INTERIM REPORT
WITH OPERATIONAL DATA
JOINT USPHS-TVA COMPOSTING PROJECT
JOHNSON CITY, TENNESSEE
June 1967--September 1969

U.S. ENVIRONMENTAL PROTECTION AGENCY
1972

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This open-file report (SW-31r.1.of)
was written by G. E. STONE *and* C. C. WILES
under the direction of C. A. CLEMONS

U.S. ENVIRONMENTAL PROTECTION AGENCY
1972

PREFACE

The completion of this report was made possible by the cooperation of many individuals, two Federal agencies, and a municipality.

The Tennessee Valley Authority (TVA) must be credited with the foresight to develop a composting system in a part of the country where the soil would benefit from the compost produced by a successful composting facility. The design and operation of the facility has been the sole responsibility of TVA. O. M. Derryberry, F. E. Gartrell, O. W. Kochtitzky, W. K. Seaman, Jack Taylor, Carroll Duggan, and Virgil Rader are just a few of the TVA people participating. David Burkhalter and James Mosier, as city managers, have been responsible for implementing the needed cooperation from the Johnson City municipality.

John S. Wiley, well known for his pilot research on composting, served as Research Director until his retirement on July 1, 1968. Gordon E. Stone became Project Engineer in July 1967. Fred J. Stutzenberger, staff microbiologist; Donald J. Dunsmore, staff sanitary engineer; and Richard D. Lossin, staff chemist, performed the majority of the tests and studies reported. Some of the assay work was performed by personnel of the Research Services Laboratory in Cincinnati, Ohio. W. L. Gaby and his staff at East Tennessee State University worked closely with project personnel in determining that compost was safe, under study conditions, for agricultural

use. (Mrs.) Mirdza L. Peterson, research microbiologist, served as the contract officer for a portion of these studies. (Mrs.) Marie T. Presnell, serving as administrative assistant, has been a key person in assuring the continued smooth operation of the project. The chief Cincinnati-based managers have been Harry Stierli and Charles G. Gunnerson. Andrew W. Breidenbach provided the general direction for the entire project.

SUMMARY

The Joint USPHS-TVA Composting Project began operation in June 1967. The purposes were to provide the then Bureau of Solid Waste Management*with more comprehensive knowledge about windrow composting as a solid waste management tool and permit better assessment of available information about this subject. Results of investigations and operational experiences obtained from the project during the period June 1967 to September 1969, are discussed in this report.

During the period, the plant processed an average of 34 tons of raw refuse per processing day received from a population of 31,200. Approximately 27 percent of the incoming refuse was rejected as noncompostable and returned to the city's landfill for disposal. The yield of unscreened compost was about 50 percent of the incoming refuse (wet weight basis) but trouble with the equipment for grinding compost hindered the production of an acceptable grade.

Investigations of the potential hazard to health from pathogenic organisms in compost showed that windrow temperatures of 122 to 130 F maintained for at least 7 days destroyed pathogens expected in refuse and those known to be in sewage sludge. Time-temperature studies showed that windrow temperatures at the 1-1/2-ft depth averaged above 140 F for 2 to 3 weeks or more.

Sewage sludge, cow manure, paunch manure, aged poultry manure, animal blood, and pepper canning wastes in varying amounts were all successfully

*The Federal solid waste management effort is now part of various components of the U.S. Environmental Protection Agency.

composted with the refuse. In the amounts used they did not greatly affect the composting process or the product. The addition of urea-ammonium nitrate appeared to inhibit microbial activity and resulted in a loss of nitrogen in the product. Although limestone added to the refuse appeared to aid the composting process, it also caused a loss of nitrogen and resulted in a poorer product.

Total construction costs, including costs of modifications made during the period, were $958,375. Actual cost for operating the plant during 1968, at a level less than capacity, was $18.45 per ton of refuse processed. Projected to full capacity, the operating cost in 1969, was $13.40 per ton of refuse processed.

Because production of an acceptable grade of compost was delayed, agricultural testing of the compost is only in preliminary stages. Therefore, insufficient data are available to assess the agricultural value of the compost produced.

CONTENTS

TABLES

Page

Page

FIGURES

APPENDICES

INTERIM REPORT

JOINT USPHS-TVA COMPOSTING PROJECT, JOHNSON CITY, TENNESSEE

June 1967 - September 1969

INTRODUCTION

The natural phenomenon of the degradation of wastes by microbiological activity has been utilized by agriculturists for centuries to produce humus. In modern times the stress upon the environment caused by wastes and the need to replenish the organic constituents removed from soils by intensive farming have created an interest in large-scale composting.*

In Europe, large-scale composting has received attention because of its possibilities for supplying organic material for the soil and a considerable number of plants have been operated successfully over the last twenty-five years. In America, where there has been a different attitude toward the conservation of resources and where the need for the replenishment of organics in the soil has been less acute, composting has only recently received attention, and here the greatest emphasis has been on its use as a method of waste disposal.[1]

In the United States, the University of California studied the composting of municipal wastes from 1950 to 1952.[2] One conclusion of this study was that composting offered an alternative method of refuse disposal that would help alleviate the growing difficulty of finding landfill sites

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

and problems of air pollution that result from incineration. However, Wiley and Kochtitsky 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 to 1964.[3] In addition to a lack of marketing knowledge, there was a dearth of reliable cost data. Certain environmental and public health aspects also required study in the United States.

In the early 1960's, F. E. Gartrell of the Tennessee Valley Authority (TVA) proposed a full-scale composting project to be jointly sponsored by TVA, the U.S. Public Health Service (USPHS), and a municipality in the Tennessee Valley. Both USPHS and TVA were interested in a sanitary method of waste disposal and TVA was also interested in the use of compost for soil improvement. In March 1963, the Division of Agricultural Development, TVA initiated a project called "The Use of Municipal and Industrial Organic Waste in the Production of Soil Amendments and Fertilizers." The compost plant was to investigate the process as a method for disposing of wastes and at the same time reclaiming waste for the benefit of the land.

In August 1964, the USPHS and the TVA agreed upon a joint research and demonstration project for composting solid wastes and sewage sludge. In November 1964, USPHS detailed John S. Wiley to the Division of Health and Safety, (now the Office of Health and Environmental Science) TVA, to collaborate in the detailed planning of the project. Under the agreement, TVA would have financed and constructed the composting plant. When the Solid Waste Disposal Act was passed in October 1965, the Bureau of Budget directed that the proposed plant be financed from funds available under the terms of the Act to the Department of Health, Education, and Welfare. Johnson City had been selected as the site for the composting project on the basis of two surveys of six Tennessee Valley area cities. One survey, conducted by TVA engineers and representatives of state and local health departments, covered disposal of refuse and sewage sludge. The other, made by TVA agricultural specialist, investigated the use of chemical and organic fertilizers in the vicinity of these cities. On February 15, 1966, the two agencies and Johnson City, Tennessee, signed a cooperative agreement for the construction and operation of the "Joint USPHS-TVA Composting Project, Johnson City, Tennessee." Ground was broken for the plant on May 18, 1966; construction was completed and the plant was put in operation on June 20, 1967.

Johnson City, Tennessee

Location, Climate, Population, Etc. Johnson City, in Washington County, is in the extreme northeastern corner of Tennessee at longitude 82° 21' W., latitude 36° 19' N. (Figure 1). It lies near the junction of the Watauga River and the South Fork Holston River in the headwaters of the Tennessee River system. The terrain immediately surrounding the city ranges from gently rolling on the east and south to very hilly on the west and north. Mountain ranges begin about 5 miles to the southeast and about 20 miles to the west and north, with many peaks rising to 4,000 and some to 6,000 ft above sea level toward the southeast in the Appalachian system. Elevations in the city range from 1,500 to over 1,700 ft.

The Johnson City area does not lie directly within any of the principal storm tracks that cross the country, but comes under the influence of

