 3*. British Society of Animal Production, London.

Sistrunk, W. A. 1979. *Water, waste and quality management during preparation and processing of vegetables*. Arkansas Water Resource Research Center, Fayetteville.

Sistrunk, W. A. 1985. *Factors affecting the removal of suspended and dissolved solids in high strength wastewater from vegetable processing*. Arkansas Water Resource Research Center, Fayetteville.

Smith, J. H. 1982. Closed cycle industrial wastes control. *Ind. Wastes (Chicago)* 28:4,30.

Smith, L. W. and W. E. Wheeler. 1979. Nutritional and economic value of animal excreta. *J. Anim. Sci.* 48:144–156.

Smith, T. J. 1976. Dry peeling of tomatoes and peaches. *Proceedings of the Sixth National Symposium on Food Processing Wastes*. EPA–600/2–76–224. U.S. Environmental Protection Agency, Washington, D.C.

Soderquist, M. R. 1975. *Characterization of fruit and vegetable processing wastewater*. Water Resources Research Institute, Oregon State University, Corvallis.

Stafford, D. A., D. L. Hawkes, and R. Horton. 1980. *Methane Production from Waste Organic Matter*. CRC Press, Inc., Boca Raton, Florida.

Stebor, T. W., C. L. Berndt, S. Marman, and R. Gabriel. 1989. Case history: Anaerobic treatment at Packerland Packing. *Proceedings of the 1989 Food Processing Waste Conference*. Georgia Technology Research Institute, Atlanta.

Stebor, T. W., M. N. Macaulay, and C. L. Berndt. 1987. Anaerobic contact pretreatment of slaughterhouse wastewater. *Proceedings of the 1987 Food Processing Waste Conference*. Georgia Technology Research Institute, Atlanta.

Steele, C. P. and J. D. West. 1989. Elimination of daf sludge disposal through resource recovery. *Proceedings of the 1989 Food Processing Waste Conference*. Georgia Technology Research Institute, Atlanta.

Steichen, J. M. 1979. *Estimating soil losses in northern Missouri.* University of Missouri Extension Division Agricultural Guide 1560. University of Missouri Extension, Columbia.

Steiner, R. J., R. O. Kellems, and D. C. Church. 1983. Feather and hair meals for ruminants. IV. Effects of chemical treatments of feather and processing time on digestibility. *J. Anim. Sci.* 57:495–502.

Steinsberger, S. C. and J. C. H. Shih. 1984. The construction and operation of a low cost poultry waste digester. *Biotechnol. Bioeng.* 26:537–543.

Steinsberger, S. C., J. F. Ort, and J. C. H. Shih. 1987. Composition and phosphorus bioavailability of a solid by-product from anaerobically digested waste from caged layer hens. *Poult. Sci.* 66:634–639.

Stephenson, A. H., T. A. McCaskey, and B. G. Ruffin. 1989. Treatments to improve the fed nutrient value of deep stacked broiler litter. *J. Dairy Sci.* 72:441.

Stephenson, A. H., T. A. McCaskey, and B. G. Ruffin. 1990. Management practices that affect the value of poultry litter as a feed ingredient. Pp. 219–226. *Proceedings of the Sixth International Symposium on Agricultural and Food Processing Wastes*, Chicago, Illinois, December 17–18, 1990.

Stevens, M. A. and D. D. Schulte. 1979. Low temperature digestion of swine manure. *J. Environ. Engr. Division, Am. Soc. Civil Engr.* 105(EEl):33–42.

Stewart, B. A. and B. D. Meek. 1977. Soluble salt considerations with waste application. Pp. 219–232. In L. F. Elliott and F. J. Stevenson (Eds.). *Soils for Management of Organic Wastes and Wastewaters*. Soil Science Society of America, Madison, Wisconsin.

Stikeleather, L. F., P. R. Ferket, and B. M. Lineberger. 1995. *Development of an automated system for on-farm lactic acid fermentation of poultry and swine carcasses*. American Society of Agricultural Engineers, St. Joseph, Michigan. In review.

Stotskopf, N. C. 1981. *Understanding Crop Production*. Reston Publishing Company, Inc., Reston, Virginia.

Stover, E. and H. W. Downs. 1989. Computerized activated sludge process control for the food processing industry. *Proceedings of the 1989 Food Processing Waste Conference*. Georgia Technology Research Institute, Atlanta.

