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AUTHOR Breidenbach, Andrew W.
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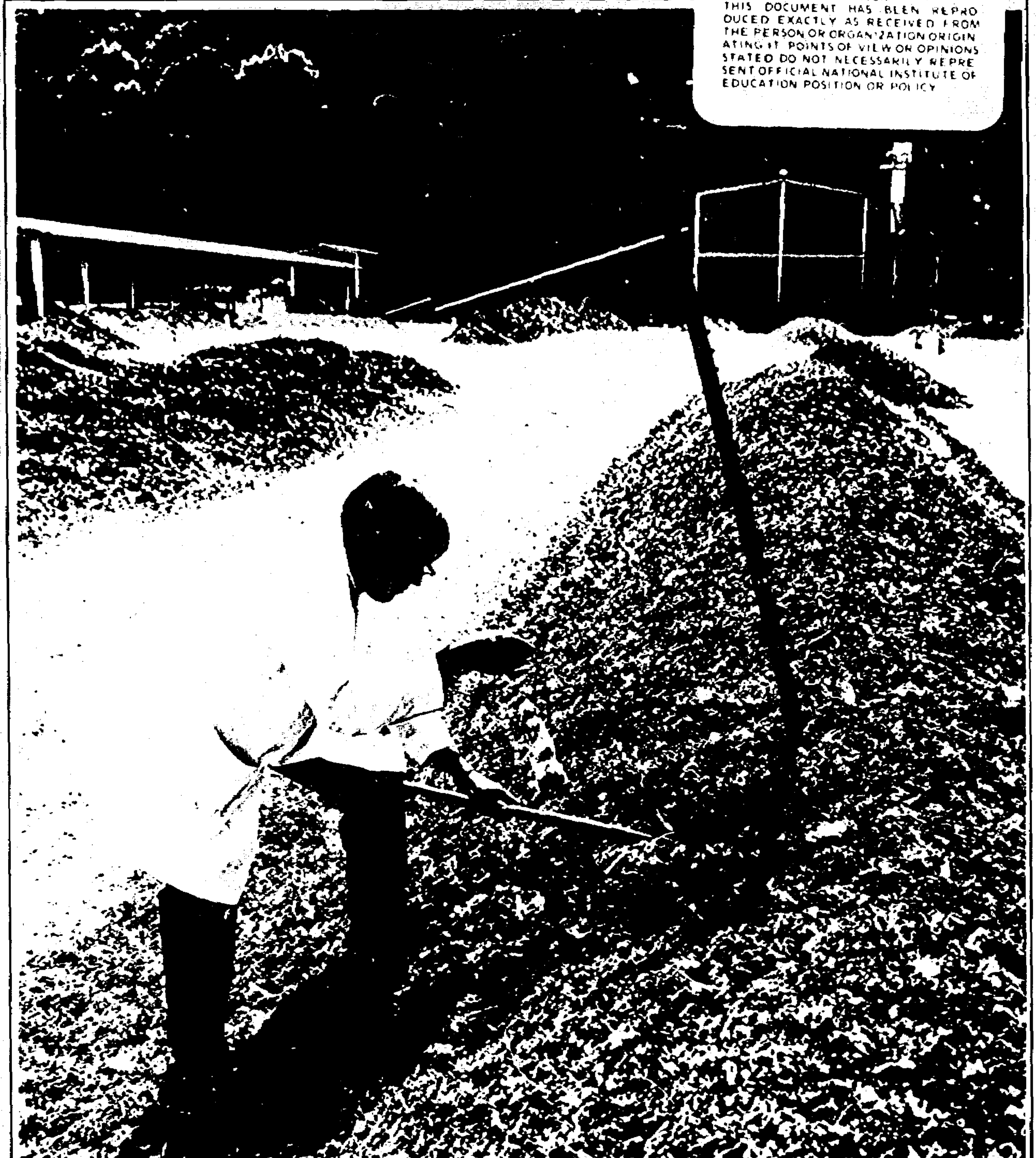
ABSTRACT

To gain more comprehensive knowledge about composting as a solid waste management tool and to better assess the limited information available, the Federal solid waste management program, within the U. S. Public Health Service, entered into a joint experimental windrow composting project in 1966 with the Tennessee Valley Authority and the City of Johnson City, Tennessee. A high-rate composting demonstration plant was also established at Gainesville, Florida under a solid waste management grant. The objectives of these projects were to investigate and demonstrate the economic and technical feasibility of composting municipal refuse. The operational experience gained there and elsewhere are presented in this report. Important conclusions drawn from this study are: (1) composting, properly practiced, can be a nuisance-free way to recycle organic wastes without significantly polluting water and land resources; (2) composting municipal refuse is technically feasible, but it costs more than sanitary landfilling and can cost more than incineration; and (3) the process cannot succeed with results from sale of salvaged or final compost because of a small and unpredictable market. The final conclusion was that waste disposal by composting is not the total answer, but rather one approach to be considered in a solid waste management system. (JP)

COMPOSTING OF MUNICIPAL SOLID WASTES IN THE UNITED STATES



COMPOSTING OF MUNICIPAL SOLID WASTES IN THE UNITED STATES

This publication (SW-47r) was prepared by members of the Federal solid waste management research staff under the direction of ANDREW W. BREIDENBACH

U.S. ENVIRONMENTAL PROTECTION AGENCY
1971

". . . inefficient and improper methods of disposal of solid wastes result in scenic blights, create serious hazards to the public health, including pollution of air and water resources, accident hazards, and increase in rodent and insect vectors of disease, have an adverse effect on land values, create public nuisances, otherwise interfere with community life and development; . . . the failure or inability to salvage and reuse such materials economically results in the unnecessary waste and depletion of our natural resources; . . ."

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FOREWORD

To gain more comprehensive knowledge about composting as a solid waste management tool and to better assess the limited information available, the Federal solid waste management program, within the U.S. Public Health Service, entered into a joint experimental windrow composting project in 1966 with the Tennessee Valley Authority and the City of Johnson City, Tennessee. A high-rate composting demonstration plant was also established at Gainesville, Florida under a solid waste management grant. The objectives of these projects were to investigate and demonstrate the economic and technical feasibility of composting municipal refuse. The operational experience gained there and elsewhere are presented in this report.

Composting, properly practiced, can be a nuisance-free way to recycle organic solid wastes without significantly polluting water and land resources. Composting municipal refuse is technically feasible, but it costs more than sanitary landfilling and can cost more than incineration.

The problems that have prevented composting from becoming an accepted method of solid waste treatment relate primarily to the inability of local governments to accept the concept that the process should be properly supported by adequate municipal funds, as are incineration, sewage disposal, and water treatment. The process cannot succeed with results from the sale of salvaged material or final compost; the market is not that large or predictable. Finally, waste disposal by composting is not the total answer, but rather one approach to be considered in a solid waste management system.

--RICHARD D. VAUGHAN
Deputy Assistant Administrator
for Solid Waste Management

PREFACE

FROM ITS 1966 BEGINNINGS to the present, when we near the end of the project, our experimental research in composting has been very much a team undertaking. It has encompassed substantial efforts by two Federal agencies and a municipality.

We are indebted to the Tennessee Valley Authority (TVA) for the foresight and concept of developing a composting system in a part of the country where, if composting municipal solid waste were successful, the soil would benefit from the application of organic amendments. The design and operation of the facility at Johnson City have been the sole responsibility of TVA, under Dr. O. M. Derryberry. F. E. Gartrell, O. W. Kochtitzky, Carroll Duggan (agriculturist on site), and Virgil Rader (foreman) are just a few of the TVA people who participated. Two Johnson City managers, David Burkhalter and James Mosier, were responsible for the initiation and implementation of the municipal contribution from Johnson City.

For our own part, two U.S. Public Health Service officers and a chemical engineer have served at successive times at Johnson City as the Project Engineer. These men devoted their time and energies around the clock. Each Project Engineer was supported by a small staff, and these personnel were likely to become completely caught up in the project. During his tenure, each Project Engineer reported to a Cincinnati-based manager, four in all, each of whom became almost as engrossed in the project as those stationed at Johnson City. All of these workers at different times have devoted their various skills and energies to reporting the results of the study.

The first Project Engineer was John S. Wiley, already well known prior to his arrival at the project for his pilot research on composting, which dates back to at least 1951. Gordon Stone, who served under Mr. Wiley until the latter's retirement, succeeded him in August 1967. When Mr. Stone became the solid waste management representative in what is now the Environmental Protection Agency's Region II, Carlton Wiles, a chemical engineer, was appointed Project Engineer, a capacity in which he still serves. For most of the study period, Fred J. Stutzenberger was microbiologist, Donald J. Dunsmore was staff engineer, Richard D. Lossin was chemist, and Marie T. Presnell was administrative assistant. The chief Cincinnati-based managers were Charles G. Gunnerson followed by Clarence A. Clemons.

John Ruf was Project Engineer of the independent but companion Public Health Service study in Gainesville, from which input was gathered for this paper. Dr. W. L. Gaby and his staff at East Tennessee State University worked closely with our personnel in determining that compost was safe under the conditions of the study for agricultural use.

Thus, the report, like the project itself, cannot be attributed to only a few people but is a contribution from all of us to the sum total knowledge of composting municipal solid wastes. The impress of all these various curiosities, intelligences, and modes of inquiry is reflected in this document.

--ANDREW W. BREIDENBACH
Director, Division of Research and Development
Office of Solid Waste Management Programs

April 1971

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SUMMARY

Composting, the biochemical degradation of organic materials, is a sanitary process for treating municipal, agricultural, and industrial wastes.

Properly managed windrow or enclosed, high-rate digestion composting, either of which may also process raw or partially digested sewage sludge, will produce a product safe for agriculture and gardening use. Compost cannot be considered a fertilizer. Its main value seems to be its high organic content as a soil conditioner, which may provide poor soils with better tilth, water-holding capacity, and improved nutrient-holding capacity.

The present technology of composting will permit the recycling of organic waste materials back to the soil without significant pollution of water or land resources. Economically, composting does not compete on a net-cost-per-ton-processed basis with either landfilling or incineration of municipal refuse. Evidence gathered from many sources indicates that the rather high cost of producing compost is not sufficiently offset by income from its sale to permit the process to compete economically with other acceptable systems. For a few favored communities some of the costs of composting may be recovered by the sale of salvageable items. The most optimistic estimates of an income-producing market for compost suggest that only a small fraction of the waste generated by

a unit of population could be marketed as compost. Many feel that if the techniques of landfilling and incineration, however, fail to keep pace with increasingly stringent environmental protection criteria or, manage to do so, but become more and more expensive, reflecting all the costs associated with their processes, composting may become a relatively more important tool in resource system management that could accommodate various proportions of municipal, industrial, and agricultural wastes. Additional support is required for a successful composting venture. This support has, in the past, developed from various combinations of political, speculative, and intuitive factors.

Preliminary studies have shown that the land may be able to accept large quantities of compost without harming its crop-producing ability. The land could thus accept compost as part of a refuse disposal system that recycles the organic wastes back into the soil in a highly assimilable and unobjectionable form. Should such a situation occur, various levels of government and private enterprise might find it beneficial to approach the production, distribution, and assimilation of compost jointly.

The factors that will influence the future of the composting process as a municipal solid waste management tool are the net costs and benefits of the process, as compared with other waste management processes. As new technology is developed and priorities change on the use of land, water, and air, the cost and usefulness of composting, as well as other solid waste management systems, will be influenced by four factors: cost per ton of solid waste for each alternative processing and disposal system; acceptance of more stringent standards for environmental quality; availability of systems to meet the standards; public policy decisions requiring beneficial recycling rather than land or sea disposal of wastes.

COMPOSTING OF MUNICIPAL SOLID WASTES IN THE UNITED STATES

CHAPTER I

BACKGROUND

Composting is the biochemical degradation of organic materials to a humus-like substance, a process constantly carried on in nature. For many centuries, farmers and gardeners throughout the world have practiced composting by placing vegetable matter and animal manures in piles or into pits for decomposition prior to use. The first significant development in composting as a systemized process took place in India in 1925.* Sir Albert Howard developed a process involving the anaerobic degradation of leaves, garbage, animal manures, and night soil for six months in pits or piles.[1] The method, known as the Indore Process, was later modified to include more turning to hasten aerobic action.[2] The Indian Council of Agriculture Research improved the method by laying down successive layers of refuse and night soil. This system is used under the name of the Bangalore Process.[2,3] Similarly, in 1922, Beccari patented a process in Italy using both anaerobic and aerobic decomposition in an enclosed system.[4]

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*Mention of commercial products or processes throughout this report does not imply endorsement by the U.S. Government.

The Beccari and Indore processes, although readily adaptable to mechanized methods, did not attract U.S. interest for several reasons. The time factor involved was unsuited to the American cultural pattern; the objective was foreign to the American heritage of wastefulness and unrelated to any recognized need; and the processes involved land areas not suited to our urban centers and to the volume and variety of our wastes. Furthermore, anaerobic composting accomplished nothing that a good sanitary landfill might not do in time with less cost and trouble, particularly when, in contrast to India, there was no demand for the final product.

Interest in composting for the disposal or treatment of municipal refuse arose in the early 1920's. In 1932, the first full-scale European composting plant was established in The Netherlands by a nonprofit utility company N. V. Vuilafvoer Maatschapij (VAM). This plant uses the van Maanen process, a modification of the Indore process, in which unground refuse is composted in large windrows.[2] Also in the 1930's, the Dano process appeared in Denmark, and Emerson patented a similar process in the United States. In 1949, the Frazer-Eweson Process was developed in the United States. In general, at least 16 types of composting processes were identified (Chapter II).

During the 1950's, basic studies and research on composting for municipal waste treatment were conducted at the University of California, by the U.S. Public Health Service, and at Michigan State University.[5-10] A comprehensive monograph on Composting and Sanitary Disposal and Reclamation of Organic Wastes was published by the World Health Organization in 1956.[11] An annotated bibliography of references on composting was also made available during this decade.[12]

A review of municipal composting projects throughout the world was published in 1961 by Davies.[3] Composting developments in the United States during the 1960-1965 period, including difficulties experienced by composting plants, were reported by Wiley and Kochtitzky.[13] The International Research Group on Refuse Disposal (IRGRD), 1956 to 1967[14,15,15a] also provided information on composting.

Although the feasibility of the composting process was established by these basic studies, there were unknowns in its large-scale application in this country. The European experience was not applicable due to the difficulty of translating costs, differences in the character of the refuse, and a different philosophy about composting. Most plants constructed in the United States were enterprises that depended on profit; they charged municipalities fees and expected to receive an income from salvage and the sale of compost. Wiley and Kochtitzky concluded that the inability to dispose of large quantities of compost at a favorable price was probably a major factor in the closing of six of nine plants during the period 1962-1964.[13]

In February 1966, the U.S. Public Health Service (USPHS), the Tennessee Valley Authority (TVA), and the Municipality of Johnson City, Tennessee, entered into an agreement to undertake a joint research and demonstration project in solid wastes and sewage sludge composting.[16] This report has drawn in part on the data collected and experience gained in conjunction with this project and from a USPHS demonstration project at Gainesville, Florida, to provide information relative to composting developments in solid waste management.[17,18] Chapter I reviews composting technology. Chapter II briefly describes processing systems and types of plants and provides a listing of municipal composting plants and their status as of December 1969. Chapter III deals with broad engineering, chemical, and microbiological aspects of composting municipal refuse, with and without the addition of other organic wastes. It also presents information to help answer such questions as "Is the finished product safe to distribute and use?" and "Are restrictions or precautions necessary for use of compost?" Much of this chapter draws upon results of studies conducted at Johnson City and Gainesville.

In general, the economics of composting are confusing. Lack of reliable cost data from operating plants and a number of intangibles are some of the factors that combine to cloud the economics of composting. This report discusses composting economics based upon information available in 1969. Capital and operating costs for the research and development plant at Johnson City and the demonstration plant at Gainesville are provided in Chapter IV. Based on this information, cost projections for larger plants are given. A report on preliminary compost utilization and marketing studies is presented in Chapter V. The role composting is expected to have in future solid waste management systems is discussed in Chapter VI.

Although portions of this report are concerned with results obtained at Johnson City, it is not within its scope to present specifics of the studies conducted. Details of the project are published separately.[17]

CHAPTER II

COMPOSTING MUNICIPAL REFUSE: PROCESSES AND TYPES OF PLANTS

Composting Systems

There are more than 30 composting systems identified by the names of their inventors or by proprietary names. In general, the systems are classified either by the method of preparation of the refuse or by the method of digestion. Sometimes both classification schemes are used in the description.

In most systems, refuse is prepared for digestion by comminuting it in raspers or in various kinds of mills, including hammermills, chain mills, and wet pulpers. Sometimes a process is named for the type of mill used, such as the Buhler or the Hazemag. Digestion is accomplished in windrows, pits, trenches, cells, tanks, multistoried or multidecked towers or buildings, and in drums and bins. There are 16 types of composting processes commonly in use (Table 1).

Present day composting plants generally provide for five basic steps in processing the refuse: preparation, digestion, curing, finishing or upgrading, and storing.

Preparation. Processing of the refuse prior to composting involves several operations, which typically may include receiving, sorting, magnetic separation, grinding, and adding sewage sludge.