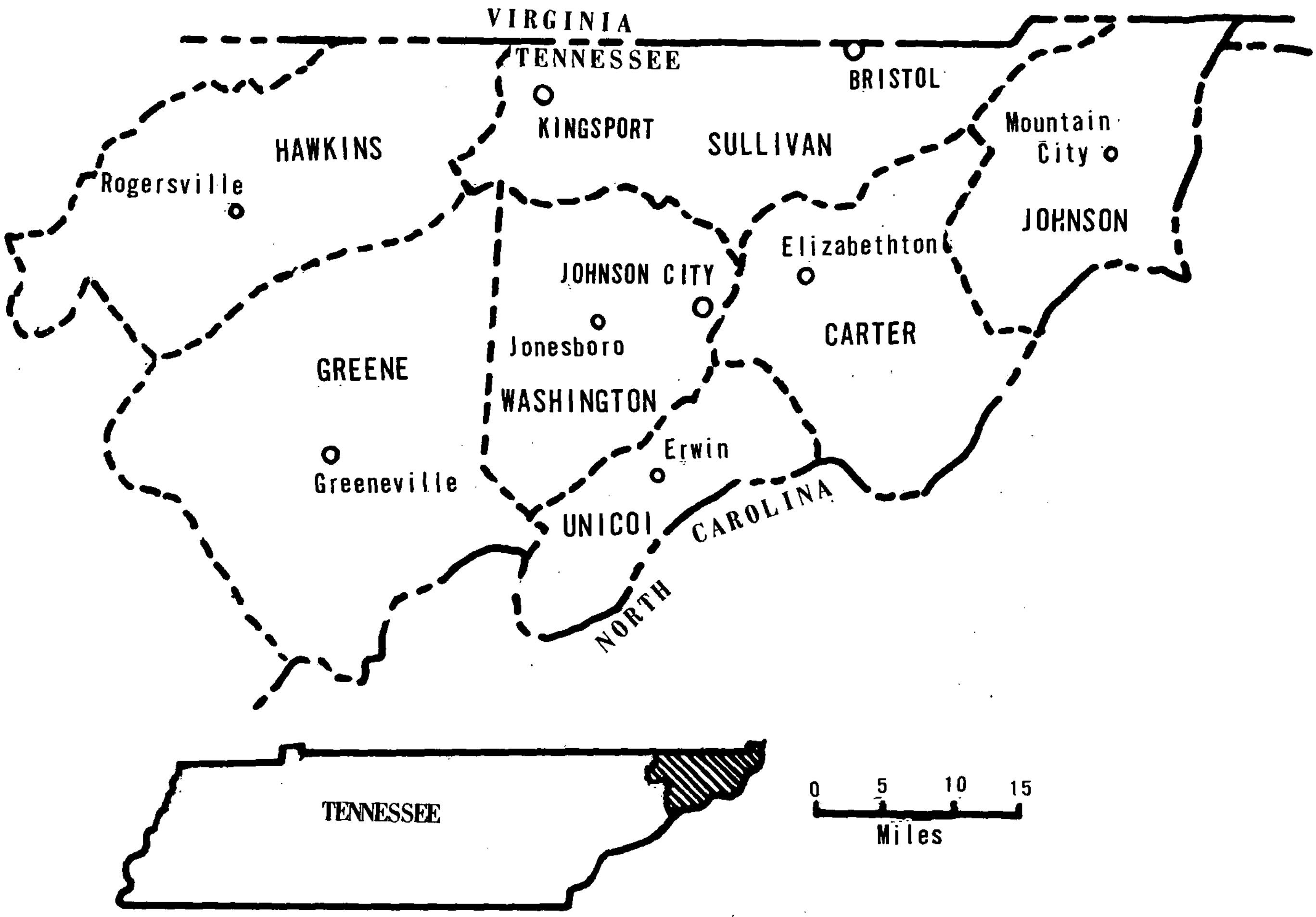


Figure 1. Map of the Johnson City-Kingsport-Bristol, Tennessee area.

storm centers that pass along the Gulf Coast and then up the Atlantic Coast toward the northeast. Table 1 gives meteorological data for the calendar years 1967 and 1968, for the Bristol, Tennessee, station of the U.S. Weather Bureau at the Tri-City Airport, 9 miles northwest of the USPHS-TVA Composting Project plant. Table 2 gives the normals, means, and extremes for this station. Since August 1967, temperature and rainfall records have been kept at the composting plant. Figure 2 shows the recorded high and low temperatures for the months through July 1969. Figure 3 shows the monthly rainfall recorded at the plant over the same period.

Johnson City, with an area of 15 square miles (Figure 4), had in 1969, an estimated population of 35,300. The city and county had an estimated population of 68,500. The trading area had an estimated population of 180,000 and the area within a 50-mile radius had an estimated population of 635,000.

The average income per family in Johnson City was $8,482 in 1968. About 36 percent are employed in manufacturing, the remainder in trade, finance, government, transportation, service jobs, etc. In the rural area, about 28 percent occupy farms. Of this population, 30 percent are engaged in manufacturing. Washington County has about 3,000 farms, averaging 55 acres each.

Tobacco is the most important crop of the area. Corn and some small grains are grown in support of the important dairy industry. Raising of beef cattle has increased in the last 20 years to become a significant part of the economy.

In the seven counties of the area, there are about 320,600 acres of cropland and 281,800 acres of pasture.

TABLE 1

METEOROLOGICAL DATA FOR JOHNSON CITY AREA

Tri-City Airport (Bristol, Tennessee, Station), latitude 36° 29' N., longitude 82° 24' W., ground elevation 1507 feet above sea level.

1967

Month	Temperature: Averages: Daily maximum	Temperature: Averages: Daily minimum	Temperature: Averages: Monthly	Temperature: Extremes: Highest	Temperature: Extremes: Date	Temperature: Extremes: Lowest	Temperature: Extremes: Date	Degree days	Precipitation: Total	Precipitation: Greatest in 24 hrs.	Precipitation: Date	Precipitation: Snow, Sleet: Total	Precipitation: Snow, Sleet: Greatest in 24 hrs.	Precipitation: Snow, Sleet: Date	Relative humidity: 1 AM	Relative humidity: 7 AM	Relative humidity: 1 PM	Relative humidity: 7 PM	Wind&: Resultant: Direction	Wind&: Resultant: Speed	Wind&: Average speed	Wind&: Fastest mile: Speed	Wind&: Fastest mile: Direction	Wind&: Fastest mile: Date	Percent of possible sunshine	Average sky cover sunrise to sunset	Number of days: Sunrise to sunset: Clear	Number of days: Sunrise to sunset: Partly cloudy	Number of days: Sunrise to sunset: Cloudy	Number of days: Precipitation .01 inch or more	Number of days: Snow, Sleet 1.0 inch or more	Number of days: Thunderstorms	Number of days: Heavy fog	Number of days: Temperatures: Maximum: 90° and above	Number of days: Temperatures: Maximum: 32° and below	Number of days: Temperatures: Minimum: 32° and below	Number of days: Temperatures: Minimum: 0° and below
JAN	48.6	27.8	38.2	72	26	14	12	821	2.00	0.75	27	4.6	4.0	19	82	86	63	66	25	2.6	5.4	28	24	27		6.6	6	9	16	8	1	0	9	0	1	22	0
FEB	43.5	23.9	33.7	67	1	- 1	25	868	4.14	1.47	17	4.8	3.1	7	76	79	62	63	27	4.4	7.2	30	30	16		6.9	6	6	16	11	2	0	1	0	3	21	1
MAR	63.8	36.5	50.2	79	27+	15	18	455	3.02	1.11	6-7	T	T	20 +	74	81	48	52	27	2.1	6.6	35	25	7		5.8	11	6	14	8	0	3	1	0	0	14	0
APR	71.2	44.2	57.7	81	16	30	29	218	2.80	1.26	26	0.0	0.0		68	78	46	51	28	3.0	7.3	25	25	17+		5.3	9	14	7	7	0	2	0	0	0	2	0
MAY	69.4	48.0	58.7	85	27	36	10	216	6.29	1.28	14-15	0.0	0.0		94	94	67	70	28	1.6	6.2	32	29	8		7.4	6	4	21	17	0	11	5	0	0	0	0
JUN	80.3	57.4	68.9	88	17	48	2+	29	2.14	0.88	31-1	0.0	0.0		91	93	60	68	07	1.3	5.7	18	31	18		5.7	7	13	10	10	0	5	2	0	0	0	0
JUL	79.4	60.1	69.8	87	24	48	5	12	4.87	2.08	28-29	0.0	0.0		95	96	69	75	26	1.5	5.1	21	28	29		7.6	2	11	18	17	0	7	5	0	0	0	0
AUG	81.4	60.0	70.7	87	3	51	14	2	3.68	1.15	22	0.0	0.0		93	94	68	77	36	0.4	3.9	15	27	10		6.7	4	12	15	11	0	4	8	0	0	0	0
SEP	76.6	48.6	62.6	87	20	34	30	107	2.59	1.29	28	0.0	0.0		92	95	56	71	03	1.0	3.6	29	31	21		4.4	16	7	7	5	0	1	4	0	0	0	0
OCT	69.3	42.9	56.1	80	16+	27	29	271	1.99	0.82	25	0.0	0.0		86	95	55	64	24	0.7	4.5	18	25	25+		5.1	10	13	8	7	0	0	10	0	0	6	0
NOV	53.5	31.8	42.7	73	11	17	29	662	3.73	1.03	1-2	T	T	29 +	79	85	53	60	27	3.4	6.0	25	31	22		5.4	11	10	9	11	0	2	1	0	0	16	0
DEC	51.3	30.2	40.8	71	21	14	24	745	5.62	1.73	18-19	4.1	2.6	28	85	89	70	74	33	0.9	5.1	25	27	12+		7.0	6	7	18	13	2	1	4	0	3	20	0
YEAR	65.7	42.6	54.2	88	JUN. 17	- 1	FEB. 25	4406	42.87	2.08	JUL. 28-29	13.5	4.0	JAN. 19	85	89	60	66	28	1.5	5.6	35	25	MAR. 7		6.2	94	112	159	125	5	36	50	0	7	101	1