Strolle, E. O. 1980. Recovering useful by-products from potato starch factory waste effluents—feasibility study. *Food Technol.* 34:2,90.

Strong, L. and R. L. Ulmer. 1989. *Project description—Use of constructed wetlands to treat wastewater from confined animal operations in Mississippi*. U.S. Department of Agriculture, Soil Conservation Service, Jackson, Mississippi.

Sumner, D. R., B. Doupnik, Jr., and M. G. Boosalis. 1981. Effects of reduced tillage and multiple cropping on plant diseases. *Annu. Rev. Phytopathol.* 19:167–187.

Surrency, D. 1991. *Constructed Wetlands for Water Quality Improvement: An International Symposium*, University of West Florida, Pensacola, October 21–24, 1991. 14 pp.

Sutton, A. L., J. V. Mannering, D. H. Bache, J. F. Marten, and D. D. Jones. 1974. The fertilizer value of animal wastes. *Proceedings of the 1974 Purdue Agricultural Waste Conference*.

Sutton, A. L., L. M. Safley, G. L. Newton, T. A. McCaskey, J. P. Fontenot, C. R. Mote, D. C. Dobson, V. W. E. Payne, E. P. Lincoln, and P. W. Westerman. 1990. Value of animal wastes as a fertilizer, feed and compost resource. Pp. 494–503. *Proceedings of the Sixth International Symposium on Agricultural and Food Processing Wastes*, Chicago, Illinois, December 17–18, 1990.

Sweeten, J. M. 1982. *Feedlot dust control*. L–1340. Texas Agricultural Extension Service, Texas A&M University, College Station. 7 pp.

Sweeten, J. M. 1988. Composting manure and sludge. Pp. 38–44. *Proceedings of the National Poultry Waste Management Symposium*, Columbus, Ohio, April 18–19, 1988.

Sweeten, J. M. 1990a. *Cattle feedlot waste management practices for water and air pollution control*. B–1671. Texas Agricultural Extension Service, Texas A&M University System, College Station. 24 pp.

Sweeten, J. M. 1990b. Water use, animal waste and water pollution. Ch. 5. In H. R. Cross and F. M. Byers (Eds.). *Current Issues in Food Production: A Perspective on Beef as a Component in Diets for Americans*. Texas A&M University, College Station; and National Cattlemen's Association, Englewood, Colorado. 286 pp.

Sweeten, J. M. and R. P. McDonald. 1979. *Results of TCFA Environmental and Energy Survey—1979*. Texas Cattle Feeders Association, Amarillo.

Sweeten, J. M. and R. J. Miner. 1979. What feedlots can do to help avoid nuisance lawsuits. *Beef Business Bulletin*. July 27. 4 pp.

Sweeten, J. M. and D. L. Reddell. 1978. Nonpoint sources: State of the art overview. *Trans. Am. Soc. Agric. Eng.* 21:474–483.

Sweeten J. M. and D. L. Reddell. 1979. Time-motion analysis of feedlot manure collection systems. *Trans. Am. Soc. Agric. Eng.* 22:138–143.

Sweeten, J. M. and R. E. Withers. 1990. Feedlot manure drops in Texas. *Beef* 27:54–55.

Sweeten, J. M., L. Lubinus, R. Durland, and B. Bruce. 1988. *Feedlot mounds. Great Plains beef cattle handbook*. GPE–7525. Cooperative Extension Service, Oklahoma State University, Stillwater.

Sweeten, J. M., C. B. Parnell, R. S. Etheredge, and D. Osborne. 1988. Dust emissions in cattle feedlots. In J. L. Howard (Ed.). Stress and Disease in Cattle. *The Veterinary Clinics in North America: Food Animal Practice*. 4:557–578. W. B. Saunders Company, Philadelphia, Pennsylvania.

Sweeten, J. M., L. M. Safley, and S. W. Melvin. 1981. Sludge removal from lagoons and holding ponds: Case studies. Pp. 204–210. *Livestock Waste: A Renewable Resource. Proceedings of the Fourth International Symposium on Livestock Wastes*. American Society of Agricultural Engineers, St. Joseph, Michigan.