TABLE 1

TYPICAL COMPOSTING PROCESSES*

Process Name	General Description	Location
Bangalore (Indore)	Trench in ground, 2 to 3 ft. deep. Material placed in alternate layers of refuse, night soil, earth, straw, etc. No grinding. Turned by hand as often as possible. Detention time of 120 to 180 days.	Common in India
Caspari (briquetting)	Ground material is compressed into blocks and stacked for 30 to 40 days. Aeration by natural diffusion and air flow through stacks. Curing follows initial composting. Blocks are later ground.	Schweinfurt, Germany
Dano Biostabilizer	Rotating drum, slightly inclined from the horizontal, 9' to 12' in diameter, up to 150' long. One to 5 days digestion followed by windrowing. No grinding. Forced aeration into drum.	Predominately in Europe
Earp-Thomas	Silo type with 8 decks stacked vertically. Ground refuse is moved downward from deck to deck by ploughs. Air passes upward through the silo. Uses a patented inoculum. Digestion (2 to 3 days) followed by windrowing.	Heidelberg, Germany; Turgi, Switzerland; Verona and Palermo, Italy; Thessaloniki, Greece
Fairfield-Hardy	Circular tank. Vertical screws, mounted on two rotating radial arms, keep ground material agitated. Forced aeration through tank bottom and holes in screws. Detention time of 5 days.	Altoona, Pennsylvania, and San Juan, Puerto Rico
Fermascreen	Hexagonal drum, three sides of which are screens. Refuse is ground. Batch loaded. Screens are sealed for initial composting. Aeration occurs when drum is rotated with screens open. Detention time of 4 days.	Epsom, England

TABLE 1 (continued)

Process Name	General Description	Location
Frazer-Eweson	Ground refuse placed in vertical bin having 4 or 5 perforated decks and special arms to force composting material through perforations. Air is forced through bin. Detention time of 4 to 5 days.	None in operation
Jersey (also known as the John Thompson system)	Structure with 6 floors, each equipped to dump ground refuse onto the next lower floor. Aeration effected by dropping from floor to floor. Detention time of 6 days.	Jersey, Channel Islands, Great Britain, and Bangkok, Thailand
Metrowaste	Open tanks, 20' wide, 10' deep, 200' to 400' long. Refuse ground. Equipped to give one or two turnings during digestion period (7 days). Air is forced through perforations in bottom of tank.	Houston, Texas, and Gainesville, Florida
Naturizer or International	Five 9' wide steel conveyor belts arranged to pass material from belt to belt. Each belt is an insulated cell. Air passes upward through digester. Detention time of 5 days.	St. Petersburg, Florida
Riker	Four-story bins with clam-shell floors. Ground refuse is dropped from floor to floor. Forced air aeration. Detention time of 20 to 28 days.	None in operation
T. A. Crane	Two cells consisting of three horizontal decks. Horizontal ribbon screws extending the length of each deck recirculate ground refuse from deck to deck. Air is introduced in bottom of cells. Composting followed by curing in a bin.	Kobe, Japan
Tollemache	Similar to the Metrowaste digesters.	Spain; Southern Rhodesia

TABLE 1 (continued)

Process Name	General Description	Location
Triga	Towers or silos called "Hygienisators." In sets of 4 towers. Refuse is ground. Forced air aeration. Detention time of 4 days.	Dinard, Plaisir, and Versailles, France; Moscow, U.S.S.R.; Buenos Aires, Argentina
Windrowing (Normal, aerobic process)	Open windrows, with a "haystack" cross-section. Refuse is ground. Aeration by turning windrows. Detention time depends upon number of turnings and other factors.	Mobile, Alabama; Boulder, Colorado; Johnson City, Tennessee; Europe; Israel; and elsewhere
van Maanen process	Unground refuse in open piles, 120 to 180 days. Turned once by grab crane for aeration.	Wijster and Mierlo, the Netherlands

*References: 2, 3, 13, 19-34.

The receiving equipment is designed to act as a refuse reservoir and to provide an even flow of refuse through the plant. It usually consists of a hopper and some device that begins moving refuse through the plant at the rate at which subsequent operations can process it.

As the refuse leaves the receiving area, noncompostables, bulky items and salvageable materials such as tires, large pieces of wood and metals, rags, plastics, rubber, leather, wood, glass, nonferrous metals, and paper may be removed by hand. Ferrous metals are removed then or later by magnetic separators. This sorting protects the machinery, improves the quality of the final product, and provides for salvage. Ballistic separation of heavier articles and pneumatic separation of light materials are sometimes applied after grinding.

Refuse grinding reduces particle size to facilitate handling, digestion, and mixing of the materials. Some processes, for example, the van Maanen and Dano, do not require grinding prior to digestion. In these cases, the compost is ground prior to distribution. Some recent work has been done in an effort to develop machinery capable of reducing the particle size of refuse on the composting field.[13]

The moisture content of ground refuse is important for proper digestion. Most values given for proper moisture content range between 45 and 65 percent by wet weight. Work at Johnson City has indicated that 50 to 60 percent moisture by wet weight is needed for good decomposition.[17] The moisture content of the ground refuse must, therefore, be adjusted to proper levels in preparation for digestion. Raw or digested sewage sludge may be added in liquid form to provide moisture. This will also provide some additional organic, inorganic, and trace materials while providing for a sanitary disposal of the sludge. If the amount of sludge to be added is greater than that necessary as a source of moisture, the sludge must be dewatered accordingly. Other wastes, such as animal and poultry manures, and canning wastes can also be added.[17]

Digestion. Digestion or decomposition is carried out either in open windrows or in enclosures. The principal objective is to create an environment in which microorganisms will rapidly decompose the organic portion of the refuse. Most modern plants use aerobic rather than anaerobic decomposition. In aerobic decomposition, microorganisms requiring free oxygen degrade the waste. To furnish the oxygen, air is introduced into windrows by turning and into enclosed systems by forced draft and agitation. Heat, which is generated profusely, reaches 140F to 160F (60C to 70C) or higher. The heat destroys pathogenic organisms, weed seeds, fly ova, etc. Decomposition proceeds rapidly and does not produce excessively unpleasant odors.

If the decomposing mass is not aerated, the free oxygen is soon exhausted and a different microflora begins to grow. These anaerobes obtain oxygen from the various compounds in the waste and decomposition proceeds much more slowly. In the van Maanen system, the windrows are anaerobic, and the composting time required is four to six months. By way of contrast, aerobic windrow composting takes only about six weeks and aerated enclosed systems only a matter of days. In anaerobic composting systems, peak temperatures are only about 100F to 130F (38C to 55C), foul odors arise, and pathogens may survive.

In methods having long digestion periods, the process includes a rapid decomposition stage and a "ripening" or curing period. In the methods involving shorter digestion, the agitation and aeration in enclosures are carried on during the earlier, more active decomposition period, and curing follows. Satisfactory stabilization is attained when the compost has the characteristics of humus, has no unpleasant odor, high temperatures are not maintained even though aerobic conditions and desirable moisture content exist, and the carbon to nitrogen ratio (C/N) is such that the humus can be applied to the soil.[11] Although a C/N of 20 is widely accepted as the upper limit for final application to the soil, the actual availability of the carbon and nitrogen is the determining factor and, in practice, the ratio is often higher.[11]

The time required for digestion depends on the initial C/N if proper moisture, particle size, and aerobic conditions are maintained. Studies at the University of California on the windrow composting of mixed refuse showed the following with regard to the more active decomposition period[7,11]:

Initial C/N	Approximate days required for composting
20	9-12
30-50	10-16
78	21

If optimum conditions exist and the initial C/N is 30 to 35, refuse will take on the color and odor of humus in 2-5 days of active decomposition.[7] The C/N may not, however, be lowered by the decomposition to a level satisfactory for most uses.[7,11]

In practice, refuse has a higher initial C/N than is considered optimum. More of the carbon is in the form of cellulose and lignin, which resist decomposition. Gotaas doubts whether materials with a high C/N or even with one above 25, can be adequately decomposed in 3 or 4 days if they contain cellulose or lignin.[11] Thus, the high-rate mechanized digesters produce a material that is given a curing period, which includes further digestion without aeration.

Curing. Curing time to permit additional stabilization depends on the use to be made of compost. If it is to be used in hotbeds, where the heat of decomposition is desirable, it can be applied as soon as the active stabilization phase is over. Compost can be applied with little curing to fields or gardens that are not to be planted for some months. If planting is to take place immediately, stabilization must have advanced to the point at which further decomposition will not "rob" the soil of nitrogen.

In a windrowing system that calls for frequent turning for aeration, composting can be satisfactorily carried out in approximately six weeks with another two weeks for curing and drying.

Mechanical processes use various curing periods. The Dano process uses as little as 7 to 10 days storage for further stabilization after the material leaves the digester.[11] In Aukland, New Zealand, however, where Dano digesters are also used, 3 to 4 months are given to curing.[35] At Altoona, Pennsylvania, where a Fairfield-Hardy digester is used, the curing or maturing time is one to three weeks.[21,22] The Naturizer-type plant at St. Petersburg, Florida, is reported to provide 10 days to two weeks for curing.[22,23]

Finishing. Screening, grinding, or a combination of similar processes is done to remove plastics, glass, and other materials from the compost that might be objectionable in its use. If the compost is to be utilized as an erosion control measure in isolated places, it can be applied without being ground or screened. For the "luxury gardening" market, such materials must be either removed or reduced to an acceptable size. Additional upgrading, such as pelletizing or fortifying with commercial fertilizer, may also be accomplished to satisfy various markets.

Storage. The demand for compost in quantity is greatest in the spring and fall. A plant must, therefore, provide storage space for up to at least six months of production. The compost can be stored outdoors in piles. The storage period can, in fact, serve as the curing phase if the compost is put into low piles until heating has ceased and is then piled higher. Compost can be stored for later finishing or the finished product can be stored; it may have to be placed under cover.

Some Recent Applications of Composting

European Practice. Since 1960, the literature has contained reports of about 2,600 composting plants operating outside the United States; 2,500 are small plants in India.[24] About 100 plants have operated elsewhere, including Great Britain (Table 2). Nine plants have operated in West Germany since World War II but have processed less than 1 percent of that nation's refuse.[25] On the other hand, one-sixth of the refuse collected in The Netherlands is processed in composting plants.[25] The van Maanen type plant, which was established in 1932, is still in operation

TABLE 2

WORLDWIDE DISTRIBUTION AND TYPES OF COMPOSTING PLANTS EXCLUSIVE OF THE UNITED STATES*
(Operating at some time during the period 1960-1969)

Process	Argentina	Austria	Belgium	Brazil	Czechoslovakia	Denmark	Ecuador	England	Finland	France	Greece	Iceland	India	Israel	Italy	Jamaica	Japan	Netherlands	New Zealand	Norway	Philippines	Poland	Puerto Rico	Saudi Arabia	Scotland	South Africa	Southern Rhodesia	Spain	Sweden	Switzerland	Thailand	U.S.S.R.	West Germany	Total
Bangalore													2500																					2500
Dano			3	2		12	1	2	2	1		1		2	2		16	4	1	1	1	1		2	6	1			1	6			2	70
Windrow					20									1		1		5												1			3	31
Tollemache															2												1	4						7
Earp-Thomas											1																			1			1	3
van Maanen																		2																2
Caspari																																	1	1
Terrascreen								1																										1
Fairfield-Hardy																							1											1
Jersey								1																										1
Triga	1									3																						1		5
Becarri										†					†															1				†
Other		1																													1		4	6
Total	1	4	3	2	20	12	1	4	2	?	1	1	2500	3	?	1	16	11	1	1	1	1	1	2	6	1	1	4	1	9	1	1	11	

*References: 2, 3, 12, 20-26, 28, 30, 33, 34, 36-42.
†Unspecified number reported.

and produces 160,000 tons of the country's annual total of 200,000 tons of compost.[25]

The large number of composting plants in India is the result of an intensive program whose objective is to utilize all organic wastes on farmland. It was started by the government in 1944 and is still being supported. By 1959, the annual production of compost was 3.34 million tons. The Bangalore process is most commonly used. Hand labor, which is plentiful and inexpensive, is used extensively. Land comprises the major portion of capital costs, since the only construction needed is a series of trenches.

Operational and cost data on some European and Middle Eastern composting plants have recently been reported.[14,15,25,43-48] Only a small fraction of municipal refuse is composted in Europe; it ranges from less than 1 percent in West Germany to 17 percent in The Netherlands. Operational data on selected plants are available (Table 3).

At 12 plants studied by Kupchick, which serve a total of 3,136,000 people, 45 percent of the refuse processed became compost. About 70 percent of the product was sold at an average of $2.73 per ton, which is equivalent to about $0.90 per ton of refuse processed.[44] Conditions which favor sales are not uniformly distributed and result in a wide range of potential revenue. Most European cities have, therefore, selected less expensive refuse disposal methods.

Buchs and Turgi in Switzerland are of particular interest. Incineration is replacing composting there but the compost plants must remain operational so that the product remains available for those who are willing to buy it despite its high cost.

TABLE 3

EUROPEAN AND MIDDLE EASTERN MUNICIPAL REFUSE COMPOSTING PLANTS

Type and location of plant	Population served	Year constructed	Year of observation	Operating features: Pre-shredding	Operating features: Sewage sludge	Refuse tons/year	Compost* tons/year
Windrow							
Arnhem, Netherlands	130,000	1961	1967	Yes	-	26,500	18,000
Blaubeuren, West Germany	20,000	-	1967	Yes	Yes	-	2,000
Buchs, Switzerland	40,000	-	1967	Yes	Yes	-	-
Lagny, France	75,000	1964	1965	Yes	-	17,500	13,200
St. Georgen, West Germany	14,000	-	1967	Yes	Yes	-	450
Stuttgart, West Germany	75,000	1959	1967	Yes	No	-	-
Tehran, Iran	2,500,000	†	1969	Yes	No	300,000‡	-
Tel Aviv, Israel	700,000	1963	1965	Yes	-	200,000	74,000
Wyster, Netherlands	800,000	1927	1967	No	No	160,000	55,000
High Rate§							
Bad Kreuznach, West Germany	45,000	1958	1967	No	Yes	8,000	2,600
Bristol, England	90,000	1964	1965	-	-	17,000‡	0
Cheadle, England	-	1965	1965	-	-	9,000	-
Duisburg, West Germany	90,000	1957	1967	No	Yes	-	10,000
Edinburgh, Scotland	210,000	1958	1965	Yes	-	32,500	5,300
Gladsaxe, Denmark	80,000	1948	1965	-	-	19,000	13,200
Haifa, Israel	170,000	1959/64	1965	-	-	46,500	26,000
Heidelberg, West Germany	30,000	1955/62	1967	Yes	Yes	-	650
Hinwill, Switzerland	100,000	1964	1967	Yes	Yes	19,000	8,800
Jerusalem, Israel	120,000	1968	1969	No	-	-	-
Olten, Switzerland	-	1964	1965	Yes	-	10,000	-
Rome, Italy	700,000	1964	1965	No	-	100,000	66,000
Soest-Baarn, Netherlands	54,000	1958	1965	-	-	10,000	4,500
Soissons, France	27,000	1963	1965	-	-	9,500	5,500
Thessaloniki, Greece	400,000	1966	1968	Yes	No	¶	0
Turgi, Switzerland	70,000	-	1967	Yes	-		-
Versailles, France	82,000	1967	1967	-	-	50,000‡	-

*Volumetric figures converted assuming 300 lb/cu yd (dry weight).

†Under construction at reported cost of $3,500,000; construction halted prior to installation of compost handling and processing equipment.

‡Estimate; based on 300 days operation at rated capacity.

§Enclosed systems with mechanical turning, often with forced aeration.

¶Not operating in June 1968 because product could not be disposed of; international loan in default.

Some recent proposals and projects for composting municipal refuse in Europe and the Middle East were unsuccessful for reasons similar to those reported in the United States. The municipalities or other operating agencies did not choose to provide the additional financial support required for composting and selected a less expensive disposal alternative. (The additional support is needed to cover the increased production and utilization costs, and it might be furnished in the future if other than strict economic factors are considered. Some of the added costs might be recovered in the form of the agricultural and other benefits derived from using compost.)

Some plants have such features as recycling of the compost, complicated materials-handling or processing procedures, or the use of inocula, which add to production expense; these reflect intensive promotional efforts. On occasion, provision is made to pay the municipality for the raw refuse; this is invariably an explicit warning of financial problems to come. In Tehran (where construction on a partially completed plant was halted) and Istanbul (where construction never proceeded beyond the ground-breaking stage) published estimates of potential revenues from compost sales ranged from half to the full wholesale value of all the fruits and vegetables entering each city.[45,49,50]

Information from Israel presents a mixed picture. Michaels reported that in five of the seven districts which form the State of Israel, either windrow or Dano composting plants are utilized to process refuse from 43 percent of the total population.[51] The largest operating plant in the world is the windrow plant at Tel Aviv; the newest is the Dano plant for 120,000 of Jerusalem's population. However, in the Ashkelon area to the south, an existing windrow plant is to be replaced by a sanitary landfill.

Cost figures from Europe and the Middle East are consistent with those reported by municipal compost plants elsewhere, including plants in the tropics, whether closed down as at Kingston in Jamaica[40] or operating as at Bangkok, Thailand.[52,53]

United States Practice. Prior to 1950, composting of municipal refuse received almost no attention in the United States. The need for new disposal methods, accompanied by an interest in returning organic wastes to the soil, stimulated basic studies and research on composting of organic wastes.[5-10] Eighteen composting plants were funded between 1951 and December 1969 (Table 4). As of the latter date, plants at Altoona, San Juan, Houston, and Johnson City were operating at essentially design capacity, those at Boulder, Mobile, and St. Petersburg were operating on a demand basis, and the Gainesville plant had recently closed down while alternative means of support were sought to replace the assistance previously provided under a U.S. Public Health Service grant. One plant, at New York, was under construction under a $1.3 million loan that had been provided by the U.S. Department of Commerce to provide employment in an economically stagnant area.[56] Except for the Johnson City plant, which is a Federally supported research project, present planning requires significant sales of compost in order for the plants to be viable.