Relative humidity hours: Standard time used: EASTERN

1968

Month	Daily maximum	Daily minimum	Monthly	Highest	Date	Lowest	Date	Degree days	Precipitation Total	Greatest in 24 hrs.	Date	Snow, Sleet Total	Greatest in 24 hrs.	Date	1 AM	7 AM	1 PM	7 PM	Resultant Direction	Resultant Speed	Average speed	Fastest mile Speed	Fastest mile Direction	Fastest mile Date	Percent of possible sunshine	Average sky cover sunrise to sunset	Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Sleet 1.0 inch or more	Thunderstorms	Heavy fog	90° and above	32° and below (Max.)	32° and below (Min.)	0° and below
JAN	43.0	23.3	33.2	62	31	1	8	979	3.58	0.95	3-4	12.1	4.5	23-24	78	81	65	68	01	0.9	5.7	24	10	13		7.1	6	6	19	13	4	0	4	0	6	26	0
FEB	41.1	19.1	30.1	64	1	4	22	1004	0.75	0.45	28-29	6.3	4.8	29	58	66	43	42	28	4.7	7.2	21	30	21+		5.7	8	11	10	5	2	0	0	0	7	27	0
MAR	60.4	33.4	46.9	80	21	18	14+	553	4.95	1.54	9-10	1.0	3.2	29-1	71	79	46	52	27	3.5	6.7	32	24	22		6.2	6	11	14	11	0	3	2	0	1	17	0
APR	67.2	44.3	55.8	82	20	31	16+	276	4.12	1.49	23-24	0.0	0.0		78	86	55	55	28	1.4	5.8	35	23	4		6.6	7	7	16	16	0	4	4	0	0	2	0
MAY	72.5	50.0	61.3	85	24	35	7+	137	3.83	0.93	26-27	0.0	0.0		82	88	60	67	27	1.9	5.2	24	30	1		7.0	3	11	17	15	0	8	6	0	0	0	0
JUN	82.7	58.8	70.8	93	30	47	1	1	2.89	0.87	7-8	0.0	0.0		87	90	58	64	30	1.0	4.6	31	31	11		6.3	8	8	14	12	0	6	8	2	0	0	0
JUL	87.7	63.9	75.8	94	21+	55	5	0	2.89	1.40	31	0.0	0.0		87	90	53	67	01	0.7	4.1	28	30	2		6.7	5	11	15	11	0	11	10	11	0	0	0
AUG	86.5	64.5	75.5	94	23+	48	30+	4	2.32	0.99	10-11	0.0	0.0		87	92	58	69	34	0.8	3.5	17	28	10+		5.9	8	12	11	10	0	8	8	12	0	0	0
SEP	80.4	53.7	67.1	87	24+	44	13	19	0.93	0.46	9-10	0.0	0.0		84	89	49	62	03	0.9	3.7	16	29	10+		5.7	8	10	12	8	0	3	4	0	0	0	0
OCT	69.6	45.6	57.6	83	13+	27	30	245	2.51	1.12	18-19	T	T	29 +	79	84	51	60	33	0.7	5.0	17	28	28+		5.8	9	8	14	11	0	2	4	0	0	4	0
NOV	55.5	34.8	45.2	75	2+	17	21	590	1.89	0.78	6-7	2.9	1.4	11-12	78	82	58	65	28	2.3	5.9	29	30	19		8.1	2	8	20	12	1	0	5	0	0	14	0
DEC	46.3	24.1	35.2	65	19	6	16	920	2.13	0.77	22	1.0	1.0	14-15	70	73	52	58	26	3.7	7.4	40	24	28		7.2	5	10	16	9	0	0	2	0	4	26	0
YEAR	66.1	43.0	54.6	94	AUG. 23+	1	JAN. 8	4728	32.79	1.54	MAR. 9-10	23.3	4.8	FEB. 29	78	83	54	61	29	1.6	5.4	40	24	DEC. 28		6.5	75	113	178	133	7	45	57	25	18	116	0

Unless otherwise indicated, dimensional units used in this bulletin are: temperature in degrees F.; precipitation, including snowfall, in inches; wind movement in miles per hour; and relative humidity in percent. Degree day totals are the sums of the negative departures of average daily temperatures from 65° F. Sleet was included in snowfall totals beginning with July 1948. Heavy fog reduces visibility to 1/4 mile or less.

Sky cover is expressed in a range of 0 for no clouds or obscuring phenomena to 10 for complete sky cover. The number of clear days is based on average cloudiness 0-3; partly cloudy days 4-7; and cloudy days 8-10 tenths.

& Figures instead of letters in a direction column indicate direction in tens of degrees from true North; i.e., 09 - East, 18 - South, 27 - West, 36 - North, and 00 - Calm. Resultant wind is the vector sum of wind directions and speeds divided by the number of observations. If figures appear in the direction column under "Fastest mile" the corresponding speeds are fastest observed 1-minute values.

TABLE 2

METEOROLOGICAL DATA FOR JOHNSON CITY AREA

NORMALS, MEANS, AND EXTREMES

Tri-City Airport (Bristol, Tennessee, Station), latitude 36° 29' N., longitude 82° 24' W., ground elevation 1507 feet above sea level.

Month	Temperature – Normal – Daily maximum	Temperature – Normal – Daily minimum	Temperature – Normal – Monthly	Temperature – Extremes Ø – Record highest	Year	Temperature – Extremes Ø – Record lowest	Year	Normal degree days	Precipitation – Normal total	Precipitation – Maximum monthly	Year	Precipitation – Minimum monthly	Year	Precipitation – Maximum in 24 hrs.	Year	Snow, Sleet – Mean total	Snow, Sleet – Maximum monthly	Year	Snow, Sleet – Maximum in 24 hrs.	Year
(a)	(b)	(b)	(b)	7		7		(b)	(b)	23		23		23		31	31		25	
J	46.8	29.7	38.3	72	1967	-15	1966	828	3.69	9.18	1957	1.85	1955	2.34	1950	4.9	22.1	1966	9.7	1955
F	50.0	30.0	40.0	76	1965	- 4	1965	700	3.56	7.29	1956	0.75	1968	1.87	1954	3.8	17.2	1947	9.7	1958
M	56.5	35.5	46.0	81	1963	12	1965	598	3.98	9.56	1955	1.33	1957	3.10	1963	2.7	27.9	1960	13.0	1960
A	68.2	44.9	56.6	85	1963	21	1964	261	3.16	5.59	1949	1.38	1963	2.32	1956	T	0.6	1962	0.6	1962
M	77.6	53.7	65.7	92	1962	30	1963	68	3.45	9.71	1950	1.31	1966	2.44	1958	T	T	1963	T	1963
J	84.5	61.9	73.2	95	1966+	38	1966	0	3.38	6.68	1957	1.14	1964	3.10	1954	0.0	0.0		0.0	
J	86.4	65.4	75.9	94	1968	48	1967+	0	5.55	9.73	1949	0.79	1957	2.90	1946	0.0	0.0		0.0	
A	85.4	64.1	74.8	95	1965	48	1968	0	3.80	7.07	1966	0.82	1954	2.50	1963	0.0	0.0		0.0	
S	80.6	57.5	69.1	92	1965+	34	1967	51	2.62	6.19	1962	0.93	1968	2.95	1962	0.0	0.0		0.0	
O	70.1	45.9	58.0	84	1964+	20	1962	236	2.15	5.65	1959	0.07	1963	3.65	1964	T	T	1968+	T	1968+
N	56.7	35.1	45.9	80	1961	15	1964	573	2.51	5.90	1948	1.07	1953	2.55	1957	1.4	18.1	1952	16.2	1952
D	47.1	29.5	38.3	73	1966	- 9	1962	828	3.21	6.75	1961	0.21	1965	2.03	1958	2.7	12.9	1963	7.5	1963
YR	67.5	46.1	56.8	95	JUN. 1966+	-15	JAN. 1966	4143	41.06	9.73	JUL. 1949	0.07	OCT. 1963	3.65	OCT. 1964	15.5	27.9	MAR. 1960	16.2	NOV. 1952

Month	Relative humidity – 1 AM	Relative humidity – 7 AM	Relative humidity – 1 PM	Relative humidity – 7 PM	Wind & – Mean hourly speed	Wind & – Prevailing direction	Wind & – Fastest mile – Speed	Wind & – Fastest mile – Direction	Year	Pct. of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days – Sunrise to sunset – Clear	Mean number of days – Sunrise to sunset – Partly cloudy	Mean number of days – Sunrise to sunset – Cloudy	Precipitation .01 inch or more	Snow, Sleet 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures – Max. – 90° and above	Temperatures – Max. – 32° and below	Temperatures – Min. – 32° and below	Temperatures – Min. – 0° and below
(a)	7	7	7	7	14	9	13	13			20	31	31	31	23	25	25	25	7	7	7	7
J	76	80	61	65	6.5	WSW	40	25	1965+		7.1	6	7	18	14	2	*	3	0	5	25	1
F	71	76	57	59	7.0	NE	46	25	1961		6.9	6	7	15	12	1	1	3	0	3	21	*
M	70	77	51	55	7.5	WNW	40	25	1952		6.7	7	7	17	13	1	2	1	0	*	14	0
A	73	82	51	53	7.3	WSW	40	23	1961		6.5	7	9	14	12	0	4	1	0	0	3	0
M	85	90	57	62	5.3	WSW	50	32	1951		6.2	6	12	13	11	0	7	3	1	0	*	0
J	86	90	57	63	4.6	NE	31	31	1968		6.0	6	12	12	10	0	9	3	4	0	0	0
J	88	91	61	67	4.1	WSW	40	23	1961+		6.4	5	13	13	12	0	10	5	4	0	0	0
A	88	91	61	69	3.9	NE	46	34	1962		5.9	7	14	10	11	0	8	7	3	0	0	0
S	85	89	54	66	4.5	NE	29	31	1967		5.3	11	9	10	7	0	4	4	2	0	0	0
O	81	87	51	60	4.7	NE	35	28	1965		4.8	13	8	10	8	0	1	5	0	0	4	0
N	79	84	57	65	5.8	W	35	29	1965		6.2	9	7	14	11	*	*	3	0	*	12	0
D	78	80	62	67	5.9	WSW	40	24	1968+		6.8	7	7	17	11	1	*	3	0	4	23	*
YR	80	85	57	63	5.6	WSW	50	32	MAY 1951		6.2	90	112	163	132	5	46	42	15	13	101	2

Relative humidity: Standard time used: EASTERN

Ø For period May 1961 through the current year.
Means and extremes in the above table are from the existing or comparable location(s). Annual extremes have been exceeded at other locations as follows:
Highest temperature 102 in July 1952.