Tadtiyanant, C., J. J. Lyons, and J. M. Vandepopuliere. 1993. Extrusion processing used to convert dead poultry, feathers, eggshells, hatchery waste, and mechanically deboned residue into feedstuffs for poultry. *Poult. Sci.* 72:1515-1527.

Tchobanoglous, G. 1976. Wastewater management at Hickmott Foods, Inc. *Proceedings of the Sixth National Symposium on Food Processing Wastes*. EPA–600/2–76–224. U.S. Environmental Protection Agency, Washington, D.C.

Texas Natural Resource Conservation Commission. 1987. Control of certain activities by rule. Chapter 321, Subchapter B, Part IX (31 TAC 321.31–321.41). Austin, Texas. *Texas Register*, March 17, 1987, pp. 904–909.

Thomas, J. D. and A. C. Mathers. 1979. Manure and iron effects on sorghum growth on iron deficient soil. *Agron. J.* 71:792.

Thorton, T. 1978. *An assessment of anaerobic digestion in U.S. agriculture*. ERS PB-278 999. Pp. 1–40. Economic Research Service, U.S. Department of Agriculture, Washington, D.C.

Thresh, J. M. 1982. Cropping practices and virus spread. *Annu. Rev. Phytopathol.* 20:193–218.

Tisdale, S. L., W. L. Nelson, and J. D. Beaton. 1985. *Soil Fertility and Fertilizers*. 4th ed. Macmillan Publishing Co., New York.

Tolan, A. 1983. Sources of food waste, UK and European aspects. Pp. 15–27. In D. A. Ledward, A. J. Taylor, and R. A. Lawrie (Eds.). *Upgrading Waste for Feeds and Food*. Butterworths, London.

Totzke, D. E. 1987. Anaerobic treatment of food processing wastes: A review of operating systems. *Proceedings of the 1987 Food Processing Waste Conference*. Georgia Technology Research Institute, Atlanta.

Totzke, D. E. 1988. Anaerobic treatment technology 1988 update. *Proceedings of the 1988 Food Processing Waste Conference*. Georgia Technology Research Institute, Atlanta.

Urlings, H. A. P., G. F. deBaer, D. J. van Roozelear, and G. Koch. 1993a. Inactivation of chicken anemia virus in chickens by heating and fermentation. *Vet. Q.* 15(3):85-88.

Urlings, H. A. P., A. J. Mul, A. Th. van't Klooster, P. G. H. Bijker, J. G. van Logtestijn, and L. G. M. van Gils. 1993b. Microbial and nutritional aspects of feeding fermented feed (poultry by-products) to pigs. *Vet. Q.* 15: 146–150.

U.S. Congress. 1985. *Environmental regulations and economic efficiency*. Congressional Budget Office, Washington, D.C.

U.S. Department of Agriculture. 1978. *Agricultural waste management field manual*. 1975 621–497/3288. U.S. Department of Agriculture, Soil Conservation Service, Washington, D.C.

U.S. Department of Agriculture. 1979. *Animal waste utilization on cropland and pastureland: A manual for evaluating agronomic* *and environmental effects*. URR 6. U.S. Department of Agriculture, Science and Education Administration, Hyattsville, Maryland. 135 pp.

U.S. Department of Agriculture. 1980. *1980 appraisal, Soil and Water Resources Conservation Act, review draft, Part 1*. U.S. Department of Agriculture, Washington, D.C.

U.S. Department of Agriculture. 1987a. *Agricultural statistics 1987*. U.S. Department of Agriculture Statistical Reporting Service, Washington, D.C.

U.S. Department of Agriculture. 1987b. *Census of manufacturers*. Statistical Reporting Service, U.S. Department of Agriculture, Washington, D.C.

U.S. Department of Agriculture. 1988. *Agricultural statistics 1988*. U.S. Government Printing Office, Washington, D.C. 544 pp.

U.S. Department of Agriculture. 1991. *Poultry Market Statistics. Annual Summary*. Agricultural Marketing Service, U.S. Department of Agriculture, Washington, D.C.

U.S. Department of Agriculture. 1992. *Food marketing review, 1991*. Agricultural Economic Report No. 657. Economic Research Service, U.S. Department of Agriculture, Washington, D.C. 137 pp.

U.S. Department of Agriculture. 1994a. *Food review*. Vol. 17, No. 3. Economic Research Service, U.S. Department of Agriculture, Washington, D.C. 46 pp.