TABLE 4

MUNICIPAL SOLID WASTE COMPOSTING PLANTS IN THE UNITED STATES (1969)*

Location	Company	Process	Capacity ton/day	Type waste	Began operating	Status
Altoona, Pennsylvania	Altoona FAM, Inc.	Fairfield-Hardy	45	Garbage, paper	1951	Operating
Boulder, Colorado	Harry Gorby	Windrow	100	Mixed refuse	1965	Operating intermittently
Gainesville, Florida	Gainesville Municipal Waste Conversion Authority	Metrowaste Conversion	150	Mixed refuse, digested sludge	1968	Operating
Houston, Texas	Metropolitan Waste Conversion Corp.	Metrowaste Conversion	360	Mixed refuse, raw sludge	1966	Operating
Houston, Texas	United Compost Services, Inc.	Snell	300	Mixed refuse	1966	Closed (1966)
Johnson City, Tennessee	Joint USPHS-TVA	Windrow	52	Mixed refuse, raw sludge	1967	Operating
Largo, Florida	Peninsular Organics, Inc.	Metrowaste Conversion	50	Mixed refuse, digested sludge	1963	Closed (1967)
Norman, Oklahoma	International Disposal Corp.	Naturizer	35	Mixed refuse	1959	Closed (1964)
Mobile, Alabama	City of Mobile	Windrow	300	Mixed refuse, digested sludge	1966	Operating intermittently

TABLE 4 (continued)

Location	Company	Process	Capacity ton/day	Type waste	Began operating	Status
New York, New York	Ecology, Inc.	Varro	150	Mixed refuse		Under construction
Phoenix, Arizona	Arizona Biochemical Co.	Dano	300	Mixed refuse	1963	Closed (1965)
Sacramento Co., California	Dano of America, Inc.	Dano	40	Mixed refuse	1956	Closed (1963)
San Fernando, California	International Disposal Corp.	Naturizer	70	Mixed refuse	1963	Closed (1964)
San Juan, Puerto Rico	Fairfield Engineering Co.	Fairfield-Hardy	150	Mixed refuse	1969	Operating
Springfield, Massachusetts	Springfield Organic Fertilizer Co.	Frazer-Eweson	20	Garbage	1954 1961	Closed (1962)
St. Petersburg, Florida	Westinghouse Corp.	Naturizer	105	Mixed refuse	1966	Operating intermittently
Williamston, Michigan	City of Williamston	Riker	4	Garbage, raw sludge, corn cobs	1955	Closed (1962)
Wilmington, Ohio	Good Riddance, Inc.	Windrow	20	Mixed refuse	1963	Closed (1965)

*References: 2, 13, 22-23, 27-29, 31, 54-55.

CHAPTER III

ENGINEERING, CHEMICAL, AND MICROBIOLOGICAL ASPECTS OF COMPOSTING

As systematized and mechanized composting operations were developed, engineering problems increased. Various digestion arrangements were developed and patented, and some work was done on special grinders. In most cases, the material-handling equipment used had been developed for other industries and modified to process refuse. Although considerable laboratory or small-scale work has been done in the last 20 years in the United States and the basic technologies are known, adequate experience in design and operating compost plants has not yet been accumulated. As a result, most plants have gone through a period of "cutting and trying" with different types of machinery and plant layouts before going into production.

The laboratory work done on the physical and chemical aspects of composting serves as a basis for process control in full-scale plants. The extreme heterogeneity of raw refuse and other factors, however, result in the composting of mixed municipal refuse being practiced, in some respects, as an art with laboratory research serving as a guide.

This chapter discusses the general engineering, chemical, and microbiological aspects of composting, based on observations made and data accumulated over nearly two years at Johnson City and a year at Gainesville. (Separate reports present the details of the engineering, chemical, and microbiological studies performed at these plants.)[17,18]

Engineering Aspects

General Design Criteria. A number of criteria must be considered in designing and operating a compost plant. One is to obtain all the information possible about the population to be served and the amount and type of refuse it generates. For example, a domestic refuse high in cellulose may make the material resistant to attack by microorganisms,[57] and the composting process may have to be changed accordingly.

On a national scale, seven pounds of urban (domestic, commercial, institutional, and municipal) solid wastes are generated per capita per day. This figure includes garbage, rubbish, trash, ashes, demolition debris, street sweepings, dead animals, abandoned vehicles, etc.; it does not include industrial or agricultural solid wastes. The amounts collected vary according to seasonal, climatic, and socioeconomic factors. Production rates for individual areas must, therefore, be determined by surveys.

A second design criterion is the length of the workweek. Thus, a plant operating on a five-day workweek is required to accept refuse at 1.4 times the rate for a seven-day design capacity.

Another factor is the number of shifts to be worked per day. To process equal amounts of material, a plant operating on two shifts does not need some of the large refuse-handling machinery or grinders that a one-shift operation has to use. The receiving area must, however, allow for storage for processing during the second shift of about one-half of the refuse delivered to the plant during the day. Digestion, storage, and curing elements must be sized for the total tonnage received.

Refuse Handling. Plants must provide an area appropriately designed for receiving refuse and large enough to store at least one day's delivery. The refuse moves from the receiving area to size-reducing equipment, frequently via a picking station, where salvageable items, noncompostables, and large items that might damage equipment are removed.

The flow of refuse from the receiving area should be controlled. Some hoppers are discharged to an oscillating belt to achieve this control while others may use a leveling gate. Arching or bridging often occurs in the receiving hopper and may be more acute if a leveling gate is used.[17] The operation often proceeds more smoothly if one or both of the hopper's long sides are nearly vertical.

If the incoming refuse has been compacted, as in a transfer trailer, it must be broken up and pushed into the hopper. A front end loader has been successfully used for this purpose.[17]

Endless moving belts are widely used to carry refuse from station to station. When hand picking is practiced, the bed of refuse should not be more than 6 inches deep; belt width and speed are the determining factors. If the belt is too wide, the pickers cannot reach its center. If the belt traverses any space outside a building, covers must be provided. They must be easily removable and high enough and wide enough that refuse does not catch on them. Sideboards or skirts should be used to keep refuse from falling from the belt.

Ground refuse moves more easily than raw. The belts should be wide enough or have sideboards to prevent spillage and minimize cleanup problems. Bucket elevators work well in lifting ground refuse, and screw feeds can be used to move it horizontally in troughs. Narrow openings, restrictions, or chutes must be avoided because ground refuse clogs easily.

In freezing weather, it may be necessary to heat the belts where they come in contact with the end pulleys. Wipers should be installed on the belts near the drop-off points, so that refuse, especially ground refuse, does not stick to the returning undersides and drop on the floor.

Hoppers and bins that hold refuse or ground refuse only temporarily should have moving belts in their floor or have openings large enough for the refuse to be pulled by gravity through the bottom.

Separation of Noncompostables and Salvage. Most plants remove as many noncompostables (wood, plastics, glass, metals, rags, etc.) as possible before the refuse reaches the size-reducing equipment. If this is not done, some picking of bulky items is necessary, either at the receiving point or from a belt, to protect the equipment. When salvaging is practiced, the material removed is usually classified, and an effort is often made to remove paper. At Johnson City, where no salvaging is practiced, two pickers can handle up to 60 tons of refuse in six to eight hours.[17] In Gainesville, where paper and metals are salvaged, six pickers are used to process 125 tons per day.[18]

At most plants, ferrous metals are removed by magnetic separators. These may be in the form of a permanently magnetized head pulley installed on the raw or ground refuse belt or an overband type that uses an electromagnet. If two grinders are used in series, the magnetic separator may be located between them.

Rejected material at Johnson City has averaged 26 percent by weight of the incoming refuse.[17] At Gainesville, about 10 percent is removed as salvaged paper while another 10 to 30 percent is rejected.[18] Some composting plants are trying to salvage up to half the incoming refuse by using special mechanical devices. Rejected, unsalvageable material must be moved to a disposal site. A market is usually available for paper and metal, and cans, glass, and certain plastics can be sold in some areas.

In Europe, refuse often has a high ash content. Rotary and vibrating screens are sometimes used to remove the ash from raw refuse before it is ground.[58]

<u>Comminution.</u> Refuse is usually ground or shredded to improve materials-handling and digestion operations. Most of the machines now used were originally designed for use with homogeneous types of materials.

The most common grinding device is the hammermill. It usually consists of high-speed swing hammers connected symmetrically on a horizontal shaft and cutter bars that have grate openings through which the refuse is forced. Refuse fed into the mill is comminuted by the application of high tensile and shearing forces. Tensile force is applied as the swinging hammers flail the refuse against the breaker plates. The shearing forces come into play as the hammers force the refuse through the grate openings. Hammers are of various types, and some are better suited than others to produce the shredding action needed. Several types of double-rotor mills have been developed in Europe,[58] and at least one is manufactured in the United States.

Hammermills require relatively large motors and must have the capacity and power to handle a flow of refuse that resists grinding; the capacity depends on the particle size desired. It is common practice to use two mills in series; the first produces a rough grind while the second reduces the particles to two inches in the largest dimension. Refuse is abrasive and the hammers must be frequently refaced. It has been found at Johnson City that the hammers need rebuilding after 30 to 40 hours of use.[17]

Since hammermills operate at 1,200 to 3,500 rpm, they produce noise and vibration. The machines should, therefore, be mounted on dampening materials, and the feed chute should be flexible or have a flexible connection.

A specialized shredder or rasper developed in The Netherlands consists of a large vertical cylinder that surrounds a vertical shaft on which heavy arms are mounted. They rotate horizontally above a perforated floor. Pins or studs, mounted in panels on the floor and along the sides of the cylinder, shred the refuse, and the particles then fall through the perforations. The revolving arms are hinged and swing when they meet resistance.

Raspers operate more slowly than hammermills and require less power, but they have a greater initial cost and require more floor space. Performance data indicate that the perforated plates and pin plates in the 10-tons-per-hour (rated capacity) rasper at Johnson City, need replacing after grinding about 10,000 tons of refuse (approximately 1,500 operating hours).[17]

Refuse must build up in the grinding compartment for about 20 minutes before effective grinding begins. If the flow of refuse stops, the machine runs at a diminishing rate of production until empty. It should, therefore, be kept full throughout the day for the greatest efficiency. The perforated floor acts as a sieve and retains oversize material that can be discharged at intervals through a chute. Raspers must be cleaned out frequently, but they are so designed that workmen can easily enter the grinding compartment.

Since large pieces of dry cardboard may build up in the machine and overload it, water is sometimes sprayed on the refuse either before it reaches the rasper or after entering it. This procedure may prove disadvantageous if sewage sludge is to be added after grinding, because the refuse may become excessively moist if the sludge is not sufficiently dewatered.

Wet pulpers, such as the one at Altoona, Pennsylvania, where cans, bottles, and other noncompostable items are not normally received in the garbage are also used to comminute refuse. They consist of a large bowl that holds a rotatable steel plate studded with hardened steel teeth. After the bowl has been partially filled with water and the plate is rotating at about 650 rpm, raw refuse is dumped in. It is whirled against the teeth and shredded. The resulting slurry, which contains about 5 percent refuse solids, is subsequently discharged through a horizontal bar screen. It must be dewatered by 40 to 50 percent to be digested.

<u>Addition of Sewage Sludge and Other Organic Wastes.</u> Sewage sludge may be satisfactorily composted along with a community's refuse. The

cost is about the same, in some cases less, as for conventional systems that use anaerobic digestion, drying beds, and subsequent disposal.[17] It is usually mixed into ground refuse in mixing drums.

When using sludge, the water content of the ground refuse-sludge mixture will normally be greater than that desired for composting unless the sludge is dewatered somewhat. Certain factors must, however, be considered when sewage sludge is added (Figures 1-3).

It is not practical to use sludge prior to rasper operations because it contaminates the refuse, which may have to be later cleaned from the rasper. Water is, therefore, often added before and during the grinding process. The amount used has an effect on the sludge dewatering operation. When a hammermill is used, water is added after grinding, and all of it may normally be obtained from sewage sludge.

Raw sludge is preferred to digested sludge because it can be dewatered more readily and has a higher nutrient content. (Digested sludge can, nevertheless, be used.) The amount of dewatering necessary depends on the ratio of sludge to refuse to be processed and the initial water content of the sludge and the refuse as received. Depending on the amount to be removed, dewatering can be accomplished in gravity tanks equipped with vacuum filters, in centrifuges, or by using rotating cell gravity filters. Gravity tanks with picket agitators may suffice in many cases. In humid climates, water is removed mechanically from sludge and refuse.

Adding other organic wastes to municipal refuse before it is composted appears feasible as a method to dispose of such wastes. The composting process is apparently not affected, and the nutrient contents of the compost may, in fact, increase.[17]

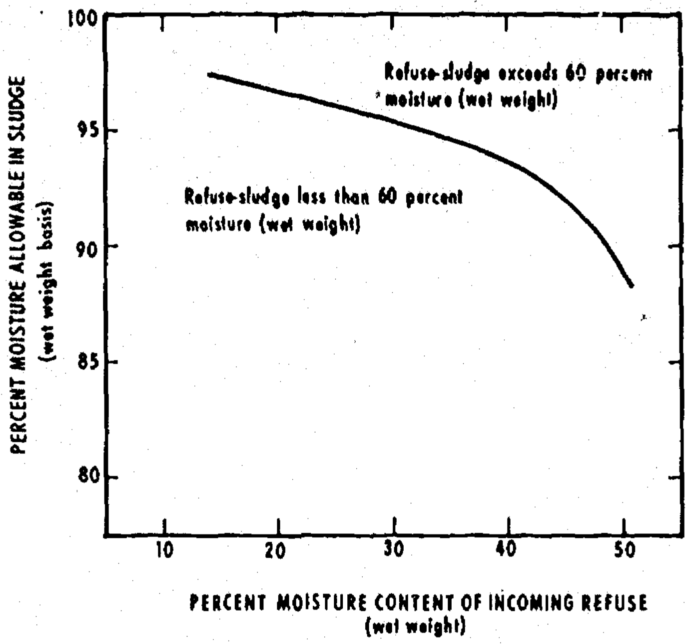

Figure 2. Refuse is not uniform in its water content. To obtain a desired 60 percent moisture level in the ground refuse-sludge mixture, the amount of dewatering required will change with the change in moisture content of the refuse. The refuse is received at a rate of 4.2 lb per capita per day before removal of 25 percent noncompostables. The refuse and sludge are from the same population with sludge (3 percent solids) generated at 0.119 lb per capita per day.

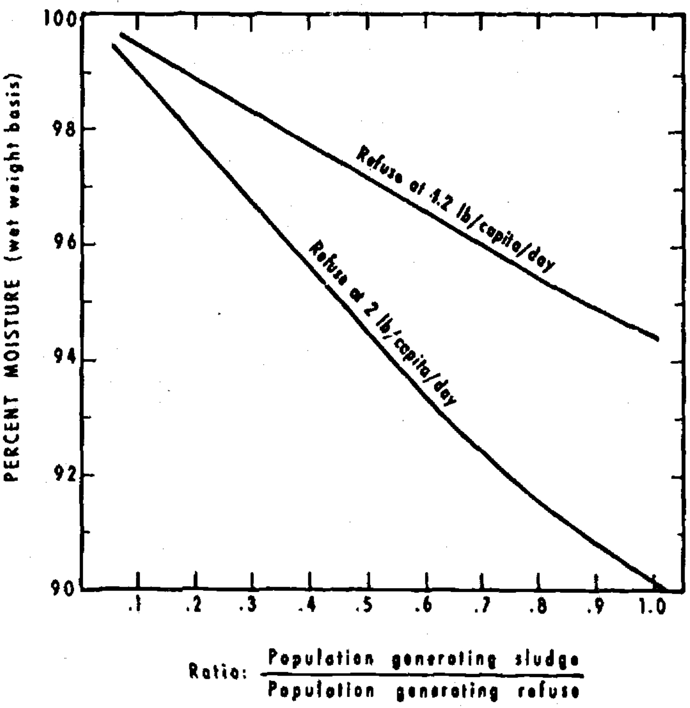

Figure 1. Assuming that a water content of 60 percent is to be maintained in the sewage-sludge-refuse mixture, sewage from only 27 percent of the population can be handled as received, where the refuse is generated at a rate of 2 lb per capita per day. However, at a per capita generation of 4.2 lb refuse per day, about 50 percent of the sewage sludge generated can be handled without dewatering, assuming 3 percent solids. Refuse received with 35 percent moisture (wet weight). Sludge solids are generated at .119 lb per capita per day. Rejects amount to 25 percent of incoming refuse.[59]

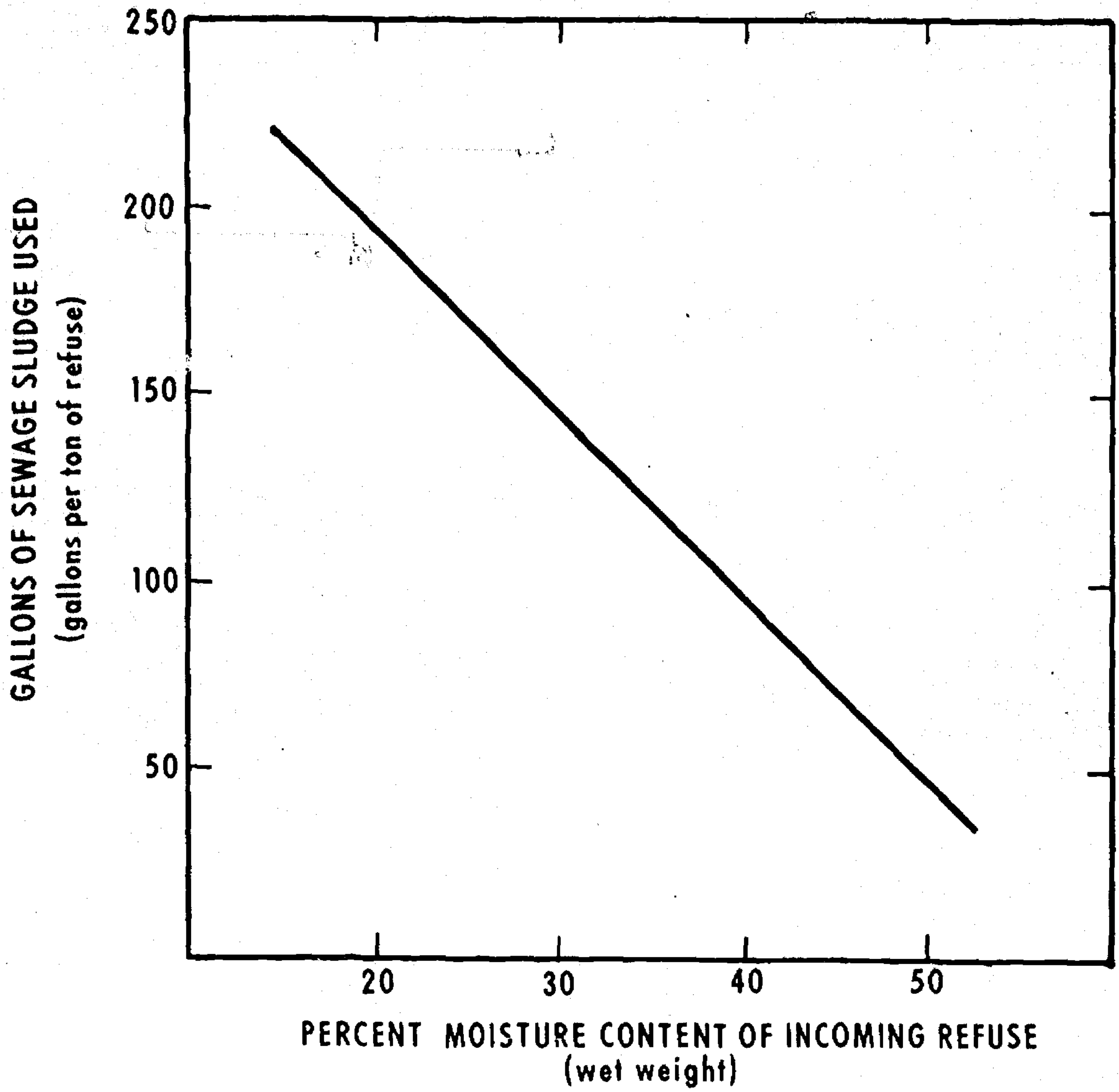

Figure 3. The amount of sewage sludge (gallons) at 3 percent solids that can be used without dewatering varies in direct proportion to the moisture content of the incoming refuse. Actual amount of refuse ground and mixed with sludge would be 75 percent of that received. These proportions would result in a mixture containing 60 percent water by wet weight.