(a) Length of record, years.
(b) Climatological standard normals (1931-1960).
* Less than one half.
\+ Also on earlier dates, months or years.
T Trace, an amount too small to measure.
Below-zero temperatures are preceded by a minus sign.
The prevailing direction for wind in the Normals, Means, and Extremes table is from records through 1963.

Unless otherwise indicated, dimensional units used in this bulletin are: temperature in degrees F.; precipitation, including snowfall, in inches; wind movement in miles per hour; and relative humidity in percent. Degree day totals are the sums of the negative departures of average daily temperatures from 65° F. Sleet was included in snowfall totals beginning with July 1948. Heavy fog reduces visibility to 1/4 mile or less.

Sky cover is expressed in a range of 0 for no clouds or obscuring phenomena to 10 for complete sky cover. The number of clear days is based on average cloudiness 0-3; partly cloudy days 4-7; and cloudy days 8-10 tenths.

& Figures instead of letters in a direction column indicate direction in tens of degrees from true North; i.e., 09 - East, 18 - South, 27 - West, 36 - North, and 00 - Calm. Resultant wind is the vector sum of wind directions and speeds divided by the number of observations. If figures appear in the direction column under "Fastest mile" the corresponding speeds are fastest observed 1-minute values.

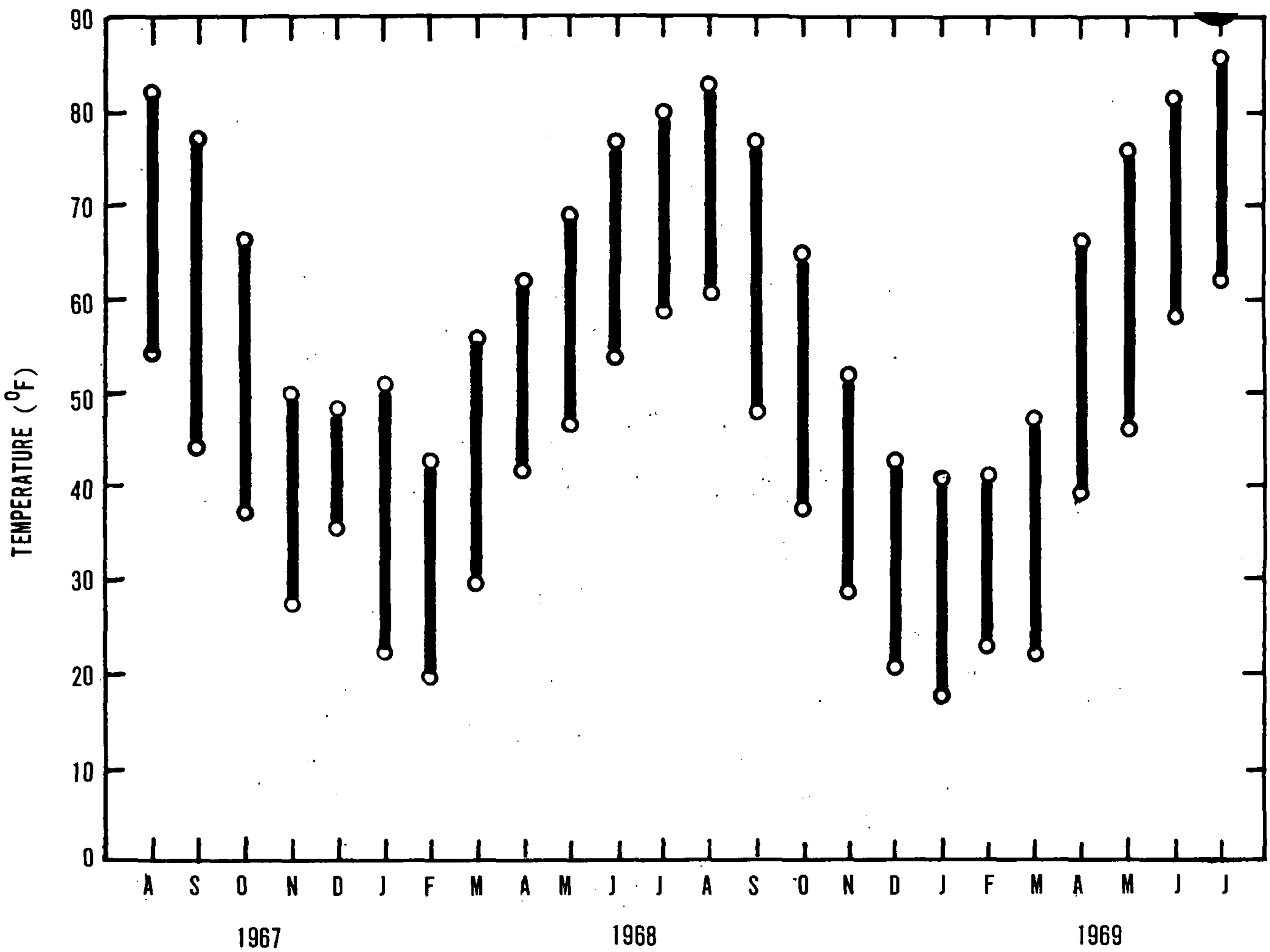


Figure 2. Average high and low temperatures recorded at the plant for the period August 1967-July 1969.

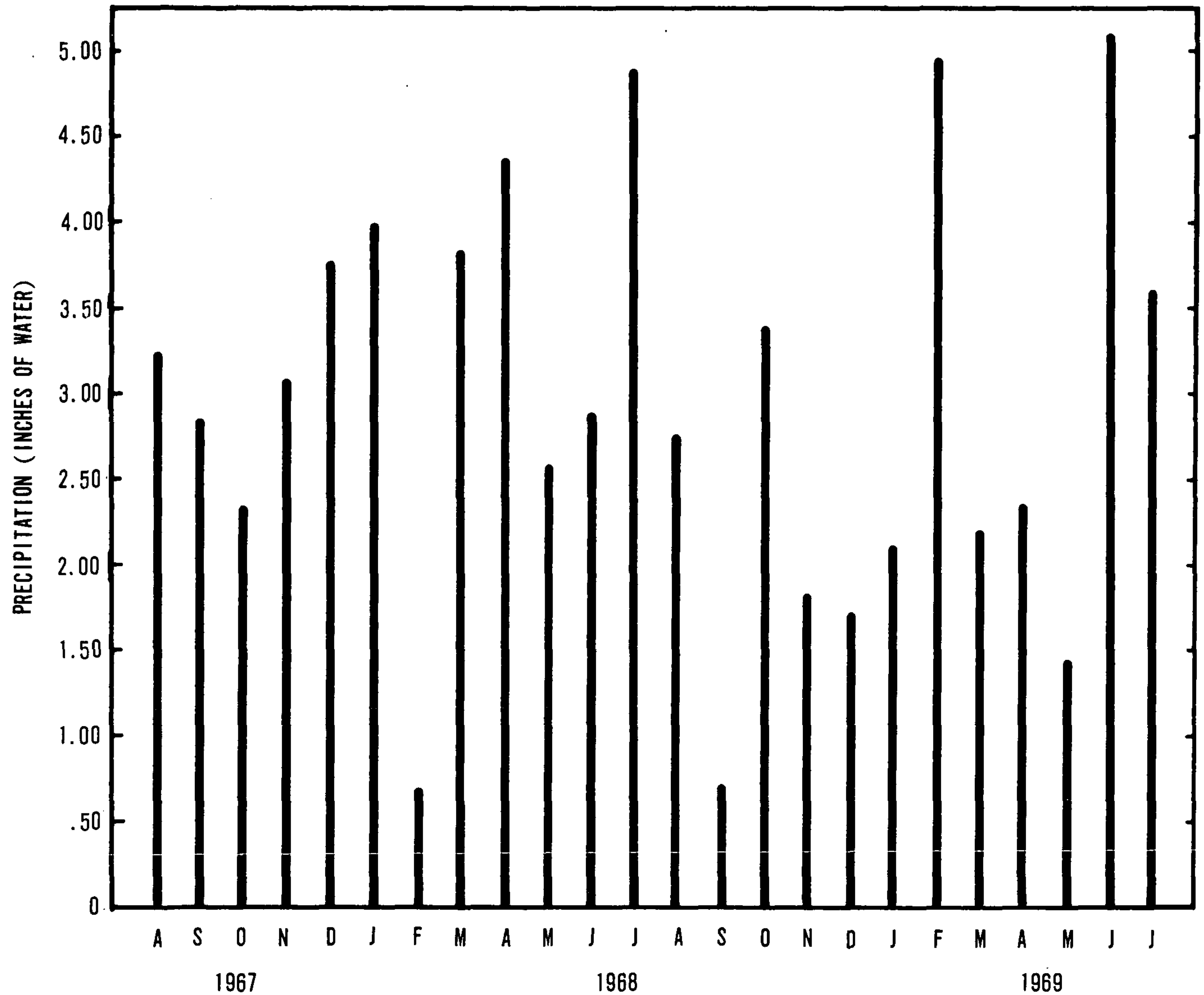


Figure 3. Monthly precipitation recorded at the plant for the period August 1967-July 1969.