U.S. Department of Agriculture. 1994b. *Poultry Market Statistics. Annual Summary*. Agricultural Marketing Service, U.S. Department of Agriculture, Washington, D.C.

U.S. Department of Commerce. 1989. *1987 Census of Agriculture*. AC–A–51. Vol 1. Geographic Area Series. Part 51 United States. U.S. Department of Commerce, Bureau of Census, Washington, D.C.

U.S. Department of Commerce. 1990. 1987 *Estimated statistics, Bureau of Census, Food Manufacturers Survey*. Survey reports for Canned Fruits and Vegetables—SIC 2033; Frozen Fruits and Vegetables—SIC 2037; Frozen Specialties—SIC 2038; Pickles and Sauces—SIC 2035; and Dehydrated Fruits and Vegetables—SIC 2034. U.S. Department of Commerce, Bureau of Census, Washington, D.C.

U.S. Department of Commerce. 1994. *1992 Census of Agriculture*. U.S. Department of Commerce, Bureau of Census, Washington, D.C.

U.S. Department of Health, Education, and Welfare. 1962. *An industrial waste guide to the fruit processing industry*. Public Health Service Publication No. 952. U.S. Department of Health, Education, and Welfare, Washington, D.C.

U.S. Environmental Protection Agency. 1971. *Liquid wastes from canning and freezing fruits and vegetables*. U.S. Environmental Protection Agency Water Pollution Control Research Series. 12060 EDK. U.S. Environmental Protection Agency, Washington, D.C.

U.S. Environmental Protection Agency. 1973. *Development document for proposed effluent limitations guidelines and new source performance standards for the feedlots point source category*. EPA–440/1–73/004. U.S. Environmental Protection Agency, Washington, D.C.

U.S. Environmental Protection Agency. 1977. *Pollution abatement in the fruit and vegetable industry-wastewater treatment*. EPA 625/3–77–0007. U.S. Environmental Protection Agency, Washington, D.C.

U.S. Environmental Protection Agency. 1983. *Methods for chemical analysis of water and wastes*. EPA/600/4–79/020. U.S. Environmental Protection Agency, Washington D.C.

U.S. Environmental Protection Agency. 1984. *National water quality inventory: 1982 report to Congress*. EPA 440/2–84–006. Office of Water Regulations and Standards, Washington, D.C.

U.S. Environmental Protection Agency. 1986. *Supplement A to Compilation of Air Pollution Emission Factors, Section 6.15: Beef Cattle Feedlots. I. Stationary point and area sources*. AP–42. Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. 3 pp.

U.S. Environmental Protection Agency. 1987a. *Nonpoint source guidance*. Office of Water, U.S. Environmental Protection Agency, Washington, D.C. 41 pp.

U.S. Environmental Protection Agency. 1987b. 40CFR50, Revisions to the National Ambient Air Quality Standards for Particulate Matter and Appendix J—Reference Method for the Determination of Particulate Matter as PM–10 in the Atmosphere. *Fed. Regist.* 52:24634, and 24664–24669.

U.S. Environmental Protection Agency. 1989. Standards for the disposal of sludge. 40 CFR. Parts 257 and 503. *Fed. Regist.* 54:5746–5902.

U.S. Environmental Protection Agency. 1993a. *Guidance specifying management measures for sources of nonpoint pollution in coastal waters*. EPA 840–B–92–002. U.S. Environmental Protection Agency, Washington, D.C.

U.S. Environmental Protection Agency. 1993b. National pollution discharge elimination system general and reporting requirements for discharge from concentrated animal feeding operations: Notice. *Federal Register* 58(4): 7627–7644.

Valentine, G. E. and W. C. Merka. 1989. Plenty of water doesn't necessarily mean cheap water; Georgia rates follow national trend. *Poultry Times*, Gainesville, Georgia. September 25, 1989.

Valentine, G. E., C. C. Ross, and S. R. Harper. 1988. *High rate anaerobic fixed-film reactor for the food processing industry*. Final Report. N 400–960 and A–4817. Georgia Technology Research Institute, Atlanta.

Vandepopuliere, J. M. 1990. Carcass preservation systems—extrusion. Pp. 64–68. *Proceedings of the National Poultry Waste Management Symposium*, Raleigh, North Carolina, October 3–4, 1990.