Efforts have been made to have water added automatically by an electrical-mechanical system, but such techniques have not worked well. Experienced plant operators can often tell by the mixture's appearance and handling characteristics when a moisture range of 50 to 60 percent has been reached.

Digestion. Aerobic composting or digestion is carried on in windrows or in such enclosures as aerated tanks or bins. The success of any aerobic method depends on aeration, mixing, and maintaining the proper moisture content. In most plants, efforts are made to maintain aerobic conditions to avoid odors, obtain higher temperatures, and achieve more rapid decomposition.

Experience has shown that unground refuse can be composted, but normally it is first ground so that the particles average 1-1/2 to 2-1/2 inches in their largest dimension. This encourages rapid decomposition either in windrows or in enclosed systems. At Wijster and Mierlo in The Netherlands, however, unground refuse is windrowed according to the van Maanen process, which calls for only one turning; composting takes four to six months. In the Dano system, the refuse usually introduced into the digester is unground. The constant turning of the drum reduces the size of the particles as they are digested. Where windrow turners are used, they may also shred the material as they mix it.

In the windrowing process, aeration and mixing can be accomplished by using a front-end loader or a clamshell bucket on a crane. Turning machines with a shoveling or screw arrangement are also used. These turners are designed to pick up the material from a belt and place it on the ground. Another type turning machine, with a rotating drum on which teeth are mounted, straddles the windrow and turns it in place.

Some preliminary turning experiments conducted at Johnson City indicated that the windrow should be turned at least once a week.[17] Two turnings per week produced the best decomposition; more frequent turnings proved less efficient because temperatures in the windrows dropped. (Higher temperatures are needed to destroy pathogens.) The degree of decomposition obtained was determined on the basis of appearance, odor, and low carbon content.

In windrow composting where supplemental aeration is not normally provided, the moisture in the material must be kept at 50 to 60 percent by wet weight to keep maximum decomposition proceeding. If the moisture content is higher, water fills the voids in the compost and slows the biological process by denying it sufficient oxygen. On the other hand, dry windrows may cool and fail to decompose properly; water is, therefore, incorporated into the mass. In wet weather, the windrows may have to be turned frequently to help release the moisture. Too much wetness may cause the decomposition to become anaerobic and give rise to odors. At Johnson City, windrows normally remain in the field for at least six weeks and temperatures of up to 160F are maintained.[17] The compost is then moved to a curing shed where it is allowed to dry for two weeks or longer. Experience has indicated that high relative humidity will prevent satisfactory air drying.

In enclosed composting systems, forced or natural draft air is provided for digestion. The material is intermittently turned in the tank by a special apparatus or constantly turned by mixers, rakes, or the rotating digester. Digestion takes 3 to 10 days; the longer period produces a more stable product.

As in windrow composting, insufficient oxygen in an enclosed digester creates odors and slow digestion. Water content must be maintained at between 50 to 60 percent. This level may be higher if means for efficient air transfer have been provided. Temperature profiles are comparable to those observed in windrow composting.

At Gainesville, the refuse is kept for about two weeks in two parallel digestion tanks, each 330 feet long, 20 feet wide, and 10 feet deep. Air is periodically introduced through perforated plates in the bottom. The tanks are equipped with movable conveyors for removing the compost; the conveyors can also mix the material but are not used for this purpose.

Curing. The period of active, rapid, digestion is followed by a slower stabilization period, called curing. In the windrowing process, if proper conditions for decomposition are maintained, digestion and curing form a continuum. Compost is usually removed from the field and cured under cover. It is then ready for many uses, but further stabilization or curing goes on for months.

Finishing. Compost can be used for various purposes as received from the windrowing field or digester. Often, however, it does not have uniform-size particles and may contain bits of plastic, glass, or other nondecomposable objects. It is usual practice, therefore, to finish the compost by regrinding and screening it. When these steps are taken, the moisture content should not exceed approximately 30 percent by wet weight. This may vary, however, depending on the finishing process used and the desired results. In proper climatic conditions, air drying alone may yield a product dry enough for satisfactory finishing, but mechanical dryers may have to be used in humid and wet areas. At Johnson City, air drying has proved difficult all year, especially during wet winter months.[17]

Hammermills may be used for regrinding. Screens can be rotary or vibrating types and have perforated plate, square mesh, or piano wire type screening elements with openings up to 1/2 inch. In the last type, the transverse wires (which are very taut and are perpendicular to the flow of compost) can be at least 1/4 inch apart and the longitudinal supporting wires up to 10 inches apart.

Regrinding can precede or follow screening. In the latter case, the material retained by the screen is sent to the grinder and then screened again. Small particles of glass, whose presence is usually objectionable, can be removed by machines using one or more of the principles described later.

For some uses, such as land reclamation or erosion control in isolated places, compost need not be finished. For general agriculture, a coarse grind is satisfactory, whereas for horticultural and luxury gardening the product must be finer. Reground and screened compost is ready for use as a soil conditioner or may serve as a carrier for fertilizers and blended products. Pelletizing, especially with blending, is sometimes done.

Storage. The use of compost in quantity is seasonal, being more in demand during the spring and fall. A plant must, therefore, be able to store its production for six months or more. Curing and storage can be combined by piling the compost after its heat has diminished or disappeared. Rough compost can be stored for later grinding or the finished product may be stored. Storing in the open may be feasible in some cases.

Special Problems

Glass Removal. Glass removal presents a problem. Pieces and articles of glass are broken as the refuse is collected and transported to the plant as well as by the receiving and processing machines; complete removal is, therefore, impossible. Glass crushers, often simply two spring-loaded rollers that exert pressure on each other, are sometimes used to break the material into small sizes.[58] Hammermills can pulverize glass particles to some extent, but a rasper's capability is minimal.

Many European plants have an apparatus that uses gravity and the differences in the inertial energy and resiliency of particles to remove glass (Figure 4).[58] A ballistic separator impels the material horizontally or at a slight upward angle. Dense and resilient particles travel farther than those that are soft and nonresilient. Although the separation is not definitive, it is satisfactory. The "secator" relies on gravity and particle elasticity to remove heavy and resilient bits of material. The bounce plate is so positioned that the compost or ground refuse lands forward of the center of rotation of the drum and is carried

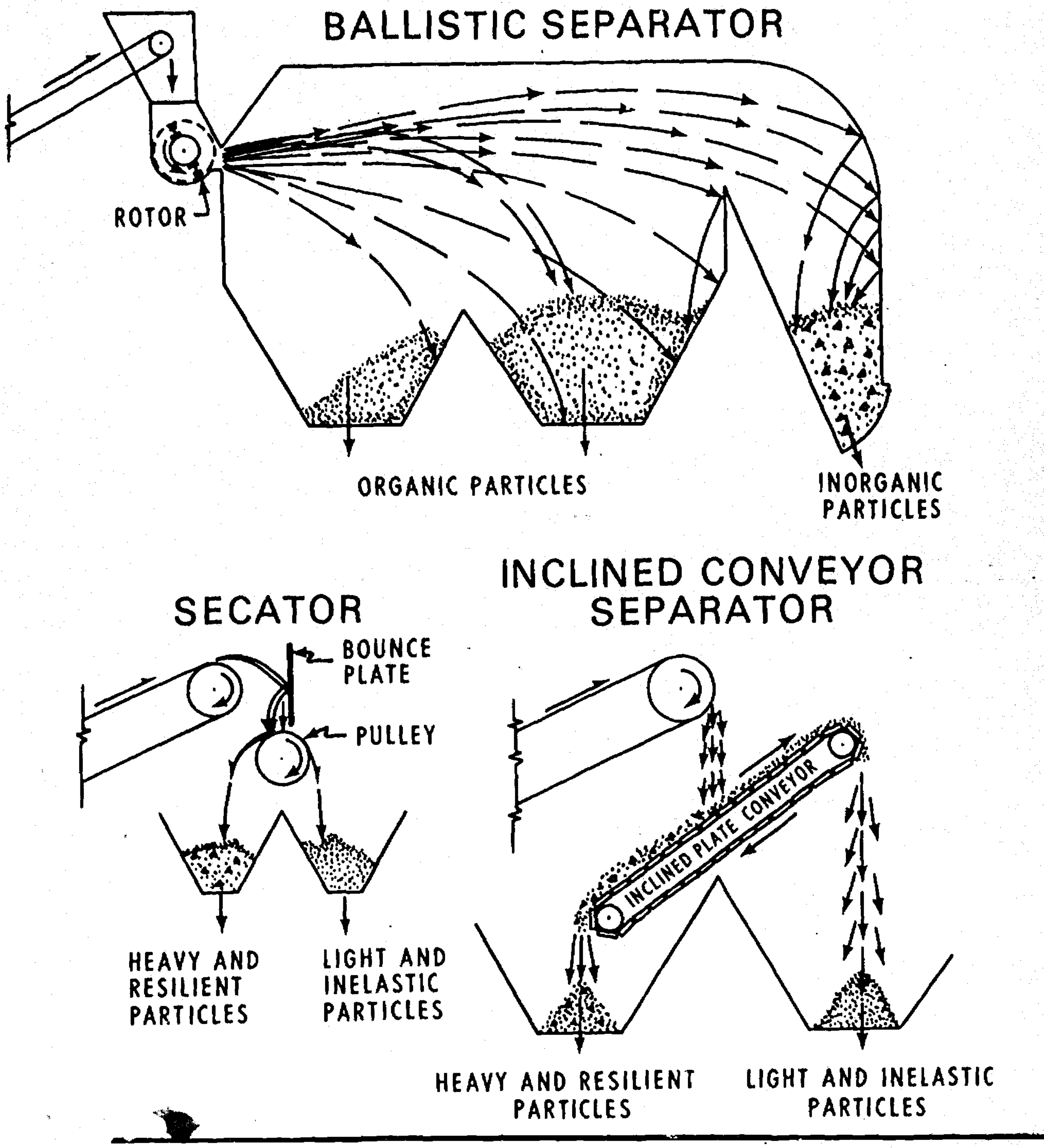

Figure 4. Types of inertial separators.

to the far bin. The resilient particles bounce off the plate to hit the drum back of the center of rotation and bounce into the near bin. In the inclined conveyor separator, the belt is made of steel plates. Heavy and resilient particles bounce down while softer ones continue upward and are deposited in another container.

Another type of separator, known as a "stoner," employs a diagonally inclined, perforated, vibrating table or plate. The material to be separated is deposited on the plate and is "fluidized" by an upward flow of air through the plate. The lighter particles are thereby separated from the heavier ones and are transferred across the plate, then down to a discharge point. Heavier particles are carried upward and discharged at the top.

Plastics Removal. Removing plastic film and similar items may also present special problems. Some film can be removed by pneumatic devices, but their development has not been perfected. Dense plastic particles also give trouble. Small, flexible items can be deformed to allow them to pass through a hammermill or a rasper, after which they resume their shape in the ground refuse. Salvaging molded plastics is being investigated in some areas.

Handling Problems. Compost requires special material-handling techniques. It tends to stick to chutes, sides of hoppers, inside surfaces of dump trucks, etc. One operator in this country has used a Teflon compound on the inside surfaces of dump trucks that carry large quantities of compost. Bulk shipments in railroad cars present unloading problems, because the compost will not flow by gravity from conventional cars, as do coal or crushed stone.

Weight and Volume Losses. As previously mentioned, 20 to 30 percent (by wet weight) of the incoming refuse is not compostable, and some of this is removed. The remaining refuse is comminuted to aid the digestion process, which, in turn, further reduces the volume. The weight lost is in the form of the two principal products of decomposition, carbon dioxide and water; it amounts to 20 to 30 percent of the dry weight.

Experience gained at Johnson City and Gainesville indicates that each ton of incoming refuse will yield, after processing, about 1,000 pounds of compost having a moisture content of approximately 30 percent.[17,18]

The volume reduction achieved in composting has created considerable interest in preparing refuse for landfilling by grinding it or by grinding then composting it. In addition to occupying less space, the ground material has other apparent advantages: it looks better than raw refuse, does not contain large pieces of paper that can blow about, and is less attractive to rodents. If it has been composted as well as ground, the refuse has an even better appearance, gives off fewer odors, restricts fly breeding, requires less or possibly no cover, and occupies less area. Since it has been digested, the compost--if well composted--should subside less and produce less gas than raw refuse. It has been estimated that if a given amount of raw refuse were divided into equal parts, one of which was buried untreated in a landfill and the other was first composted, the latter would occupy 21 percent less space.[60]

Another source states that if refuse containing noncompostables is ground and then composted, it can double the life expectancy of the standard sanitary landfill for a given depth of fill.[61]

Work being done at Madison, Wisconsin, has shown that milled refuse, compacted to a depth of six feet with a D-8 bulldozer, takes up only about half the volume in a landfill as unmilled refuse handled in accordance with usual sanitary landfill practices.[62] Further reduction in volume may be achieved by using special compactors. It is likely that if the material had also been composted, even less space would have been required. At Johnson City, 42-day-old compost has 28 percent less volume than ground but uncomposted refuse. This compost, however, does not contain the proportion of noncompostables contained in the previously mentioned raw refuse.[17,63]

These observations indicate that if refuse is milled (except items that could jam or damage the machinery) and then composted, its volume is reduced by at least half. Composting costs in this case would be reduced as there would be little sorting, compost could be removed from the digesters as soon as a practical point of decomposition had been reached, no curing or drying period would be needed, and no finishing would be required.

Epilog. Only general engineering problems, and some solutions, have been discussed. Although many plants have had to use a "cut and try" approach to design, construction, and operation, there does exist sufficient knowledge to permit a good engineering design of compost plants. The problems are varied, and many have offered a new challenge to the design engineer. However, with proper techniques the problems can be overcome. It would be reasonable to expect, as in the case with many past products, that if compost plants become popular, along with good product development programs, equipment, buildings, and engineering, problems will become more routine and relatively less expensive to handle. It is not intended to imply that the actual cost of composting will decrease in the future. It may be possible, however, that the differences that exist today between the cost of composting and the costs of other refuse treatment methods may decrease in the future.

Environmental Aspects

Composting plants may affect the surrounding environment and the neighborhoods in which they are situated, because they are potential sources of odors and may provide breeding places for flies and rodents. Good management, especially the maintenance of aerobic conditions in the composting refuse, can, however, minimize the odor problem. Managers should insist on meticulous housekeeping and avoid holding unground refuse from one day to another.

Adult flies and fly larvae and pupae are brought into a plant with the refuse, especially if the collection system does not provide frequent pickups. At the receiving point, the application of a residual insecticide around the unloading apron and on the walls of the receiving building has successfully killed larvae migrating from the refuse.[17] Grinding also destroys many of the larvae and pupae.

Flies are also attracted to fresh ground refuse, and they may breed during the digestion period if proper conditions are not maintained. On the other hand, the temperatures reached in aerobic composting are lethal to fly larvae and eggs.[11] Care should, therefore, be taken to ensure that all portions of the windrows reach these temperatures. This can be done by proper shaping and piling prior to turning. If the windrows are turned approximately every three days, this may also aid in controlling flies by breaking their life cycle.[11,17] The judicious use of an insecticide will also help.[17] Rodents can be controlled with poisons and by denying them hiding places.

Noise and dust may be hazardous to the workers. Since hammermills can generate intolerable noises, they should be isolated from the building by dampening materials. Materials falling into a metal-sided reject hopper from a picking station may also cause excessive noise. Lining with wood or some other soft material can ameliorate this condition.

In areas where much coal is burned, ash-impregnated refuse may be a problem because of the dust generated. The same could be true if street sweepings are part of the refuse.

Chemical Aspects

Carbon-Nitrogen Relationship. The rate at which organic matter decomposes is determined principally by the relative amounts of carbon and nitrogen present. In living organisms, the ratio is about 30 to 1 and, theoretically, this should be the optimum ratio in municipal refuse also.[11] In actual practice, however, it is much higher. Composting, nevertheless, can successfully create a product suitable for agricultural use, since it is pathogen- and nuisance-free and is produced in a reasonable length of time from refuse having initial carbon-to-nitrogen ratios ranging from 21 to 78.[64]

As composting proceeds, the causative organisms use the carbon for energy and the nitrogen for cell building. The C/N becomes smaller with time, since the nitrogen remains in the system while the carbon is released as carbon dioxide.