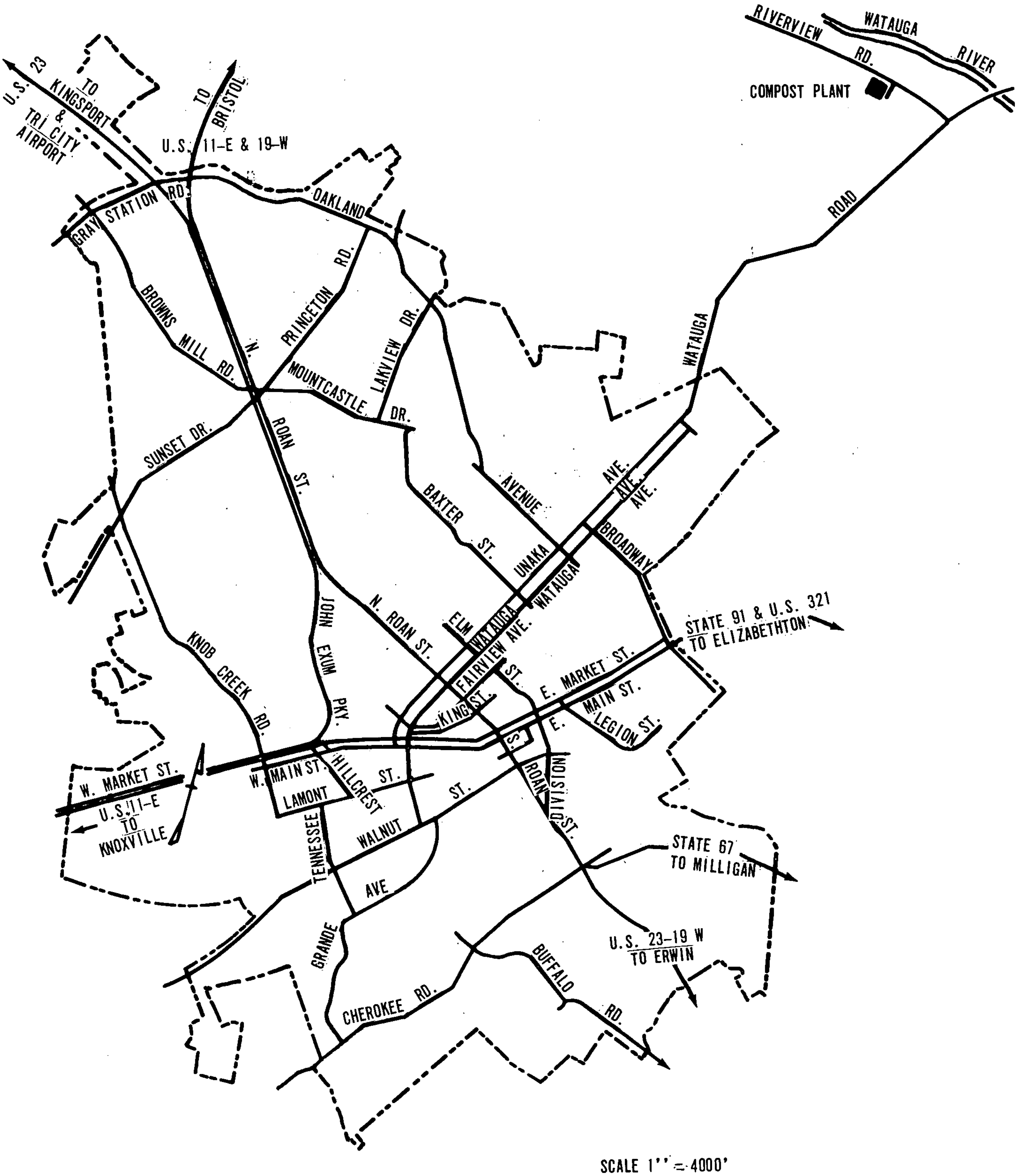


Figure 4. Map of Johnson City, Tennessee showing the location of the compost plant.

Residential wastes of 31,200 persons and 40 percent by weight of the commercial wastes are collected weekly in Johnson City by the Sanitation Department using five three-man crews with compactor trucks. Sixty percent of the homeowners, however, burn some wastes in their backyards. Others employ private collectors to provide supplemental service once a week. Street sweeping and brush are collected by the Street Department and are deposited in the city's landfill.

Industries in Johnson City generate about 130 tons of solid wastes weekly. The majority of these are hauled to disposal sites by employees of the industries. The Sanitation Department collects from seven industries, totalling about 9 tons per week.

Wastes collected by the Sanitation Department are delivered to a transfer station. Here they are transferred to either a 53 or a 65 cu yd compaction trailer for hauling to the compost plant or the landfill. One load per day of commercial material, about 95 percent paper, and averaging about 10 tons, is routinely hauled to the landfill. Hospital wastes and some yarn wastes from an industrial establishment also do not reach the composting plant. When the compaction trailers are out of service for any reason, the 16 cu yd packer trucks used for residential collection deliver their refuse to the composting plant.

For the period January 1968 through June 1969, the compost plant received an average of 33.8 tons of refuse per day for 5 days per week. This collection with the 10 tons per day sent directly to the landfill, is about 2.8 lb per capita per day on a 5-day-week basis and 2 lb per capita on the 7-day-week basis. The low figure probably does not represent the true per capita generation of refuse in Johnson City.

Composition of the Municipal Refuse. Two studies of the production of refuse per capita and the composition of that refuse have been made in the same residential area of Johnson City. The first was performed by the Division of Technical Operations, Bureau of Solid Waste Management, in October 1967, and the second by the staff at Johnson City in July 1968.

The first study showed a production rate of 1.1 lb per capita per day of residential waste and the second showed a rate of 1.4 lb per capita per day (Table 3).

The composition of these samples was found by manually sorting the refuse into ten categories (Table 4). This refuse was higher in food wastes and lower in paper wastes than the averages usually reported since it was collected from a residential district. The refuse received daily at the Johnson City plant probably has a greater paper content. As previously mentioned, one load of commercial waste, with a very high paper content, is not received at the compost plant but is hauled directly to the landfill.

USPHS-TVA Composting Project

Description of the Project. The joint USPHS-TVA Composting Project has been for demonstration and research to study the feasibility of composting as a possible answer to the problem of increasing quantities of municipal solid wastes produced by municipalities. The major responsibilities of the principals are as follows:

TABLE 3

MUNICIPAL REFUSE PRODUCTION
Johnson City, Tennessee
(Residential Area)

	October 1967	July 1968
Refuse production (lb/capita/day)	1.1	1.4
Number of homes sampled	136	144
Population sampled	519.8	550.0
Population density (people/home)	3.82*	3.82*
Weight of refuse collected, lb (wet weight basis)	4,003	5,400
Sample period, days	7	7

*Based on 1967 study.

TABLE 4

COMPOSITION OF REFUSE
Johnson City, Tennessee

Category	Wet weight, pounds: October 1967	Wet weight, pounds: July 1968	Percent of total sample: October 1967	Percent of total sample: July 1968
Paper products	1,820.4	794.5	45.5	34.9
Food wastes	1,036.5	788.5	29.5	34.6
Metals:				
Ferrous		211.5		9.3
Nonferrous		24.5		1.1
Combined	433.0	236.0	10.8	10.4
Glass products	436.1	206.0	10.9	9.0
Plastics	67.0	76.5	1.7	3.4
Leather and rubber	40.0	55.5	1.0	2.4
Yard wastes	63.5	53.0	1.6	2.3
Cloth and synthetics	56.0	47.0	1.3	2.0
Brick, rock, dirt, etc.	39.0	3.5	1.0	0.2
Wood	11.5	18.5	0.3	0.8
Total	4,003.0	2,279.0	100.0	100.0

1. USPHS pays all costs incurred in the design, construction, operation, and maintenance of the plant and conducts research related to the process of composting, the nature of compost, the health aspects of compost, and the efficient operation of the composting plant.

2. TVA designs, constructs, operates, and maintains the compost plant and conducts research on the feasibility of commercial and agricultural use of the compost produced, on a reimbursable basis.

3. The city of Johnson City provides the site for the plant, mixed refuse from its collection system, and raw or digested sewage sludge from its sewage treatment plant.

While TVA operates and maintains the composting plant, USPHS has the responsibility for technical direction, which includes developing schedules for certain operations, monitoring the physical and chemical characteristics of the maturing compost, and altering schedules and procedures where these characteristics dictate such changes. The USPHS is studying plant operation and sanitation methods to avoid the production of odors and the propagation of flies and rodents and, in close collaboration with the TVA agriculturist assigned to the project is studying the improvement of composting methods and compost. East Tennessee State University, under contract with USPHS, and a microbiologist on the project staff, studied the survival of pathogens throughout the composting and curing periods.