Vandepopuliere, J. M., W. Jaynes, H. V. Walton, and O. J. Cotterill. 1974. Poultry-hatchery by-product, a feedstuff for hens. *Poult. Sci.* 53:1985.

Vandepopuliere, J. M., H. K. Kanungo, H. V. Walton, and J. O. Cotterill. 1977. Broiler and egg type chick hatchery by-product meal evaluated as laying hen feedstuffs. *Poult. Sci.* 56:1140–1144.

Vanderholm, D. H., E. C. Dickey, J. A. Jackobs, R. W. Elmore, and S. L. Spahr. 1979. *Livestock feedlot runoff control by vegetative filters*. EPA–660/2–79–143. U.S. Environmental Protection Agency, Ada, Oklahoma. 66 pp.

van der Sluis, W. 1990. Manure, a fantastic carbon source. P. 81. *Misset-World Poultry*, October/November.

Van Dyke, N. J., T. J. Prince, and D. T. Hill. 1983. Digestibility of energy and protein in screen waste solids by gestating sows. *J. Anim. Sci.* 57(1):273.

Van Dyne, D. L. and C. B. Gilbertson. 1978. *Estimating U.S. livestock and poultry manure and nutrient production*. ESCS–12. Economics, Statistics and Cooperatives Service, U.S. Department of Agriculture, Washington D.C. 150 pp.

Verdonck, O. 1983. Reviewing and evaluation of new materials used as substrates. *Acta Hortic.* 150:467–473.

Viraraghavan, T., A. A. Coca, and R. C. Landine. 1983. Green vegetable processing wastewater characterization. *Agric. Wastes (G. Brit.)* 6:2,115.

Vuori, A. T. and J. M. Nasi. 1977. Fermentation of poultry manure for poultry diets. *Brit. Poult. Sci.* 18:257–264.

Walker, R. D. and R. A. Pope. 1983. *Estimating your soil erosion losses with the Universal Soil Loss Equation (USLE)*. University of Illinois Cooperative Extension Service Circular 1220. Uni-