If fresh or insufficiently decomposed compost, with high carbon and low nitrogen values, is applied to soil, the continuing microbial activity could, in theory, rob the soil of nitrogen if the ratio exceeds 20:1. In practice, however, a higher ratio can be tolerated if the carbon is not readily available to the organisms, i.e., is in the form of paper.[11,57]

Experience at Johnson City indicates that refuse with an initial ratio of between 39 and 49 will decompose in about six weeks into a compost with a ratio of between 28 and 35, a median reduction of 27 percent. The product is safe with respect to health, has a satisfactory appearance and odor, and is comparable to that produced by other plants and systems.[17] In preliminary experiments at Gainesville on refuse and refuse-sludge mixtures, the initial ratios generally ranged from 57 to 68. After digestion, the span was 54 to 59, a 6 to 14 percent reduction.[18]

<u>Composition of Compost.</u> The composition of compost varies widely, and data have been collected on the values of certain constituents observed at Johnson City (Table 5). Carbon, nitrogen, phosphorus, potassium, sodium, and calcium occur mostly in a combined form; iron and aluminum, and possibly magnesium and copper, are present primarily as uncombined metals. The values found for nitrogen, phosphorus, potassium, calcium, and percent ash correspond to those found by investigators of other composts.[65]

TABLE 5

ELEMENTS IN 42-DAY-OLD COMPOST AT JOHNSON CITY

Element	Percent dry weight (average)		Range (all samples)
	Containing sludge (3%-5%)	Without sludge	
Carbon	33.07	32.89	26.23 - 37.53
Nitrogen	0.94	0.91	0.85 - 1.07
Potassium	0.28	0.33	0.25 - 0.40
Sodium	0.42	0.41	0.36 - 0.51
Calcium	1.41	1.91	0.75 - 3.11
Phosphorus	0.28	0.22	0.20 - 0.34
Magnesium	1.56	1.92	0.83 - 2.52
Iron	1.07	1.10	0.55 - 1.68
Aluminum	1.19	1.15	0.32 - 2.67
Copper	<0.05	<0.03	
Manganese	<0.05	<0.05	
Nickel	<0.01	<0.01	
Zinc	<0.005	<0.005	
Boron	<0.0005	<0.0005	
Mercury	not detected	not detected	
Lead	not detected	not detected	

Gotaas has reported that the organic content of compost is between 25 and 50 percent by dry weight[11]; at Johnson City, it has been 60 to 70 percent for finished compost.[17]

Compost is not a fertilizer but is comparable to a good topsoil because of its nitrogen, phosphorus, and potassium content. Since it has a high organic content, it helps to provide good tilth, water-holding capacity, and nutrient-retaining capacity when mixed with poor soils.

Although such elements as iron and aluminum occur in relatively high amounts, they are present as metals and metal oxides and should not pose any problems. Aluminum is a major constituent of most soils, and causes difficulties only in very acid soils, those with a pH well below 5.0.

As is the case with fertilizers, liming agents, and other materials placed on the soil, consideration should be given to the effects of soluble salts present in compost and drainage must be provided so that they do not accumulate in the soil.

Moisture in Composting. To achieve the greatest decomposition, the water content of compost should be maintained at 50 to 60 percent by wet weight, and aeration should be provided. As water is added, the compost becomes more compact and this reduces the amount of air present. Anaerobic conditions then arise and objectionable odors are created. If too much water is introduced, the material becomes difficult to handle and to dry for finishing. On the other hand, if the mositure content falls below 50 percent, high temperatures are achieved in the center of the mass and it gives off few odors, but the rate of decomposition slows.

Composting Temperatures. Temperature readings made in a composting mass may indicate the amount of biochemical activity taking place. A drop in temperature could mean that the material needs to be aerated or moistened or that decomposition is in a late stage.

It has been noted that the windrowing method produces a typical temperature profile. Temperatures between 150F and 160F (66C to 71C) are easily reached and maintained for about 10 days (Figure 5). Temperatures between 140F and 150F (60C to 66C) can be kept for about three weeks. Temperatures of up to 170F (77C) have been observed in the center of a composting mass. Time-temperature relations are important in freeing the compost of pathogens.[17] At Johnson City, it has been found that a single weekly temperature reading will help determine if composting is progressing normally and that temperatures necessary to destroy pathogens are being maintained.[17]

At Gainesville, the compost has sometimes reached 180F (82C) on the sixth day of composting in open-tank digesters. Forced aeration is used at this plant, but agitation is provided only intermittently or not at all.[18]

On the Fairfield-Hardy digester at Altoona, Pennsylvania, temperatures between 140F and 160F (60C and 71C) are normally attained and occasionally rise to 176F (79C). In this enclosed system, the composting material is continually agitated for 7 to 9 days; forced aeration is used.

Composting pH. The initial pH of refuse at Johnson City is usually between 5 and 7 unless a large amount of alkaline material is present.

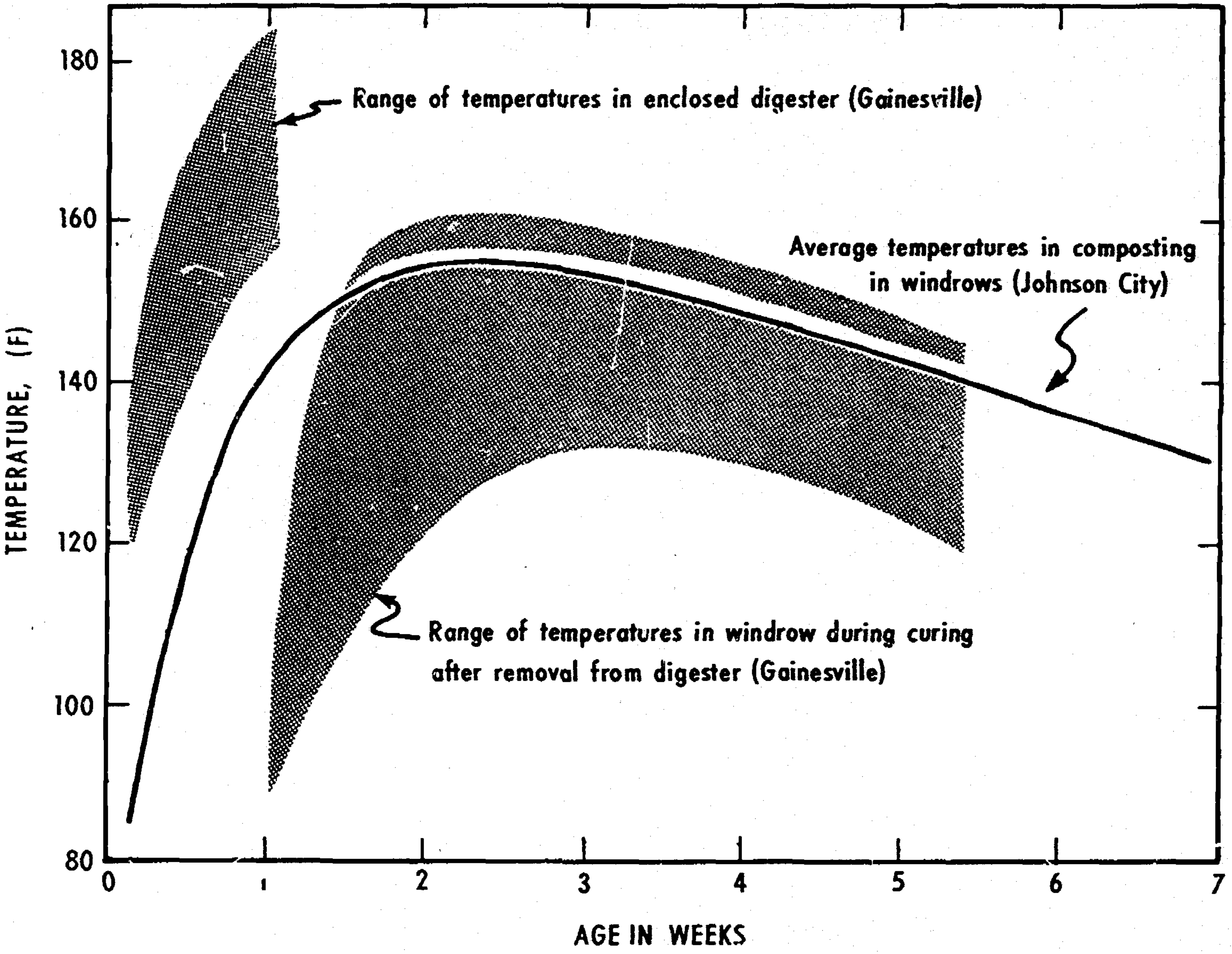

Figure 5. Typical and comparative temperature profiles obtained from composting municipal refuse indicate that temperatures in excess of 140F are easily attained during aerobic composting.

On an average, the refuse is at least three days old when it arrives. The pH drops to 5 or below in the first two to three days of composting and then begins to rise; it usually levels off at about 8.5 and remains there as long as aerobic conditions are maintained (Figure 6). If the compost becomes anaerobic, as it does when stored in deep piles at Gainesville, the pH drops to about 4.5.[18]

Ordinarily, pH is not used for process control, but if an operator knows the normal pattern it follows, he may be alerted to the presence of unusual substances if differences are noted.

Microbiological Aspects

General. Composting as a microbiological process is the conversion of biodegradable organic matter to a stable humus by indigenous flora, including bacteria, fungi, and actinomycetes, which are widely distributed in nature. In composting, however, such selective factors as moisture content, oxygen availability, pH, temperature, and the carbon/nitrogen ratio determine the prevalence and succession of microbial populations. As Waksman, Cordon, and Hulpoi have pointed out in extensive studies on the aerobic composting of manure and other organic matter, a variety of microorganisms has a number of specific functions, all of which are interrelated in the total process.[66] During the course of composting, both qualitative and quantitative changes occur in the active microflora; some species multiply rapidly at first, change the environment, and then disappear to allow other populations to succeed them.

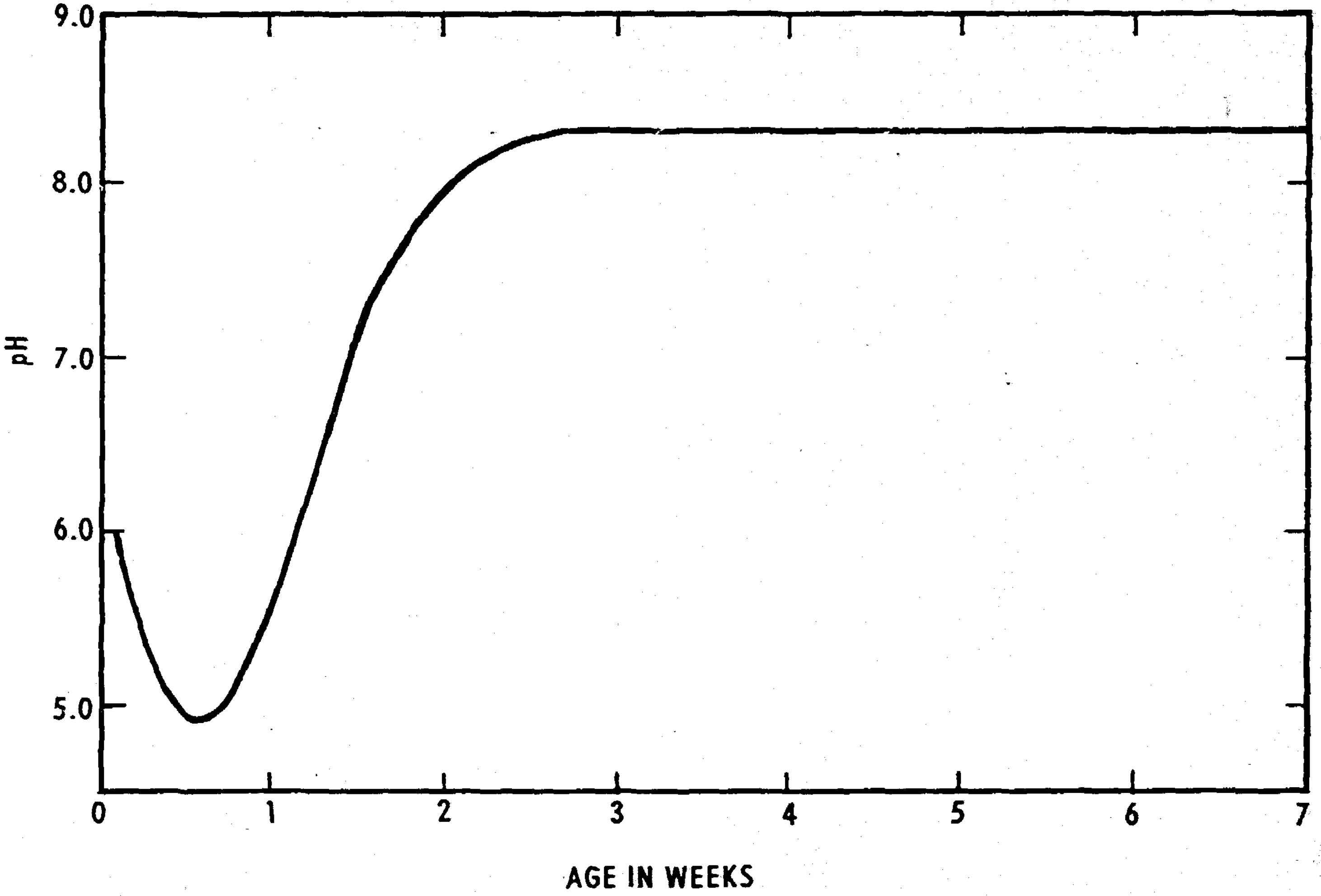

Figure 6. A typical pH profile obtained in windrow composting proceeds from an initial acidic condition within the first week to become rather alkaline.

When composting begins, the mesophilic flora (microorganisms able to grow in the 77F to 113F (25C to 45C) temperature range) predominate and are responsible for most of the metabolic activity that occurs. This increases the temperature of the composting materials, and the mesophilic populations are replaced by thermophilic species, those that thrive at temperatures about 113F (45C). This rise in temperature is influenced to a great extent by oxygen availability. When municipal refuse is composted at Johnson City, for example, windrows kept for the most part aerobic reach temperatures up to 167F (75C) and produce few objectionable odors. When a windrow is allowed to become anaerobic through lack of turning, however, the temperature peaks at about 130F (55C) and drops much lower after the first two weeks of composting.

Even though composting materials usually contain a wide range of active flora, many attempts have been made to develop an inoculum of microorganisms that would speed the decomposition process. Their use has, however, usually proved to be of little value.[11] Nevertheless, it would seem worthwhile to study the merit of adding nitrogen, phosphorus, or other elements to supply essential nutrients for the active flora in the composting of straw, paper, and other materials that, alone, are nutritionally unbalanced.[67,68] The key to successful composting in the United States may well depend on acquiring the ability to degrade the increasingly high concentrations of cellulose found in solid wastes.[57] Advances in this area appear to depend on the gathering of more knowledge about the functions of specific flora in the composting process, a field in which relatively little research has been done.

Pathogen Survival in Composting. Studies conducted at Johnson City and by Morgan and MacDonald indicate that properly managed windrow composting turns out a product that is safe for agricultural and gardening use.[17,69] Proper management consists of keeping the moisture content at between 50 and 60 percent by wet weight, maintaining aerobic conditions by turning the material periodically, and assuring that the windrows are throughly mixed.

Specifically, investigations made at Johnson City in conjunction with East Tennessee State University showed that:

1. Pathogenic bacteria that may be associated with sewage sludge and municipal refuse were destroyed by the composting process after being inserted into windrows;
2. There was a consistent, inverse relationship between the number of total and fecal coliforms in the compost and the windrow temperatures recorded. A heat range of 120F to 130F was sufficient to reduce the coliform populations significantly, often to a level at which they could not be detected by the Most Probable Numbers Method. Significant numbers of coliforms reappeared, however, when the temperature dropped during the last stages of the composting process.
3. *M. tuberculosis* was normally destroyed by the 14th day of composting if the temperature had averaged 149F (65C). In all cases, the organisms were destroyed by the 21st day.
4. Composting that attains a temperature range of 130F or higher for as little as 30 minutes also deactivates the polio virus.

5. There are no references in the literature to any sanitation workers having been infected by fungi as a result of handling solid wastes. This suggests that there should be no restrictions put on the use of compost.

No extensive studies regarding pathogen survival in mechanical composting systems in the United States have been completed, but there are indications that the product is safe to use if it has been properly mixed in a mechanical digester-composter and then cured.

CHAPTER IV

ECONOMIC CONSIDERATIONS

Composting in the United States has not been looked upon as a method of waste disposal but as a business; as such, it has had an unsuccessful history. Considering it as a disposal method, the expectation of a profit or an income to balance the cost adds a burden not imposed upon landfilling or incineration. Thus, one deterrent to more widespread development of composting as a means of municipal solid waste treatment in this country has been this widely advanced premise that composting must produce a profit, or at least pay its own way. No other method of waste disposal or treatment is expected to accomplish such a goal.

In the last 20 years, the technology of composting municipal refuse has been investigated rather intensively, and there is the knowledge and equipment to enable engineers to design mechanized compost plants and to produce compost. Although corresponding information on costs is much less satisfactory, it has become increasingly apparent that composting is not an inexpensive method of refuse treatment.

This chapter considers the monetary aspects of composting. Further research in the use of compost in agriculture and land management may help to furnish a gauge by which to measure economic benefits not now quantified. Elements of the cost of disposal by composting, expressed as a gross cost per ton for processing raw refuse, and the credits that may accrue from salvage, the sale of compost, and other considerations are discussed.

A reader attempting to discover the cost of composting is confronted with an array of costs ranging from about $2.50 to $20.00 per ton of refuse processed.[70,71] Cost figures for individual plants are available but variations in size, methods of operation, plant complement and wage scales, number of shifts, accounting systems, financing details, land costs, and final disposal make comparisons almost impossible. Until recently, the principal source of such information was Europe. To apply costs developed in Europe or elsewhere to composting in the United States is even more difficult. Because of this lack of reliable cost data on the construction and true operating costs of composting plants in general, the major portion of the information that follows is based on observations of the U.S. Public Health Service--TVA Composting Project, Johnson City, Tennessee, although it is limited to the general conclusions and aspects of costs as derived from these observations.