As part of the feasibility study, USPHS and TVA are studying the economics of the plant operation on the basis of detailed cost records that TVA maintains.

Since TVA operates the National Fertilizer Development Center (NFDC) at Muscle Shoals, Alabama, one of the world's largest institutions for research and development of fertilizer, TVA has important resources for testing and demonstrating the value of compost as a soil amendment and for studying the marketing of compost. The principal use of compost is expected to be as a soil builder and conditioner with potential for application on lawns, gardens, parks, golf courses, and truck or specialty farms. Tests may show how compost fortified with nitrogen, phosphorus, and potassium can be used to produce an organic-base fertilizer. Disposal of the compost has been a major factor in the success or failure of many composting plants. Marketing, therefore, should be an integral part of the demonstration project and the study of the economics of composting.

The Division of Agricultural Development, TVA, has a number of test plots and demonstrations under study by the project agriculturist in the Johnson City area. Test plots have also been established at the NFDC, Muscle Shoals, Alabama. Such factors as the rate of application and effect of compost, on various crops, etc., are being studied. Greenhouse studies will be made, and some work has been started with the use of compost on bare areas, such as abandoned strip mines and highway cuts, for revegetation and erosion control.

Description of the Composting Plant. The composting plant began operating on June 20, 1967, to demonstrate composting of municipal solid wastes by the windrow method.

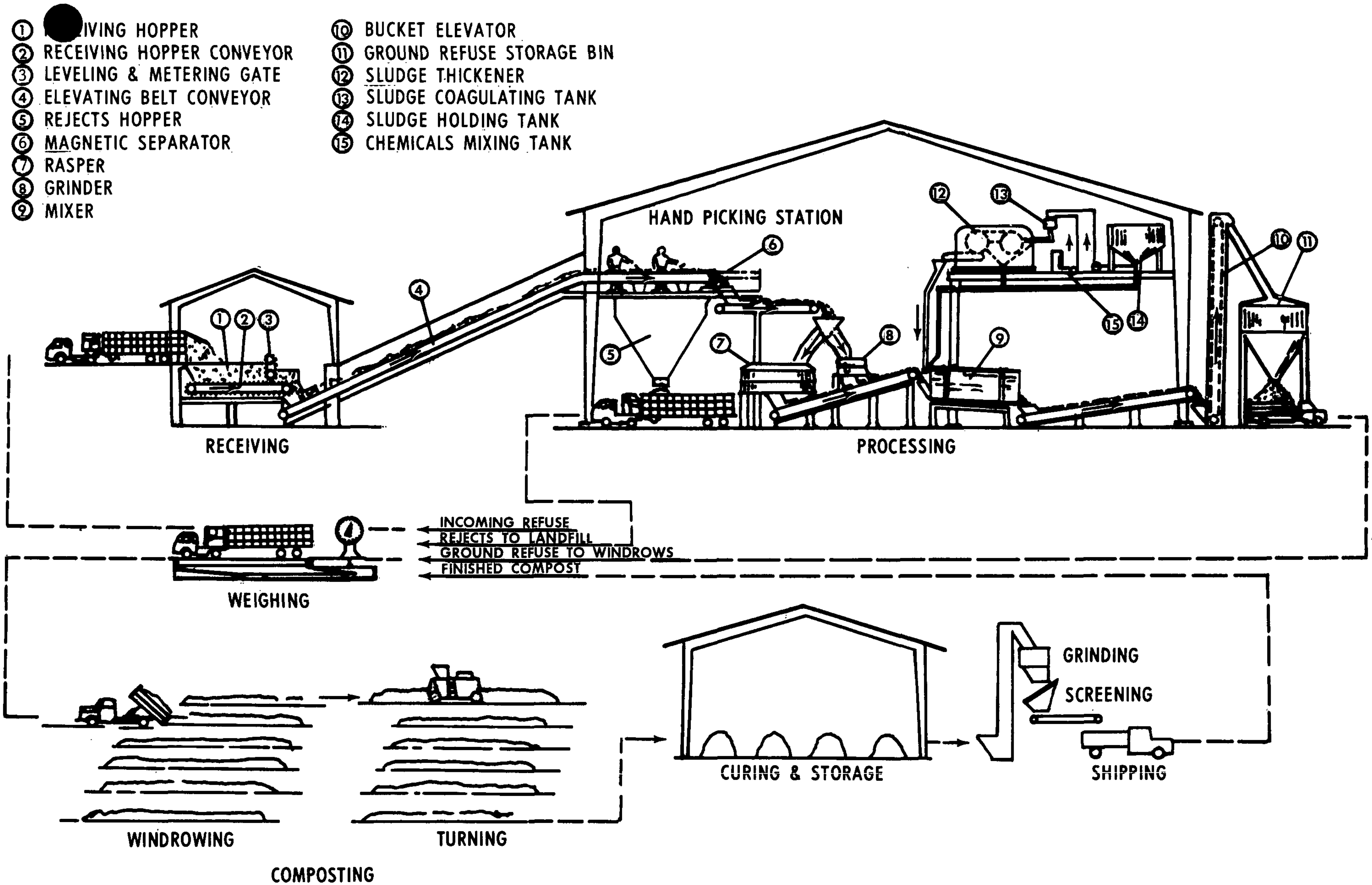
The plant was designed to process during a 5-day-week raw refuse and sewage sludge of 33,000 people, approximately the present population of Johnson City. Nominal capacity is 60 tons per day for an 8-hr shift.

Figure 5 shows an overall view of the plant. Figure 6 is a schematic layout of the processing steps, and Table 5 lists the plant equipment and specifications.

Refuse is delivered to the plant, 5.4 miles distant, in 53 and 65 cu yd compaction trailers from a central transfer station in Johnson City. The refuse is weighed and then dumped into a hopper in the receiving building or onto the paved apron to be later moved into the hopper by a front-end loader (Figures 7 and 8). Items such as mattresses, bed springs, bicycle frames, wire, which might block or entangle the equipment, are removed. A 6-ft wide plate conveyor, forms the bottom of the hopper and advancing at a rate of 2 to 10 ft per minute, carries the refuse under a vertical leveling gate and drops it onto a 3-ft wide elevating belt that carries it into the processing building. The receiving building is roofed and enclosed on three sides. The belt conveyor is covered between the receiving and the processing buildings (Figure 9).

The processing building is 40 ft by 60 ft and houses all of the refuse processing operations, the sludge thickener, and the refuse-sludge mixer. The elevating belt conveyor from the receiving building becomes horizontal after it enters the upper level of the processing building. It carries the refuse past a picking station at a rate of 60 ft per min (Figure 10). Two or more pickers manually remove bulky paper, rags, glass, plastics, metals, and other noncompostable material. The refuse placed in paper or plastic bags may arrive at this point with the bag still intact. Either the pickers must discard the entire bag or permit

Figure 5 - Joint USPHS-TVA Composting Project
Johnson City, Tennessee



① [illegible]IVING HOPPER
② RECEIVING HOPPER CONVEYOR
③ LEVELING & METERING GATE
④ ELEVATING BELT CONVEYOR
⑤ REJECTS HOPPER
⑥ MAGNETIC SEPARATOR
⑦ RASPER
⑧ GRINDER
⑨ MIXER
⑩ BUCKET ELEVATOR
⑪ GROUND REFUSE STORAGE BIN
⑫ SLUDGE THICKENER
⑬ SLUDGE COAGULATING TANK
⑭ SLUDGE HOLDING TANK
⑮ CHEMICALS MIXING TANK
HAND PICKING STATION
RECEIVING
PROCESSING
INCOMING REFUSE
REJECTS TO LANDFILL
GROUND REFUSE TO WINDROWS
FINISHED COMPOST
WEIGHING
GRINDING
SCREENING
CURING & STORAGE
SHIPPING
WINDROWING
TURNING
COMPOSTING

TABLE 5

DESCRIPTION OF MACHINERY AND EQUIPMENT
USPHS-TVA COMPOSTING PROJECT, JOHNSON CITY

Item	Description	Manufacturer & model	Capacity	Power Rating
Truck scale	Mechanical 10 x 34-ft platform scale with tare beam and remote dial weighs incoming refuse.	Fairbanks, Morse, Inc. Model 6507B	30 tons	
Refuse feeder and leveling grate	Double-beaded 5 x 28-ft apron feeder in bottom of hopper (fabricated at plant) moves refuse at 2-10 ft/min; vertical, hydraulically controlled leveling gate regulates flow of refuse.	Websters Mfg., Inc. Feeder and gate driven by Falk helical-geared speed changers, models 51BN2 and 224F2, respectively.	10 tons/hr	5 hp
Raw refuse elevating conveyor	Rubber-covered belt 3-ft wide moves raw refuse at 60 ft/min from receiving building to processing building under cover and then to picking station. Head pulley is permanent magnet (field: 400 Gauss, 5 in. from face at center) for removing ferrous metal.	Continental Conveyor and Equipment Co.	10 tons/hr	2 hp
Raw refuse cross conveyor	Rubber-covered belt 3-ft wide moves refuse at 60 ft/min from picking station to grinders.	Continental Conveyor and Equipment Co.	7.5 tons/hr	1 hp
Rasping machine	Arms on rotating vertical shaft force refuse against rasping pins projecting from sides and bottom of 18-ft-diameter housing until reduced to less than 2-in. particles that drop through perforated steel floor.	Dorr-Oliver N.V., Amsterdam. Type R.T.M. 55 V.S.T.D.	7 tons/hr	40 hp each, 2 motors
Hammermill	Mill with 44 chisel-point swing hammers (21 lb each) reduces refuse to particles that pass grate openings 2 in. by 1.5 to 2.5 in.	Gruendler Crusher and Pulverizer Co.	12 tons/hr	250 hp