versity of Illinois Extension, Urbana.
Wallingford, G. W., L. S. Murphy, W. L. Powers, and H. L. Manges. 1974. Effect of beef feedlot lagoon water on soil chemical properties—growth and composition of corn forage. *J. Environ. Qual.* 3:74–78.
Walsh, J. L. and G. E. Valentine. 1989. *Continuous operation of a thermally enhanced sludge dewatering system.* Paper 89–6094. American Society of Agricultural Engineers, St. Joseph, Michigan.
Walsh, J. L., C. C. Ross, M. S. Smith, S. R. Harper, and W. A. Wilkins. 1988. *Handbook of biogas utilization.* Environmental Sciences and Technology Division, Georgia Technology Research Institute, Atlanta.
Warren, S. L. and C. D. Safley. 1990. Use of composted poultry litter in the horticultural industry. Pp. 144–150. *Proceedings of the National Poultry Waste Management Symposium*, Raleigh, North Carolina, October 3–4, 1990.
Waterman, J. J. 1975. Measures, stowage rates and yields of fishery products. *Torry advisory note no. 17.* Torry Research Station, Aberdeen, Scotland.
Webb, K. E. and J. P. Fontenot. 1975. Medicinal drug residues in broiler litter and tissues from cattle fed litter. *J. Anim. Sci.* 41:1212–1217.
Webb, K. E., J. P. Fontenot, W. H. McClure, R. F. Kelly, and K. E. Webb, Jr. 1980. *Virginia Polytechnic Institute and State University Research Division report.* 156:130. Virginia Polytechnic Institute and State University, Blacksburg.
Weimar, M. R. and S. Cromer. 1990. *U.S. egg and poultry statistical series, 1960–89.* Stat. Bull. No. 816. U.S. Department of Agriculture, Economic Research Service, Washington, D.C.
Westerman, P. W., W. L. Hankins, and L. M. Safley. 1988. *Nitrogen availability from poultry processing plant daf sludge.* Paper 88–2054. American Society of Agricultural Engineers, St. Joseph, Michigan.
Westerman, P. W., M. R. Overcash, R. O. Evans, L. D. King, J. C. Burns, and G. A. Cummings. 1985. Swine lagoon effluent applied to coastal Bermuda grass: III. Irrigation and rainfall runoff. *J. Environ. Qual.* 14:22–25.
Wheatland, A. B. 1960. In P. C. G. Isaac (Ed.). *Waste Treatment.* Pergamon Press, Oxford.
White, R. K. 1988. Upgrading a poultry processing plant wastewater treatment system. *Proceedings of the 1988 Food Processing Waste Conference.* Georgia Technology Research Institute, Atlanta.
Wiener, B. A. 1983. *Swine waste—Corn silage and the survival of dysentery bacteria.* Paper No. 83–4062. American Society of Agricultural Engineers, St. Joseph, Michigan. 13 pp.
Williams, C. M. and J. C. H. Shih. 1989. Enumeration of some microbial groups in thermophile poultry waste digesters and enrichment of a feather-degrading culture. *J. Appl. Bacteriol.* 67:25–35.
Williams, C. M., C. G. Lee, J. D. Garlich, and J. C. H. Lee. 1991. Evaluation of a bacterial feather fermentation product, feather lysate, as a feed protein. *Poult. Sci.* 70:856–94.
Williams, C. M., C. S. Richter, J. M. MacKenzie, Jr., and J. C. H. Shih. 1990. Isolation, identification, and characterization of a feather-degrading bacterium. *Appl. Environ. Microbiol.* 56:1509–1515.
Willson, G. B., J. F. Parker, E. Epstein, P. B. Marsh, R. C. Chaney, D. Colacicco, W. D. Burge, L. J. Sikora, C. F. Tester, and S. Hornick. 1980. *Manual for composting sewage sludge by the Beltsville Aerated-Pile Method.* Report USEPA 600/8–80–022. MERL/ORD, Cincinnati, Ohio.
Wilson, P. N. and T. D. Brigstocke. 1983. Economic considerations. In D. A. Ledward, A. J. Taylor, and R. A. Lawrie (Eds.). *Upgrading Waste for Feeds and Food.* Butterworths, London.
Wineland, M. J. 1990. Pit disposal. Pp. 69–74. *Proceedings of the National Poultry Waste Management Symposium*, Raleigh, North Carolina, October 3–4, 1990.
Winkel, K. 1988. *Ammoniakemissiefactoren voor Veehouderij.* Directie Lucht. Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer, Leidschendam, the Netherlands.
Wisman, E. L. 1964. Processed hatchery by-product as an ingredient in poultry rations. *Poult. Sci.* 43:871–876.
Wisman, E. L. 1965. Utilization of hatchery by-product meal by the laying hen. *Poult. Sci.* 44:1332–1333.
Wolverton, B. C. 1986. Aquatic plants and wastewater treatment (An overview). *Proceedings of the Conference on Research and Applications of Aquatic Plants for Water Treatment and Resource Recovery*, Orlando, Florida. 17 pp.
Wright Associates Inc., R. E. 1990. Assessment of field manure nutrient management with regards to surface and ground water quality. *Project completion report.* REWAI Project 88232. Prepared for the Pennsylvania Department of Environmental Resources, Bureau of Soil and Water Conservation, Harrisburg. 160 pp.
Yoong, C. K., P. R. Ferket, and L. N. Thomas. 1993. Nutritional value of extruded poultry and sweet potato by-products. Pp. 137. *Proceedings of the Fourth Annual Research Symposium, Institute of Nutrition.*
Young, K. S. 1986. Treatment of combined municipal/packing house wastewater using an innovative continuously fed-intermittently operated activated sludge process: A design rationale. Pp. 115–122. *Proceedings of the 41st Industrial Waste Conference.* Ann Arbor Science Publishers, Ann Arbor, Michigan.
Zall, R. R. 1972. Characteristics of milking center waste effluent from New York state dairy farms. *J. Milk Food Technol.* 35:53–55.
Zall, R. R. 1979. Cost effective disposal of whey. Pp. 30, 32, 34, 37, 39. *Dairy Ind. Intl. J.* April 1980.
Zall, R. R. 1984. Trends in whey fractionation and utilization, a global perspective. *J. Dairy Sci.* 67:2621–2624.
Zimmerman, M. H. and R. B. Jacquez. 1980. Poultry waste pretreatment through dissolved air flotation coupled with lime-polymer conditioning. Pp. 586–595. *Proceedings of the 35th Industrial Waste Conference.* Ann Arbor Science Publishers, Ann Arbor, Michigan.
Zublena, J. P., J. C. Barker, J. W. Parker, and C. M. Stanislaw. 1993a. *Swine manure as a fertilizer source.* AG–439–4. North Carolina Agricultural Extension Service, Raleigh. 6 pp.
Zublena, J. P., J. C. Barker, and T. A. Carter. 1993b. *Soil facts: Poultry manure as a fertilizer source.* Bulletin AG–439–5. North Carolina State Agriculture Extension Service, Raleigh.