Capital Cost

Windrowing Plants. Estimates of the capital costs for various capacity windrow composting plants, based on the actual costs encountered for the Johnson City composting plant, range from $16,560 per ton of daily capacity for a 50-ton-per-day plant to $5,460 per ton of daily capacity for a 200-ton-per-day plant on a two-shift operation (Table 6.) The estimates of the total yearly capital investments for these

TABLE 6

ESTIMATED CAPITAL COSTS FOR WINDROW COMPOSTING PLANTS

Item of cost	Daily plant capacity in tons per day (T/D)				
	52 T/D (Johnson City Plant - 1 shift)*	50 T/D (1 shift)†	100 T/D (50 T/D 2 shifts)‡	100 T/D (1 shift)‡	200 T/D (100 T/D 2 shifts)‡
Buildings	$368,338	$210,000	$231,000	$231,000	$251,000
Equipment	463,251	482,700	482,700	607,100	607,100
Site Improvement§	126,786	126,800	126,800	152,000	152,000
Land cost¶	7,600	8,400	12,400	12,400	21,200
Total cost	$965,980	$827,900	$852,900	$1,002,500	$1,031,300
Total cost per ton daily capacity	$18,580	$16,560	$8,530	$10,020	$5,156

*Actual cost of the research and development PHS-TVA Composting Plant at Johnson City, Tennessee.

†Based on Johnson City cost data adjusted for building and equipment modifications.

‡Estimates based on actual Johnson City cost data projected to the larger daily capacity plants.

§Includes preparation of composting field with crushed stone and needed utility lines.

¶Land costs are estimated based on approximate land values near Johnson City, Tennessee, of $800 per acre.

plants on the basis of cost-per-ton-of-refuse-processed, range from $6.15 for the 50-ton-per-day plant to $2.01 for the 200-ton-per-day plant on two shifts.

The actual initial capital costs for the USPHS-TVA Composting Plant were $18,580 per ton daily capacity (Table 7). On a per-ton-refuse processed basis, the yearly capital investment cost is $12.98 (at 34 tons per day in 1968). Operated at the design capacity of 52-tons-per-day, the yearly capital investment cost would have been $6.88 per-ton-refuse processed.

The capital cost of $965,980 for the Johnson City plant is subject to some qualifications. A high proportion (38 percent of plant cost) is in buildings, partly because of the multi-story design with equipment installed on the second- and third-floor levels. More ground-level floor space and simpler framing, as used in common mill buildings, with installation of machinery independently of the structure would have permitted a less expensive structure. Similar reductions were used in the cost projections for the other plants. A case in point is the 150-ton-per-day plant at Gainesville, Florida, where the cost of the building, estimated at $150,000, is approximately 11 percent of the total plant investment.

These cost estimates include equipment for processing sewage sludge from the population generating the refuse. Since these composting plants include sludge processing equipment, caution must be exercised; costs developed here cannot be directly compared with capital costs of landfills or incinerators that do not include equipment for sludge processing.

TABLE 7

ESTIMATED INVESTMENT COSTS FOR WINDROW COMPOSTING PLANTS (1969)

Item of cost	Plant capacity in tons per day (T/D)				
	52 T/D (Johnson City, 1 shift, 7,164 tons, 1968)*	50 T/D (1 shift, 13,000 T/year)†	100 T/D (2 shifts, 26,000 T/year)†	100 T/D (1 shift, 26,000 T/year)†	200 T/D (2 shifts, 52,000 T/year)†
Construction	$958,380	$819,500	$840,500	$989,100	$1,071,100
Land costs	7,600	8,400	12,400	12,400	21,200
Total	$965,980	$827,900	$852,900	$1,001,500	$1,092,300
Depreciation/year‡	$47,920	$41,000	$42,000	$49,500	$53,550
Interest/year§	45,080	38,600	39,800	46,200	51,000
Cost per ton daily capacity	18,580	15,560	8,530	10,020	5,460
Cost per ton refuse processed	12.98 (6.88)¶	6.12 (5.38)#	3.15 (2.76)#	3.68 (3.28)#	2.01 (1.73)#

*Actual costs of plant as built at Johnson City. Plant operates on 1-shift day. Cost per ton based on 1968 level of 7,164 tons of refuse processed.

†Based on Johnson City plant cost data adjusted for less elaborate equipment, buildings, and modifications.

‡Straight line depreciation over 20 years of buildings and equipment, excluding land.

§Bank financing at 7½ percent over 20 years. Yearly figure is average of 20-year total interest charge. Land cost included.

¶Cost of Johnson City plant adjusted to design capacity of 13,520 tons refuse processed per year.

#Estimated cost without sludge processing equipment.

Enclosed Digestion Plants. Enclosed digestion plants are similar to windrowing plants with respect to receiving, sorting, grinding, adding sewage sludge, final grinding and screening, curing, and storage. Plants of both types require area for the storage of compost for curing and stockpiling. Seasonal use of compost makes stockpiling necessary. The estimates for the windrow plants include land for storage, in rectangular piles 15 feet high, of 6 months' production. Land required for the composting area is also important. Land costs used in the estimates were $800 per acre; this figure is consistent with land values near the Johnson City plant. By way of comparison, land near the Gainesville plant costs about $4,000 per acre.

Comparing the capital costs per-ton-refuse-processed for the digestion systems of a 150-ton-per-day windrowing plant with those of an enclosed type plant, shows that, although the windrowing plant requires more land, capital cost per ton processed will be less for a reasonable range of land prices. Many of the other costs associated with these plants would be similar (Table 8).

Other Countries. Capital costs reported in 1965 for European plants vary from $0.76 to $1.91 per ton of raw refuse processed using the windrow methods. For enclosed systems, the range was $1.18 to $3.98.[44]

It must be noted again that it is difficult to compare plant costs because of such factors as variations in size, type, and operation. Comparisons with foreign plants are even more difficult. The complexity of construction will, of course, influence costs. In warm climates, heating of buildings may not be necessary. For windrowing plants, the

TABLE 8

ESTIMATED INVESTMENT COSTS FOR COMPOSTING PLANTS
(Windrowing and Enclosed Digestion Systems)

Item of cost	150-ton/day capacity	
	Windrowing	Enclosed
Construction and equipment	\$185,500.00*	\$300,800.00†
Depreciation‡	9,280.00	15,040.00
Interest (7½%)§	8,660.00	14,040.00
Capital cost per ton daily capacity	1,237.00	2,005.00
Total cost per ton refuse processed	0.46	0.75
Land	9,300.00	2,640.00
Interest (7½%)	430.00	120.00
Cost per ton daily capacity	62.00	18.00
Cost per ton of refuse processed¶	0.01	<0.01 (.003)
Total cost		
Per ton of daily capacity	1,300.00 (1,550.00)#	2,023.00
Per ton of refuse processed	0.47 (0.52)#	0.75

*Based on costs from PHS-TVA Composting Plant at Johnson City, Tennessee, and land at \$800 per acre.

†Based on costs from composting plant at Gainesville, Florida, and land at \$4,000 per acre.

‡Straight line depreciation of equipment and buildings over 20 years.

§Average yearly interest, bank financing over 20 years.

¶Computed from interest only; land is assumed not to depreciate.

#Computed with comparable land values estimated at \$4,000 per acre.

size and spacing of the windrows will influence land requirements. In wet periods and in humid climates, mechanical dryers may have to be installed.

Operating Costs

Windrowing Plants. Estimates of the yearly per-ton-of-refuse-processed operating cost for windrow plants of varying capacities, again made by projecting the actual costs encountered in operating the composting plant in Johnson City, ranged from \$13.65 for the 50-ton-per-day plant to \$8.70 for the 200-ton-per-day plant on a two-shift operation (Table 9).

Actual costs for operating the Johnson City composting plant in 1968 were \$18.45 per ton of refuse processed (Table 10). The nature of the research conducted there and the inability of the Johnson City municipality to deliver enough refuse for operation at full-plant capacity are some of the reasons for the seemingly high cost. A cost of \$13.40 per ton of refuse processed was projected for operating this plant at full-design capacity (52 tons per day) in 1969, with some modifications for the research work being conducted. Labor expenses for 1968 amounted to about 75 percent of the operating costs. In 1969, they accounted for approximately 78 percent.

Up to 30 percent of the refuse delivered to a compost plant is non-compostable. If salvaging is not practiced, all of this material should be disposed of in a sanitary landfill. An estimated cost of from \$.50 to \$1.00 per ton of refuse processed must then be added to operational

TABLE 9

ESTIMATED YEARLY OPERATING COSTS FOR VARIOUS CAPACITY WINDROW COMPOSTING PLANTS

Plant capacity (tons of refuse processed/ day) (T/D)	Number of shifts	Plant operating costs ($)			Operating costs per ton refuse processed ($/ton)
		Operations	Maintenance	Total	
52 T/D 1968 Johnson City (7,164)*	1	$99,575 (139,817)†	$32,590 (41,200)†	$132,165 (181,017)†	$18.45 (13.40)†
50 T/D (13,000)‡	1	133,950	43,700	177,650	13.65
100 T/D (26,000)‡	2	213,795	59,150	272,945	10.50
100 T/D (26,000)‡	1	197,850	59,850	257,700	9.90
200 T/D (52,000)‡	2	357,015	95,400	452,415	8.70

*Figure in parentheses is total tons of raw refuse processed in 260-day work year.

†Costs projected for operating USPHS-TVA composting plant at design capacity of 52 tons per day (13,520 T/year) in 1969.

‡Estimated costs based on USPHS-TVA composting project operating cost data.

TABLE 10

ACTUAL COST OF OPERATIONS FOR THE USPHS-TVA COMPOSTING PLANT (1968)*
(7,164 tons processed in 210 days)

Activities	Operations								Maintenance						
	Salaries and benefits	Supervision	Electric power	Utilities (excluding electricity)	Truck use	Supplies and materials	Miscellaneous	Total	Salaries and benefits	Supervision	Supplies and materials	Repairs	Miscellaneous	Total	Total
Receiving*	$6,905	$1,181	$59			$28		$8,173	$974	$250	$661	$480		$2,365	$10,538
Picking and sorting	8,116	1,388	17			319		9,840	305	78	30			413	10,253
Disposal of rejects†	7,351	1,258			$3,524	38		12,171	620	159	56			835	13,006
Grinding (rasper)	3,211	549	770					4,530	2,134	548	2,925			5,607	10,137
(hammermill)	39	7	17					63	231	59				290	353
Composting															
Hauling and handling	5,930	1,015	28		5,764	327	$50	13,114	3,073	789	677	140		4,679	17,793
Turning and wetting	4,615	790				291	21	5,717	2,342	600	1,548	783		5,273	10,990
Curing	982	168			224	9		1,383	45	12		15		72	1,455
Storage	2,477	424			577		48	3,526							3,526
Operation and maintenance Grounds, buildings, and utilities			1,165					1,165	4,506	1,156	509		$68	6,239	7,404
Cleanup of process and receiving buildings	9,556	1,635				123		11,314							11,314
Office and laboratory	6,123	1,048	378	$614		800	144	9,107							9,107
Other	1,712	293		134	1,044	4,519	624	8,326							8,326
Regrinding and screening	4,293	734	130		1,230			6,387	846	217			409	1,472	7,859
Sewage sludge processing	3,350	573	54			782		4,759	2,970	762	1,395	218		5,345	10,104
Total	64,660	11,063	2,618	748	12,363	7,236	887	99,575	18,046	4,630	7,801	1,636	477	32,590	132,165

*At plant site.
†Includes cost of haulage to landfill (no landfilling costs).

costs. If the compost must be eventually disposed of in a landfill, the additional cost per ton of refuse processed may reach $0.50.

High-Rate Digestion Plants. Operating cost data for many of the high-rate digestion plants is incomplete, adding to the difficulty in comparing costs. Yearly operating costs per ton of refuse processed for the Gainesville plant were $7.56 for 157 tons per day and $6.94 for 346 tons per day.[18] Operating costs for some European plants have ranged from about $1.51 to $2.76 per ton of refuse processed.[44]

Total Cost of Composting. The estimated total costs per ton of refuse processed for various composting plants ranged from $3.85 to $20.65 (Table 11). The range for windrowing plants, estimated from data obtained from the USPHS-TVA project, however, was from $11.23 for a 200-ton-per-day plant to $20.65 for the 50-ton-per-day plant. The total cost for the high-rate digestion plant at Gainesville was estimated at $10.53 per ton of refuse processed at 157 tons per day and $8.58 per ton of refuse processed at 346 tons per day.

The $32.31 per ton cost of composting municipal refuse at the USPHS-TVA composting plant (Table 12) is subject to the qualifications as stated in the discussion of its capital and operating costs. The projected cost of $21.16 per ton of refuse processed at full operating capacity is also subject to the same general qualifications.

Partial Recovery of Costs

The cost of composting municipal refuse may be reduced in several ways. Direct returns are possible if compost and salvageable material

TABLE 11

SUMMARY OF TOTAL COSTS FOR COMPOSTING PLANTS*

Capacity (tons/day)	Number of shifts	Type plant†	Capital cost (per ton/day)	Cost per ton refuse processed		
				Capital	Operating‡	Total
50	1	W	16,560	6.12	14.53	20.65§
100	1	W	10,000	3.68	10.62	14.30§
100	2	W	8,530	3.15	11.22	14.37§
100	1	HR	5,400[70]	1.66	-	-
157	1	HR	8,830	2.97	7.56	10.53¶
200	1	HR	4,800[70]	1.48	-	-
200	2	W	5,460	2.01	9.22	11.23§
300	1	HR	8,600[72]	2.76	-	-
300	?	W	5,000[72]	1.53	5.00	6.53#
300	1	HR	5,000[73]	1.45	2.40	3.85
300	1	HR	4,500[70]	1.38	5.12	6.50
346	2	HR	4,420	1.64	6.94	8.58**

*Cost data provided for plants other than Johnson City and Gainesville, were used without adjusting to current economic conditions.

†W, windrowing; HR, enclosed high-rate digestion.

‡In the case of the 50-, 100-, and 200-tons-per-day windrowing plants, an estimated cost of $0.88, $0.72 and $0.52 per ton of refuse received has been included for landfilling rejects.

§Projected from Johnson City composting project data, at 26,000 tons per year per 100 tons per day capacity (260 days), straightline depreciation of equipment and buildings over 20 years. Bank financing at 7½ percent for 20 years. Includes disposal of rejects into landfill.

¶Actual data from Gainesville plant with interest at 7½ percent over 20 years, at 45,000 tons per year (286 workdays). Includes sludge handling equipment and disposal of noncompostables remaining after paper salvage.

#Actual data from Mobile, Alabama, composting plant. Components of costs not known.[44]

**Gainesville plant at 90,000 tons processed per year.

are sold. An indirect benefit may derive from processing sewage sludge with the refuse and disposing of it as a component of the compost.

TABLE 12

ACTUAL COSTS FOR USPHS-TVA COMPOSTING PLANT, JOHNSON CITY, TENNESSEE*

Tons per day	Capital cost-per-ton daily capacity	Cost per ton refuse processed		
		Capital	Operating†	Total
34 (7,164 tons/year)‡	18,580	$12.98	$19.33	$32.31
52 (13,520 tons/year)§	18,580	$6.88	$14.28	$21.16

*Based on actual costs of Johnson City composting plant with 7-1/2 percent bank financing over 20 years. Equipment and buildings depreciated over 20 years (straight line). Operating costs based on actual costs for calendar year 1968.

†Includes costs for landfilling rejects.

‡Actual processing for 1968 operations.

§Operations projected to full capacity.

Compost Sales. The price at which compost can be sold depends on the benefits to be obtained from its use and what customers are willing to pay for such benefits, which have yet to be accurately ascertained. One source estimated a benefit value of $4.00 per ton of compost for the first-year application on corn.[74] In this case, the value of the benefit might pay only for hauling. However, corn is a relatively low-priced crop, and the compost may have more value in other uses. Benefits from using compost over a number of years and residual benefits over a period of time from one application may increase its value. TVA is conducting studies on the use of compost to help answer some of the questions relating to its value.

Compost has been sold for horticultural use, and viniculture may offer a market in some areas. Conditioning or improving the product by screening, pelletizing, bagging, and providing well-planned sales promotion and distribution may result in a greater gross return. Compost may also be sold in bulk, finished or unfinished, as well as fortified with chemical fertilizers.

The University of California estimated in 1953 that farmers would pay from $10 to $15 per ton[71]; in fact, they showed little interest. A plant in San Fernando, California, sold compost in 1964 at $10 per ton.[75] Other sources estimated a bulk selling price of $6.00 per ton in 1967.[70,72] In 1968, a St. Petersburg plant attempted to sell compost for commercial agriculture at $9.00 per ton. The Lone Star Organics Company, Houston, Texas, was reported by one source to have sold compost at $12.00 per ton and at $6.00 per ton by another source.[72] The Gainesville plant has sold compost for about $7.00 per ton. This was for a ground, unfortified, unpelletized product.

Altoona FAM, Altoona, Pennsylvania, sold a pelletized product in 1966-67 for $16.50 per ton (bulk basis) and $42.50 per ton in 40-pound bags. In the 1967-68 season, orders were taken at $20.50 per ton in bulk.[72]

Because of the prices that might be obtained from the luxury gardening market, a few favored municipalities may expect to operate a self-supporting compost plant. Note, however, that the markets being promoted for existing plants include areas with distances up to 1,000 or more miles, indicating a diffuse, low-level demand at this time. Also, the price obtained must absorb costs of final conditioning and marketing. Possibly, $3 to $7 could be obtained at the plant for compost in bulk. Since the yield of compost (30 percent moisture) is about 50 percent of incoming refuse, the revenue from sales would be approximately $1.50 to $3.50 per ton of raw refuse processed. Although this income is used for discussion, the possibility must be considered that all or part of the compost cannot always be sold.

Sale of Salvaged Materials. The income from salvaging depends on the cost of salvaging operations, the volume of salable materials, and the prices paid for the recovered materials. There may, however, be no market for salvaged materials in some localities. One source has stated that salvage can be practiced to at least the break-even point if a 300-ton-per-day capacity plant is located near an industrial city.[73]

Materials most easily salvaged for which a market often exists are paper, metals, rags, and glass. There may develop a market for some type of plastics. Actual data on the income possible from salvaging are few. The plant at Gainesville is equipped to salvage and market paper and metals. In 1968, paper was sold at $15 to $20 per ton. Shredded cans at destination could have been sold for $20 a ton, but shipping charges made this impractical. Although few rags were salvaged, they brought $18 per ton at the plant, baled. Projections for this plant have shown an expected net income from salvaged paper of $1.50 per ton of refuse processed.