TABLE 5 (continued)

Item	Description	Manufacturer & model	Capacity	Power Rating
Ground refuse cross conveyor	Rubber belt 2.5 ft wide moves ground refuse from hammermill to ground refuse conveyor.	Fabricated by TVA	7.5 tons/hr	1 hp
Ground refuse conveyor	Rubber belt 2 ft wide moves ground refuse from rasper to mixer at 200 ft/min.	Continental Conveyor and Equipment Co.	7.5 tons/hr	1.5 hp
Sludge concentrator	Electric-motor-driven stationary sewage sludge concentrator, traveling screen type, utilizing gravity as the dewatering driving force. The nylon filter cloth moves at a variable speed of 1.5 to 4.5 fpm. The unit is designed to dewater raw sewage sludge containing 3 to 5 percent solids and deliver a sludge cake with approximately 15 percent solids. In addition to the filter, there is a Wallace & Tierman flocculant dosing pump and a Worthington metering pump of the diaphragm type.	Permutit Co. Model DCG-200	Designed for 1200 gal/hr	
Refuse-sludge mixer	Rotary drum mixer, 3 ft in diameter and 10 ft in length. Internal vanes are designed for mixing the refuse and sludge and discharging mixture at outlet.	Designed and fabricated by TVA		
Conveyor for ground refuse-sludge mixture	Moves mixed refuse and sludge from mixer to bucket elevator. Rubber belt type, 2 ft wide.	Continental Conveyor & Equipment Co.	Rated at 890 cu ft/hr or 11.3 tons/hr at belt speed of 200 ft/min	1 hp

TABLE 5 (continued)

Item	Description	Manufacturer & model	Capacity	Power Rating
Conveyor for ground refuse-sludge mixture	Replaces sludge-ground refuse mixer when mixer is not in use. Belt is 2 ft wide and 15 ft long.*	Fabricated by TVA		1 hp
Conveyor for discharge of ground refuse	Used to transfer ground refuse to trucks when bucket elevator and storage hopper not used. Belt is 2 ft wide and 25 ft long.	Fabricated by TVA		2 hp
Bucket elevator	Vertical centrifugal type. Electric-motor-driven. Buckets are cast malleable iron, 14 x 7 in., 16 in. on center. Elevator used to transfer ground refuse to storage bin.	Fairfield Engineering Co. Model VCE, No. 147	Rated at 1650 cu ft/hr (75% of theoretical) at chain speed of 200 ft/min	3 hp
Storage bin	Cylindrical storage bin designed to hold several truckloads of ground refuse. Discharge to truck through horizontal sliding gate. Bin is 12 ft in diameter at largest dimension.	Designed and fabricated by TVA	About 110 cu yd	
Bucket elevator	Electric-motor-driven, vertical bucket, centrifugal discharge type. Used in moving compost from feed hopper to vibrating screen.	J. B. Ehrsam and Sons Mfg. Co. H-17	Rated at 1715 cu ft/hr (75% of theoretical) at chain speed of 221 ft/min	3 hp
Vibrating screen	Electric-motor-operated. Vibrating inclined screen with interchangeable wire mesh screens of 1/4- and 1/2-in. openings. Used to screen the compost.	Link Belt		

TABLE 5 (continued)

Item	Description	Manufacturer & model	Capacity	Power Rating
Compost grinding hammermill	Swing hammer type with 30 hammers each weighing approximately 2-3/4 lb. Electric-motor-driven, heavy duty type. Used to regrind compost.	J. B. Sedberry, Inc. 5W-26	10 tons/hr rated, did not grind compost at this rate.	100 hp
Windrow turner	Diesel-engine-driven, self-propelled. A rotating drum turns the windrow as the machine straddles the row. The drum has teeth arranged so as to move the material toward the center of the windrow as it is turned. The material is picked up from the ground, passed over the drum and redeposited behind the machine. The machine moves through the row at approximately 0.27 mph and is capable of turning windrows approximately 8-ft wide and 5-ft high.	General Products of Ohio, Inc. (Cobey) Model 003	500 tons/hr (spec. claim 1500 tons/hr of 700-lb/cu yd material)	100 hp + (122 BHP by specs)
Tractor shovel	Rubber-tired, gasoline-engine-driven front-end loader with general purpose bucket transports refuse, ground refuse, and compost.	International Harvester Company, Model H-50 (Ser. C)	Lifting: 13,200 lb Bucket: Heaped: 3-1/2 cu yd Struck: 3 cu yd	103 bhp at 2,500 RPM

*In late 1969 the mixer was found to be too small for the capacity of the new Gruendler hammermill. As sludge was not being processed, the mixer was temporarily removed and replaced by this conveyor.

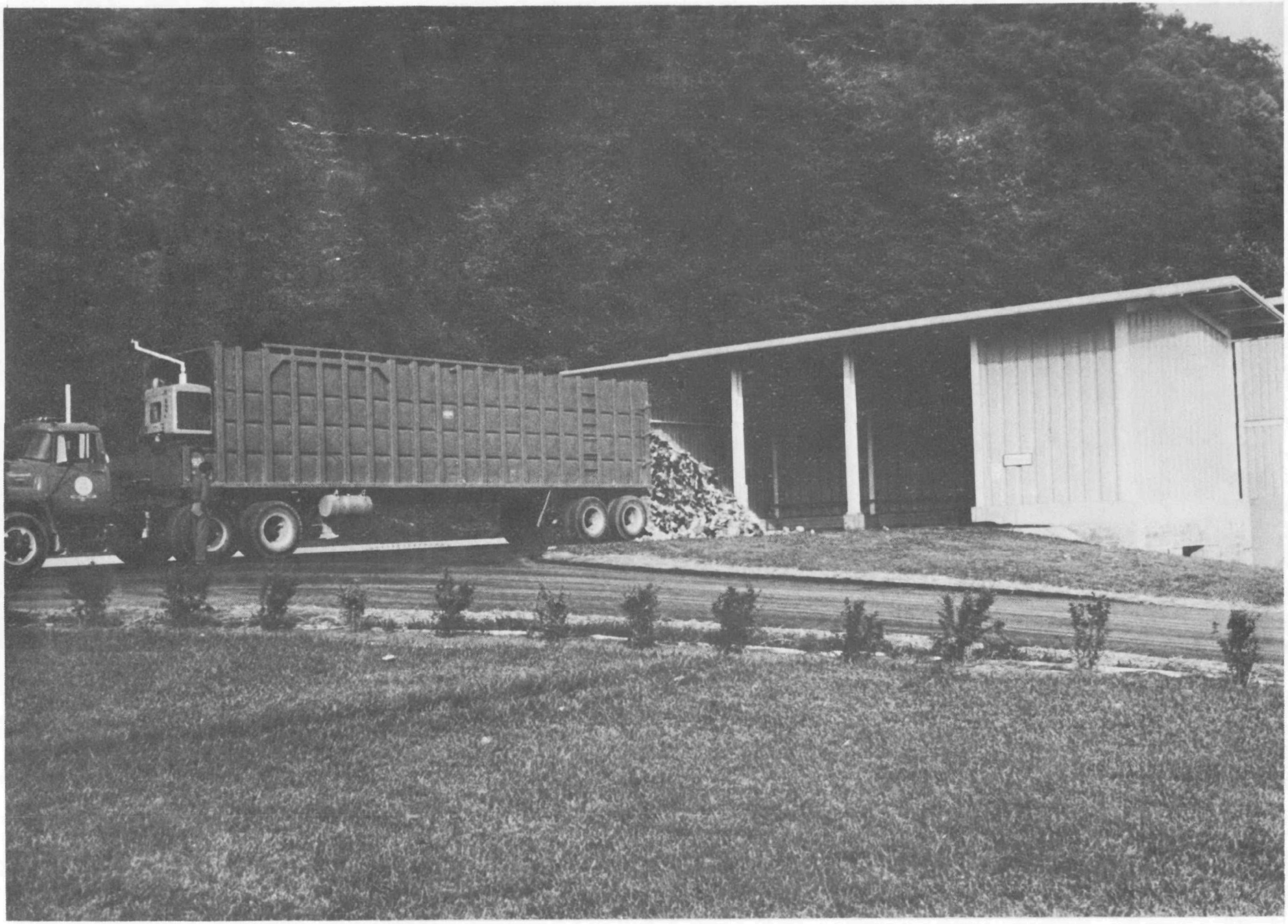


Figure 7 - Receiving building with a 65 cubic yards compaction trailer discharging refuse