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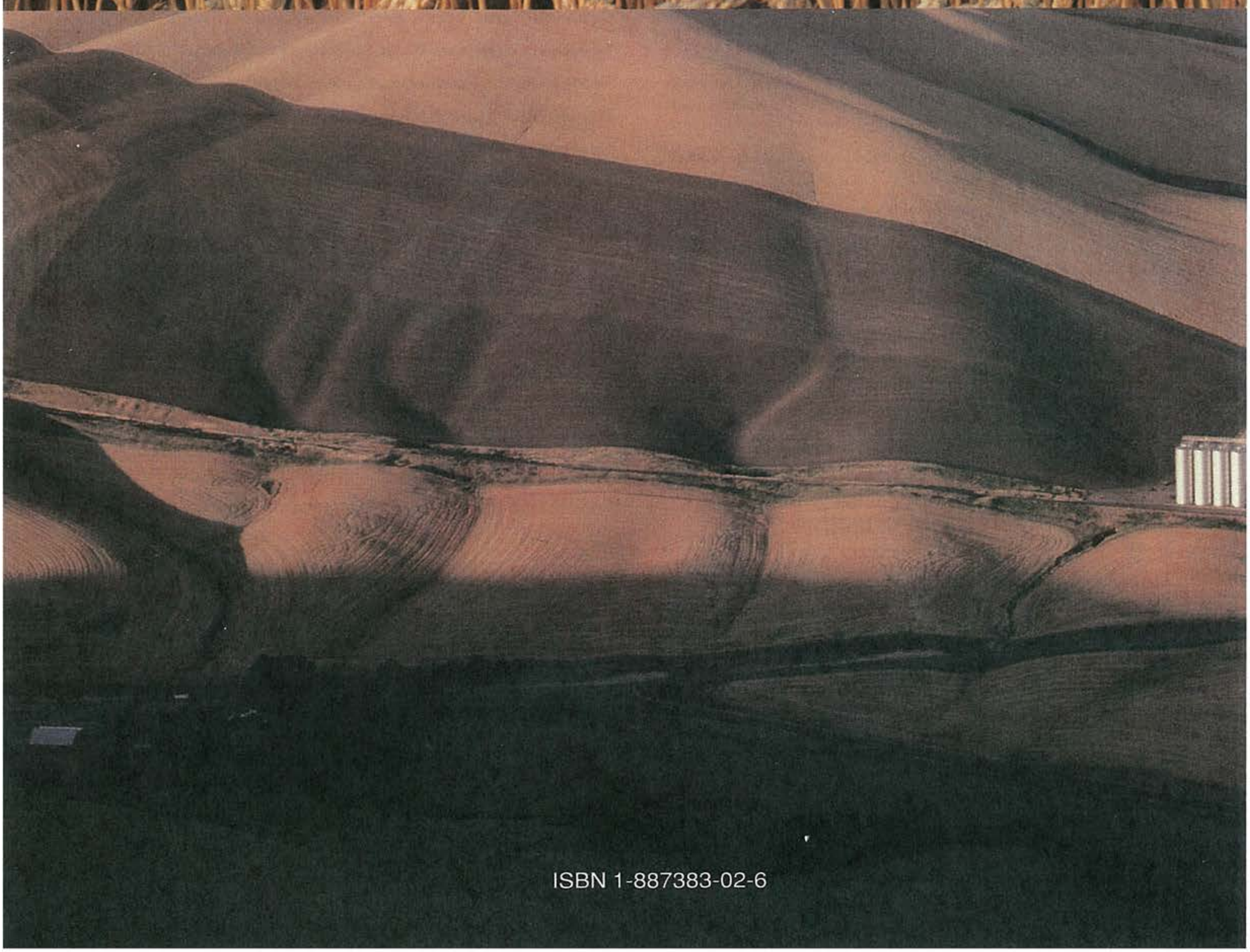

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