A feasibility study for a 300-ton-capacity composting plant in Michigan assumed that paper would be salvaged in the amount of 15 percent; metal and cans, 9 percent; and glass, 10 percent of incoming refuse.

Paper was assumed to be salable at $10 to $15 a ton, metal and cans at $8 to $12 a ton, and glass at $8 to $10 a ton. The estimated income from the salvage of each category was $1.80, $0.90, and $0.80, respectively, per ton of refuse received, totaling $3.50.[72]

The price of paper, for which there is the greatest market, can fall to as little as $5 per ton. At these times, such plants as the Gainesville installation and the hypothetical one mentioned above would obtain an income from paper of only $0.40 to $0.75 per ton of refuse received. According to one source, the total to be expected from salvaging without sophisticated equipment might be in the range of $1 to $2 per ton of refuse received.[70]

Composting Sewage Sludge With Refuse. A composting plant may be operated to obviate part of the cost of handling the sewage sludge received from the population it serves. For a 200-ton-per-day plant processing all of the sludge from the population generating the refuse, the estimated savings could range from 0 to $35 per ton of sludge solids, depending on degree of treatment. Based on this estimate, the credit to composting would be from 0 to $1 per ton of refuse processed. These estimates are based on data from the windrowing plant at Johnson City. Savings might be greater for plants using high-rate enclosed digesting systems.

Composting and Landfill Operations. There is interest in reducing landfill requirements by grinding and composting refuse prior to depositing into the fill. The crushing of cans and bottles, the reduction in size of other noncompostables, and the reduction of the volume of organic material by digestion will reduce the volume of the refuse. The digestion results in a less noxious material, less gas production in the fill, and possibly less subsidence. The compost is less attractive to rodents and insects and its appearance is more acceptable to most people. Less cover will be needed as it may be applied only to prevent a fire hazard and to keep small pieces of plastic film, shards of glass, and bits of metal from showing, as compost for landfilling would not be finished to remove these.

It has been stated that with good compaction, the landfill volume required will be about half that required for well compacted, unground refuse. More work will be required in this area on the compactibility of compost. Organic materials tend to be springy on compaction.

Landfill sites are becoming scarcer near urban centers especially due to the resistance of citizenry to such operations. When sites are found at greater distances the same difficulty is often experienced where people do not want the city's refuse disposed of in their area. Composting may offer a solution in some cases. The reduction in volume can result in savings in handling costs, and sites nearer to cities may be tolerated where predigested material is deposited.

It would thus appear that composting may effect savings where hauls are long, but will not provide savings in land costs unless they are very high. Where the availability of land is the problem and not the cost, composting could extend the life of landfills. Well digested, but unfinished compost could be used for fills in many places in a community and the unused product could be put into landfills. The recovery of salvageable materials would reduce the volume of material to be composted and to be disposed of by landfill.

Net Cost of Composting

Estimates of the net cost of composting municipal refuse have been developed (Table 13). Although the costs for processing sewage sludge have been included, no credit was given to the composting plant for savings which might be realized by not processing the sewage at a sewage treatment plant.

The net costs estimated for the windrowing plants range from $18.65 (per ton of refuse processed) for the 50 ton-per-day plant to about $7.73 (per ton of refuse processed) for the 200 ton-per-day plant on two shifts. Net costs for the high-rate plant at Gainesville, Florida, were estimated at $6.90 (per ton of refuse processed) at 157 tons per day to about $3.45 (per ton of refuse processed) at 346 tons per day (Table 13).

Composting Costs Compared with Sanitary Landfilling and Incineration. Even with an income from compost and, in some cases, from salvage sales, most composting plants show a deficit or an expected deficit. Based entirely on economic considerations, most composting plants would not, at this time, be able to compete with sanitary landfilling as a refuse treatment method.

As with compost plants, the operating costs reported for incinerators vary greatly, due to the same factors that cause differences in composting costs, land values, labor costs, residual disposal, etc. For incinerators constructed after 1950, averaging a daily input of 375 tons, the operating

TABLE 13

ESTIMATED NET COSTS OF COMPOSTING (DOLLARS)

Plant capacity (tons/day)	Type of plant*	Number of shifts	Total cost per ton refuse processed†	Estimated potential income per ton processed		Estimated net cost per ton refuse processed‡
				Compost sales	Salvage sales	
50§	W	1	$20.65	$2.00–$3.50	-	$17.15–$18.65
100§	W	1	14.30	2.00– 3.50	-	10.87– 12.30
100§	W	2	14.37	2.00– 3.50	-	10.94– 12.37
157¶	HR	1	10.53	2.00– 3.50	1.63	5.40– 6.90
200§	W	2	11.23	2.00– 3.50	-	7.73– 9.23
300#	HR	?	7.88	3.24	3.50	1.14
300**	W	?	4.03	-	-	-
300††	HR	9	3.85	3.00– 6.00	-	-
346‡‡	HR	2	8.58	2.00– 3.50	1.63	3.45– 4.95

*W, windrowing; HR, high-rate digestion, enclosed type.

†Estimated costs included sludge processing.

‡No credit has been estimated for handling sewage sludge.

§Estimated from 1968 data from the Johnson City composting project. Costs include depreciation, interest, land, and operations.

¶Projected costs for Gainesville plant at 39,000 tons per year.

#A hypothetical plant.[72]

**Based on data from Mobile, Alabama, plant[72]; all components of cost are not known.[44] There was no sludge processing.

††Reported costs do not include administration.[72,73]

‡‡Projected costs for operating Gainesville plant at 90,000 tons per year.

costs have been reported at $3.27 to $4.05 per ton.[76] A 168-ton-per-day incinerator reports a total cost of $6.40 per-ton-processed,[77] while a 300-ton plant is estimated at $5.20 per ton.

Investment costs of municipal incinerator plants are currently in the range of $7,500 to $10,000 per ton of capacity based on 24-hour operation.[78] The average for those in operation in 1968 was $7,100 per ton of capacity.[82]

Although references to incinerators with costs between $3,000 and $5,000 per ton of daily capacity can be found, those now being planned are more complicated and costly because of new or contemplated air pollution control measures. Costs to achieve these new criteria may have the effect of almost doubling the price for small incinerators and adding at least 30 percent to the cost of larger plants.[77] An 800-ton-per-day plant considered for Washington, D.C., was estimated at $4,500 to $5,400 per ton of daily capacity. The additional cost per ton for installing air pollution control equipment was $2,800 to $3,700.[79]

In comparing cost of compost plants to incinerators, note that a direct comparison is not correct for incinerators operating continuously for 24 hours, as most of the compost plants considered operate only on one 8-hour shift. Also, the composting plant cost includes sewage sludge processing equipment not included in incinerators.

Thus, although the capital costs for composting plants are greater than those for landfilling, they fall in the range expected for incinerators. Some compost plants in the 300-ton-per-day size range may equal some incinerator costs without the benefit of income from salvage and compost sales. At present, however, indications are that many will not. The 150- and 200-ton-per-day plants may compete economically with incineration if there is an assured market for compost and salvaged materials. Plants under 100-tons-per-day capacity appear uneconomical.

The accurate prediction of a market for compost and salvage materials and the intensive cultivation of this market is thus essential in determining the economic potential for a given compost plant and will help determine whether incineration is less expensive than composting for a given community.

Summary

This chapter considered primarily the economic factors in conjunction with composting. At this time, composting cannot compete economically with sanitary landfilling when the net costs are compared. However, the larger size plants fall into the cost range which may be expected for incinerators operating with appropriate air pollution abatement devices.

A burden has been placed on composting which has not been imposed on sanitary landfilling and incineration: a premise that composting must pay its own way. This has led to many compost plant failures and has probably deterred many municipalities from composting their refuse.

There are intangibles such as nuisance-free disposal associated with composting that have not been quantified. These intangibles, once quantified, may induce a community to compost even if the product must be disposed of by giving it away. If this becomes the circumstance, there may still be a benefit to the public of a kind which cannot be credited to other refuse disposal methods.

CHAPTER V

AGRICULTURAL AND HORTICULTURAL UTILIZATION OF MUNICIPAL COMPOST

Agricultural Productivity and Soil Erosion Control

An excellent review of plant and soil relationships and the results of studies on compost utilization are contained in a recent paper by Tietjen and Hart.[80] The following discussion of benefits and limitations of composting related to agricultural productivity and soil erosion control draws heavily upon that paper.

Plants can grow in almost any type of soil, but its fertility is closely related to the amount of organic matter it contains and particularly to the amount of nitrogen present. Organic matter includes humus, living plant roots, bacteria, fungi, earthworms, insects, etc. When a virgin soil is cultivated without being fertilized, its organic content and yield are reduced with time (Figure 7). High productivity can be maintained if manures or chemical fertilizers are applied in the amount and at the time the crop needs such nutrients. Over long periods, higher yields result from the use of combined chemical and manure fertilizations (Figure 8). This was confirmed over a 9-year period in which chemical fertilizers with compost added were applied to soils (Figure 9). Increased crop yields may, however, be obtained more economically if chemicals alone are added.

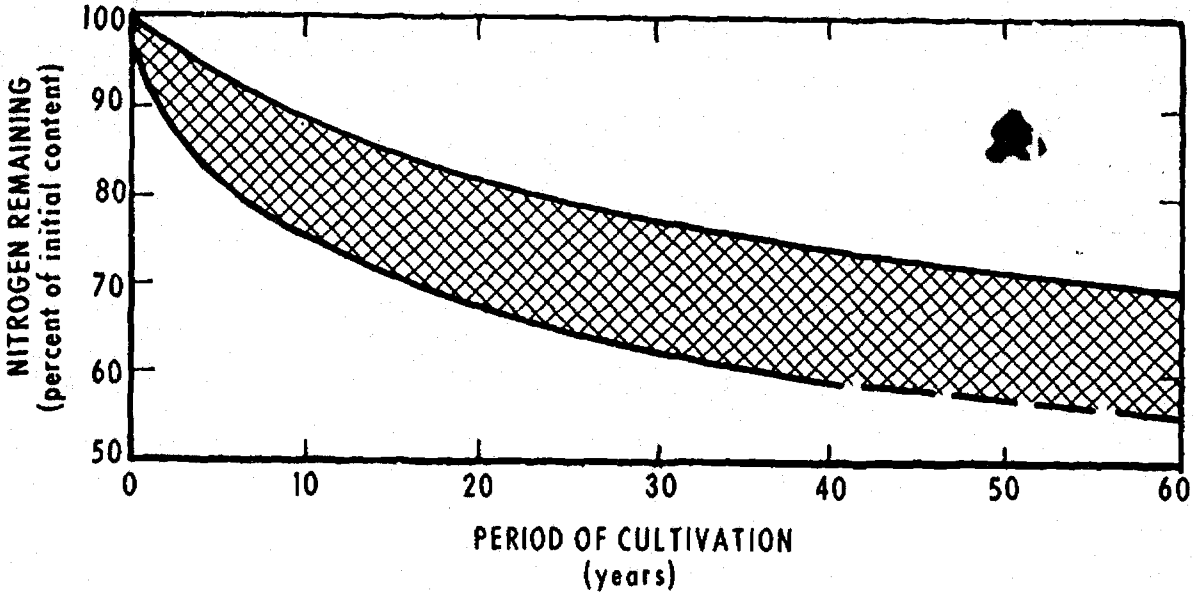

Figure 7. Effect of cultivation on nitrogen content of soil.[80,81] Soil repeatedly cultivated without fertilization for replenishment of nitrogen.

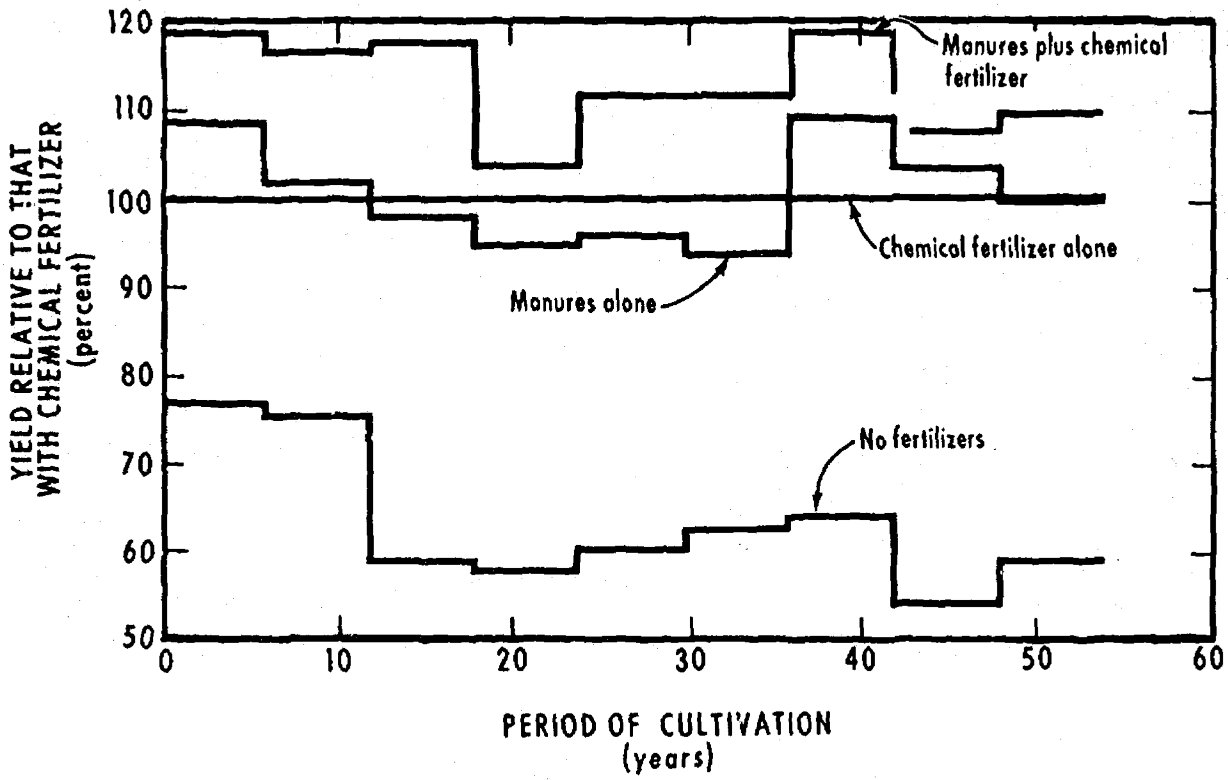

Figure 8. Relative yields of winter wheat with different fertilizer treatments.[80]

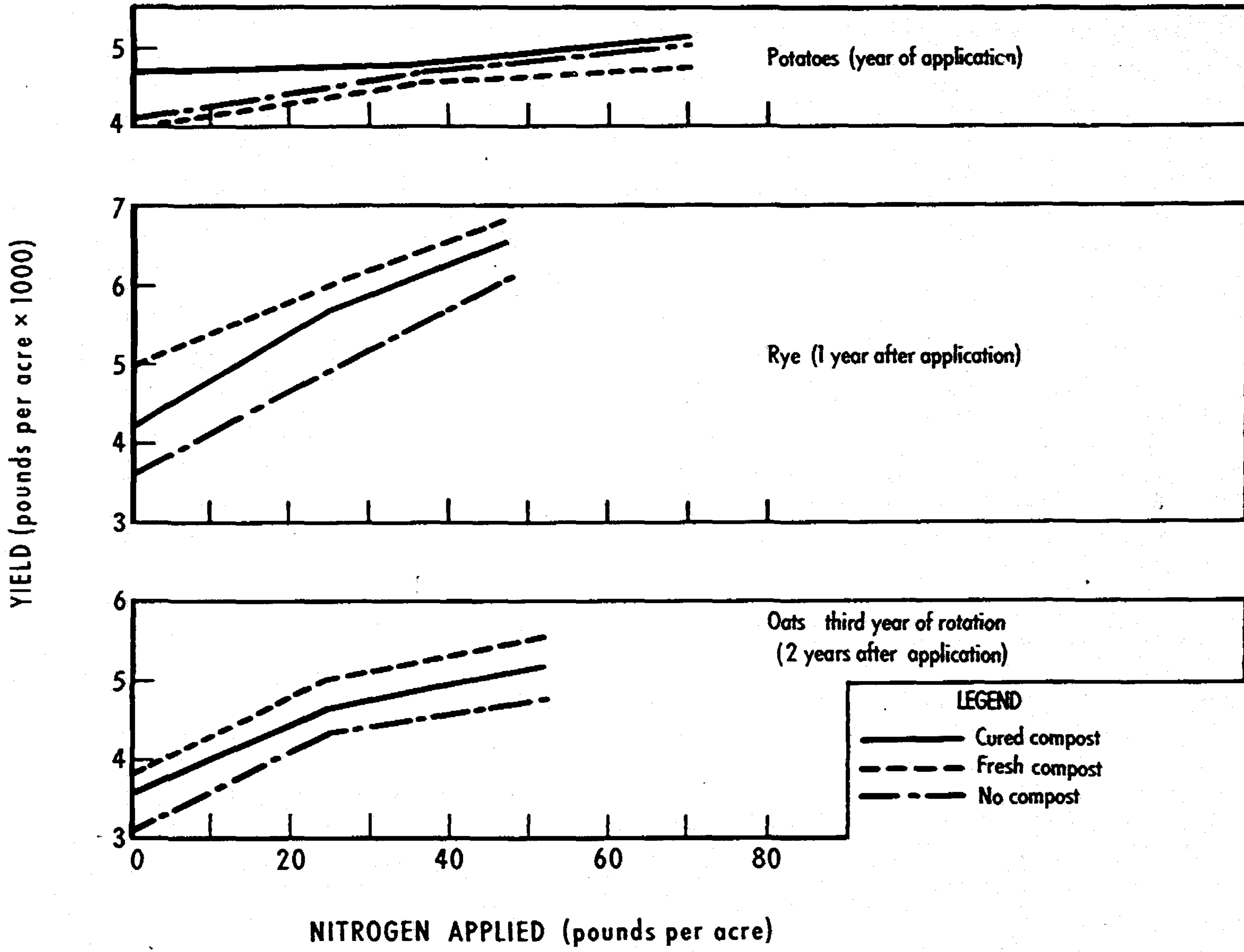

Figure 9. Data from a 9-year experiment by Tietjen and Hart indicated that there may be yield benefits from the use of compost.[80]

With regard to supplying plant nutrients, compost neither performs as well as chemical fertilizers nor meets the legal requirements established by several States for designation as a fertilizer. A typical compost contains approximately 1 percent nitrogen, one-quarter percent phosphorus, and one-quarter percent potassium. The slightly higher values that result when sewage sludge and municipal refuse are composted together are derived from the sludge.

The type of soil is an important factor to be considered in evaluating how the continued use of a chemical fertilizer will affect productivity. If the soil is low in organic matter, the continued use of chemical fertilizers that do not have an organic amendment may decrease crop yields over a period of time. The benefits of using compost to supply organic matter to various types of soils, and the other benefits that might be derived from its continued use over a long period of time have not been adequately defined.

Tietjen and Hart point out that yields are not the only consideration in evaluating the benefit of compost. They report the following additional information on the 9-year experiment mentioned above. The nutrient levels of the crops were measured each year. Potatoes grown on composted plots averaged 6 percent more nitrogen, phosphorus, and potassium per pound of crop harvested than those grown on uncomposted but fertilized plots. On an average, compost-grown rye and oats had 4 percent and 9 percent higher nutrient contents, respectively. These are significant increases.

Organic matter affects the physical characteristics of soil. Benefits that may be obtained by the addition of humus (from compost) to soil are improved workability, better structure with related resistance to compaction and erosion, and increased water-holding capacity. Improved workability is generally described as tilth; it is measured by the farmer in terms of easier plowing or cultivation which results in savings of power and time. Better structure and improved water-holding capacity are particularly important for erosion control on steep slopes. Comprehensive research on erosion control of hillside vineyards was conducted by Banse at Bad Kreuznach, Germany. The results of his field tests on compost applied every three years to a 30° vineyard slope showed that compost was very effective in reducing erosion (Figure 10).[80]

Tietjen and Hart indicated that it is difficult to put an economic value on compost applications for improvement of soil physical properties. They concluded that an improved water-holding capacity has not yet been related definitively to either increased yield or reduced irrigation requirement, nor has improved soil workability been related to a lower plowing and cultivation cost.[80] In basic agriculture, maintenance of acceptable soil physical properties and prevention of erosion are obtained economically through such practices as crop rotation (often with legumes, green manuring, contour farming, and fallowing). Although compost application might improve soil physical characteristics or erosion control still further, an economic analysis to prove the worth of composting has not yet been made.

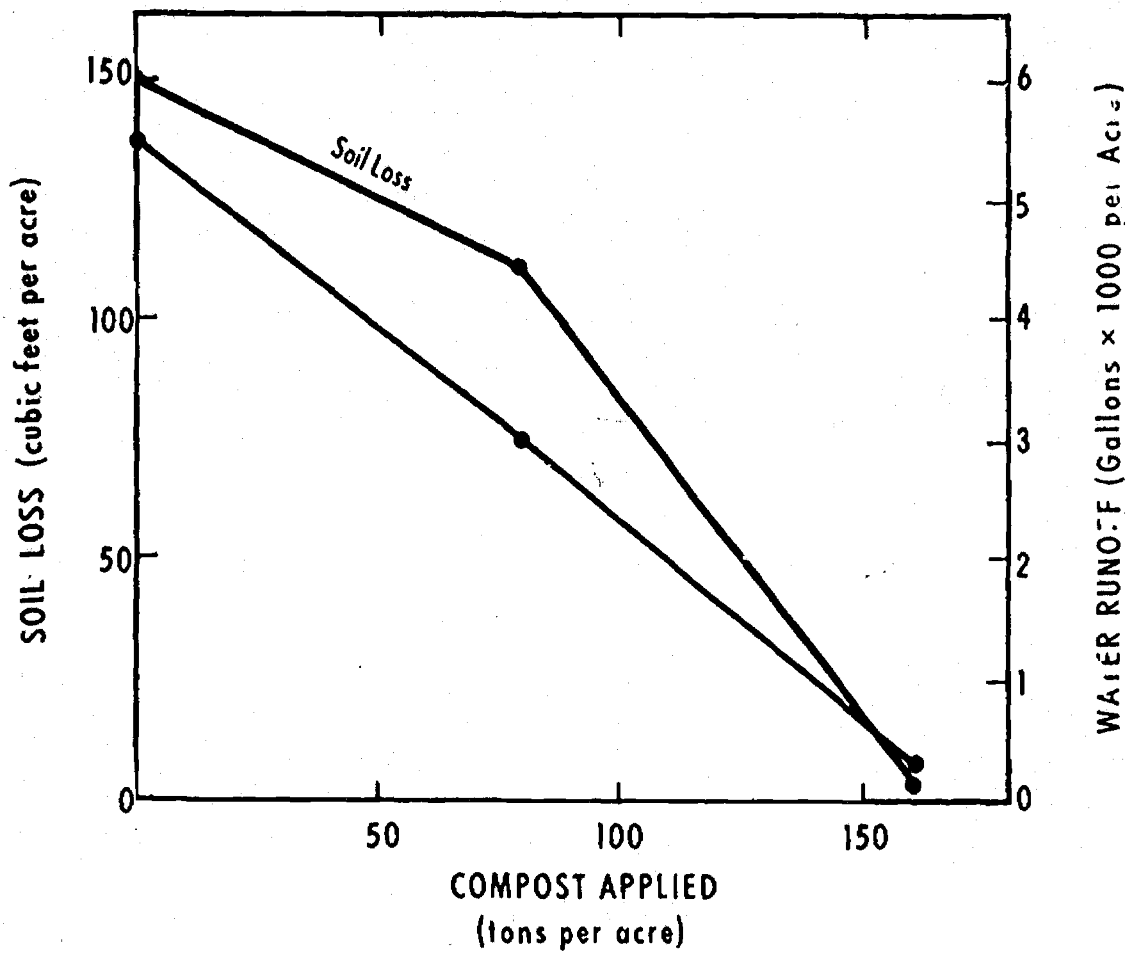

Figure 10. Compost applied every three years to vineyard slopes at Bad Kreuznach, West Germany was found to be effective in preventing soil erosion and water runoff.[80]

The preceding examples of potential benefits from compost utilization are derived from Europe where compost has been used more extensively than in the United States. There is, therefore, a need for quantitative data on its costs and the benefits in this country.

Although there has been considerable speculation about the values of trace elements, qualitative evidence indicates that the benefits derived result from the humus component when compost is applied to lawns. There is sufficient information regarding commercial agriculture.[82]

Demonstration and Utilization

None of the compost produced at the Johnson City plant has been sold. Prior to March 1969, the then Bureau of Solid Waste Management asked TVA to restrict the uses to which it was put pending the evaluation of possible health hazards. These restrictions and the lack of a suitable finished product limited the activity of TVA's Division of Agricultural Development in its utilization studies.

Where owners agreed to abide by such restrictions, 4,691 tons of compost were placed on 208 demonstration areas and two experimental sites between July 1, 1968, and May 31, 1970. The latter, which are at Johnson City and Muscle Shoals, Alabama, are "in-house" or TVA undertakings. The demonstration areas are on public lands or private farms whose owners have agreed to allow the agriculturist to supervise the application of compost and to follow the progress of the plantings. Many were selected because they were depleted, nonproductive, or problem areas where fertilizer alone had not been successful. In each case, the farmer has planted an untreated area for comparison purposes.

The bulk of the material used in Fiscal Year 1969 was neither reground nor screened and represented 80 percent of the total produced during the year. About 57 percent of the demonstration areas was established between mid-March and the end of June 1969.

Tobacco is grown on 81 of the demonstration plots, corn and grain sorghum on 23, garden vegetables on 35, grass or sod on 23, shrubs and flowers on 24, fruit trees on 5, and soybeans on 1. Erosion control and land reclamation are studied at 5 plots. Three golf courses and 8 miscellaneous plots are also involved. Both of the experimental sites have 52 test plots, 12 x 30 feet each, to which compost is applied at a rate of 4 to 200 tons per acre; a fertilizer additive is used sometimes. One site is in corn and the other in grain sorghum.

The rate of application on the demonstration plots ranges from 10 to 100 tons per acre for corn and 5 to 30 tons per acre for tobacco. By evaluating the experimental sites over a 3-1/2 year period, TVA expects to determine the merits of various application rates of compost and fertilizer.

Three other soil improvement demonstrations deserve special mention. Two involve erosion control and the reclamation of strip mine spoil bank areas. One project is being conducted in cooperation with TVA's Strip Mine Reclamation Section and the other with the Southern Soil Conservation Committee in Mercer County, West Virginia. In the third demonstration, approximately 100 tons of compost were shipped to Oak Ridge National Laboratory and used as a soil amendment to help establish a growth of white clover for special ecological studies. Radioactive solid wastes had been buried at the site under very poor soil, and earlier efforts to grow vegetation on this soil had been unsuccessful.

During the first 16 months of operations at the Gainesville plant (March 1968-June 1969), 17,514 tons of compost were produced and 1,774 tons were sold. Another 5,841 tons were donated for various public uses, leaving over 55 percent to be stockpiled or disposed of in some manner. The proximity of the St. Petersburg compost plant has undoubtedly restricted the amounts that can be utilized, and some compost was shipped up to 170 miles away. It has been applied at rates varying from 1 to 10 tons per acre at citrus groves, 16 tons per acre for strawberry crops, and up to 100 tons per acre for pine and fern seedlings. Observations indicate that growth, crop yield, and erosion control improved. Long-term information is required to determine benefit-cost relationships. Some results from Northern Florida, however, have indicated that at least 20 tons per acre of compost must be used to achieve meaningful benefits.

Horticultural Utilization of Compost

The demonstrated benefit of compost applied to lawns has been previously mentioned. The "luxury" market, which includes private lawns, gardens, golf courses, hothouses, and similar applications, is governed by an entirely different set of factors from those that apply to agricultural markets. The luxury market is small-scale, labor-intensive, more sensitive to aesthetic, conservationist, and emotional considerations, and less able to evaluate extravagant promises of benefits that are claimed by advertisers of competing products. In contrast, large-scale agriculture is characterized by the need for showing profits over short periods of time comparable to that considered by other industries.

CHAPTER VI

POTENTIAL OF MUNICIPAL REFUSE COMPOSTING IN THE UNITED STATES

With present technologies of solid waste production and disposal, together with currently effective economic and environmental constraints, most communities are not willing to fund the cost of composting their municipal refuse. Other chapters in this report have identified the factors upon which this decision is based.

The Problem

In 1967, there were an estimated 260 million tons of solid wastes generated by urban domestic, commercial, institutional, and municipal sources. The 1970 level is estimated at approximately 300 million tons. With a 50 percent yield, this would provide 150 million tons of cured compost. (The other 50 percent would be accounted for almost equally by weight lost during composting and material sorted from the incoming refuse as salvage or rejects to be disposed of separately.) Cured compost typically contains 30 percent water and weighs about 600 pounds per cubic yard. The volume of the 150 million tons of compost produced would, therefore, be 500 million cubic yards. The fraction of municipal compost that can be marketed depends upon the costs of producing and applying it, relative to the benefits derived from using it.

Compost is not a fertilizer but a soil conditioner. Some feel that its important value lies in its organic matter, which may improve the physical properties of the soil. Observations indicate that it will make soil easier to till, increase its porosity, raise its moisture-absorption and -holding ability, and prevent the leaching out of nutrients, including fertilizer. It also increases the biological activity in the soil, which st'mulates plant growth. Although compost is not a fertilizer, it can be blended with chemical fertilizers.

It is generally accepted that the cost of composting and the need to enrich the product or supplement it with chemical fertilizers restrict its marketability to buyers in the specialty fertilizer field. In this respect, municipal compost is in competition with aged cattle manure from dairies and feed lots and with peat moss.

Agricultural Effects from Compost Utilization

Although there are some benefits and some drawbacks associated with the utilization of municipal refuse compost, the economic realities associated with commercial agriculture or horticulture, which would be affected the most, have discouraged the widespread production and consumption of compost. Even barnyard manures, which are relatively rich in nitrogen, have become a disposal problem because their assumed cost-benefit ratios compare unfavorably with those of chemical fertilizers. Organic materials, including compost, have been cited by Kilmer as "the nearest thing to a cure-all for soil problems that we have."[83] Municipal compost, however, is at a disadvantage, because it has low nitrogen values and contains plastic and glass fragments. Since World War II, the availability of artificial fertilizers has ". . . led to the situation in which nitrogen from chemical fertilizers is cheaper than that from manure, even if only handling charges of the latter are taken into account . . .."[84] It is probably valid to state that the farmer has followed the established practice of industrial or commercial solid waste producers and determined that waste disposal practices with the least immediate expense must be followed in order to maintain his competitive position. Like his urban counterpart, the farmer has assumed that environmental problems resulting from inadequate disposal techniques will be solved when "research" provides an effective method, hopefully at no increase in cost.

A dilemma results from accepting the validity of compost systems--they turn out a product that may have some value but they cost more to operate than the end product is apparently worth. McGauhey suggests that this dilemma be solved by postponement. Conversion of a "low-value waste material that nobody wants into a low-value resource that nobody wants" should be deferred. This can be done, McGauhey suggests, by placing solid wastes in landfills until their value warrants mining and recovering them.[82]

Bowerman has recommended that composting be applied to regional solid waste management in the Fresno, California, area.[85] He proposes that poultry and livestock manures with low carbon-nitrogen ratios be mixed with municipal refuse and composted. The product, along with that resulting from fruit and vegetable processing wastes, would be applied to the land at a rate of 75 tons per acre per year. According to Bowerman, 20 percent of the nation's municipal refuse could be processed and disposed of in this way by the year 2000. Digested sewage sludge could also be disposed of onto the land. Except for its suggestion that a market might be developed for the compost, the proposal is an example of a rather advanced systems approach to regional solid waste disposal problems based on existing technology.

The Potential of Composting in Resource Systems Management

Resource systems management is defined as directing and maintaining the development and utilization of air, water, mineral, and living resources and their interactions under steady-state conditions. This means that proper incentives and recycling technologies must be found to ensure that elements, compounds, mixtures, and total energy maintain essentially their historical distribution in time and space.

The economics of scale that are utilized in resource development, processing, transportation, and disposal become diseconomies at that point at which materials are finally returned to the environment. These diseconomies are minimized by returning residuals to the environment through dispersed rather than concentrated mechanisms. Engineering control can provide greater initial dilution or dispersion. For example, a large number of factory chimneys or stacks discharging steam and carbon dioxide to the atmosphere is preferred on both economic and environmental grounds to a single stack through which a combined discharge of carbon dioxide and water would go. Modern sewers that discharge sewage treatment plant effluents or cooling waters into marine or lake waters have multiple discharge ports spaced over perhaps a half-mile, not just a single port at the discharge end. On land, farming of digested sewage sludge, oily sludge from refinery operations, or livestock manures promotes more rapid assimilation by the environment than if these wastes are concentrated in a small area. The organic residual of municipal refuse may also be rapidly assimilated by the soil provided that it is dispersed and has good physical, chemical, and sanitary characteristics. Compost is amenable to such initial dispersion and assimilation.

Although the utilization of compost from municipal refuse has been successful for a long time in a number of foreign countries, results in the United States have not been encouraging because of economic considerations. Because Americans have an attitude that composting plants--unlike other methods used to process or dispose of wastes--must operate at a profit or at least break even,[82] all of them have either shut down or are operating under some sort of subsidy. The latter development is enthusiastically supported by some conservationists.[86] The comparative costs for different methods of refuse disposal vary from zero to $50 per ton (Table 14).

A community may or may not be geographically located to maximize salvage of paper, metal, and other materials at a compost plant. Net costs of $8 to $12 per ton may be expected in favorable locations (Table 15).

The factors that will influence the future of the composting process as a municipal solid waste management tool are the costs and benefits of the process, as compared with other municipal solid waste management

TABLE 14

DIRECT COSTS FOR THE DISPOSAL OF SOLID WASTES*

Disposal method	Dollars per ton
Promiscuous dumping and littering	0†
Open dump, usually with burning	½ to 2
Sanitary landfill	1 to 3½
Incineration, current technology	8 to 14‡
Incineration, with air pollution control	9 to 15‡
Composting	8 to 30
Sea disposal of bulk material§	1 to 10
Sea disposal of baled, barreled, or otherwise contained material	7 to 50#

*Costs are for the middle 80-percentile range for disposal only; they do not include collection, transportation, or indirect environmental costs.

†The cost to the public for removal and subsequent disposal is from $40 to $4,000 per ton.

‡For installations featuring heat recovery, add $3 per ton.

§Wet weight basis; for example, sewage sludge at 95 percent moisture, dredging spoils, waste oils.

#Costs are at dockside; higher costs are those associated with toxic or otherwise hard-to-handle wastes.

processes. The present and potential technology of composting will permit organic materials to be recycled back into the soil without significantly polluting water or land. The cost is, however, higher than that associated with other acceptable management methods. On the other hand, changes in designated priorities on the use of land, sea, or air may occur as per capita waste generation rates rise. For example, a decision by Southern Californians to eliminate backyard incineration of household refuse led to a reevaluation of other alternatives available at the time. Similar incidents may well happen.

TABLE 15

ESTIMATED COSTS FOR COMPOSTING MUNICIPAL SOLID WASTES IN FAVORABLE LOCATIONS

Costs	Plant input	
	50 tons/day	300 tons/day
Operating and capital	$10-20/ton	$8-12/ton
Income		
Paper, metal, and miscellaneous salvage	0-2	2-5
Compost	0-4	0-2*
Net cost		
Range	4-20	1-10
Probable	12	8

*Costs are per ton of refuse processed; assuming a typical 50 percent compost yield, the actual sale prices for the compost would be twice the values shown.

The potential usefulness of all solid waste management systems, including those that employ composting, will be influenced by changes during future decades of the value assigned to, or the emphasis placed upon, any of the following four factors: the acceptance of more stringent standards for environmental quality; the availability of systems to meet these standards; cost per ton of solid waste managed for each available system; public policy decisions requiring beneficial recycling rather than land or sea disposal of wastes.

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