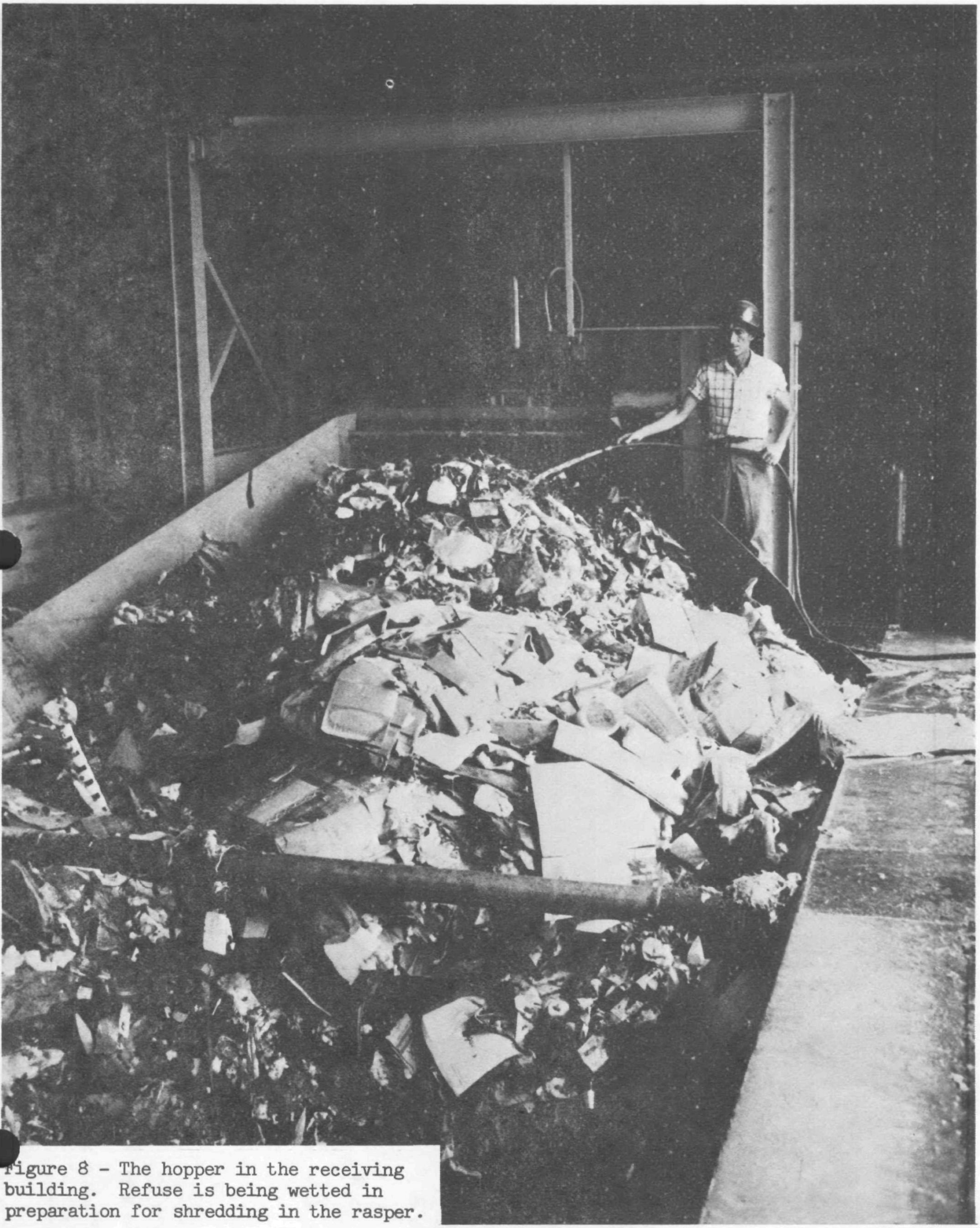


Figure 8 - The hopper in the receiving building. Refuse is being wetted in preparation for shredding in the rasper.

Figure 9 - Receiving building on the left and processing building on the right. The covered conveyor which transports refuse to the processing building can be seen between the two.

Figure 10 - The picking station inside the processing building. The men are attempting to remove noncompostable items and large items which might damage equipment.

some cans and bottles to pass since they cannot tear open all the bags. The belt then passes around a magnetic pulley where cans and other ferrous metal objects are separated from the refuse. Some plants may employ a primary grinding operation prior to magnetic separation to reduce the amount of compostable material that might be trapped by the ferrous materials and removed with them. The rejected material, including that removed at the receiving building, is weighed and hauled 4.6 miles to the Johnson City landfill. About 27 percent of the incoming material was rejected during the period of this report because no salvaging was practiced.

After removal of noncompostables the refuse proceeds to either a hammermill or a rasping machine for comminution. These are so placed that they can be used alternately for comparison of efficiency and costs of operation and maintenance.

The hammermill (Figure 11) is of the swing-hammer type, having 44 chisel point hammers each weighing 21 lb. The grate bars have 1-1/2- and 2-1/2-in. openings. The mill is driven at 1,150 rpm by a 250 horsepower electric motor and has a rated capacity of 12 tons per hr.

The rasping machine (Figure 12) is similar to that developed by the Dutch N. V. Vuilafvoer Maatschappij (VAM). It was imported from the Netherlands where it was constructed by the Dorr-Oliver Company. This machine consists of a covered cylindrical housing 18 ft in diameter and 8 ft 6 in. high not including the height of the conical cover. The perforated floor is about 3 ft above the bottom of the housing. Revolving arms attached to a vertical shaft in the center scrape the refuse against projecting pins in the floor and on the wall of the housing, finally

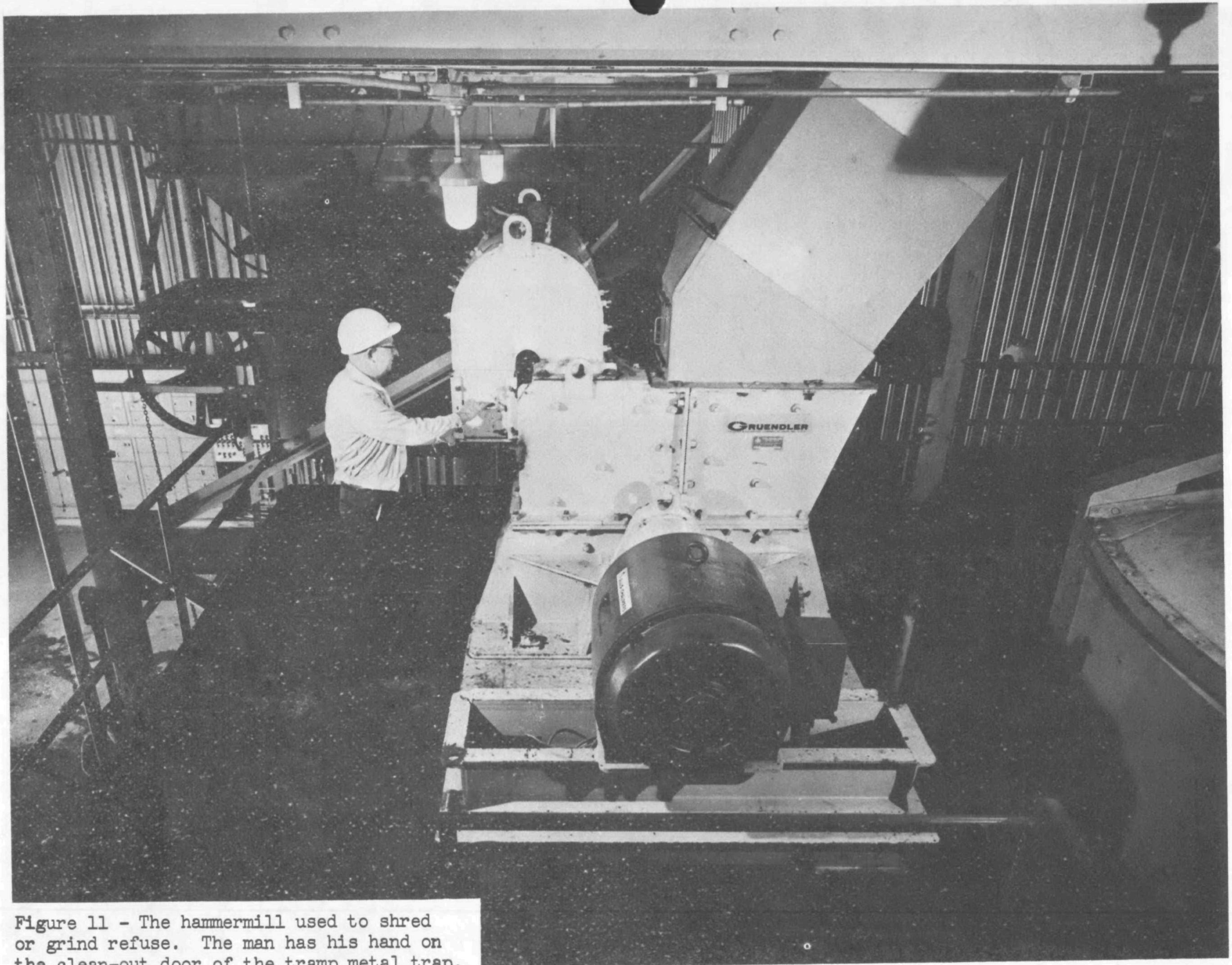


Figure 11 - The hammermill used to shred or grind refuse. The man has his hand on the clean-out door of the tramp metal trap.

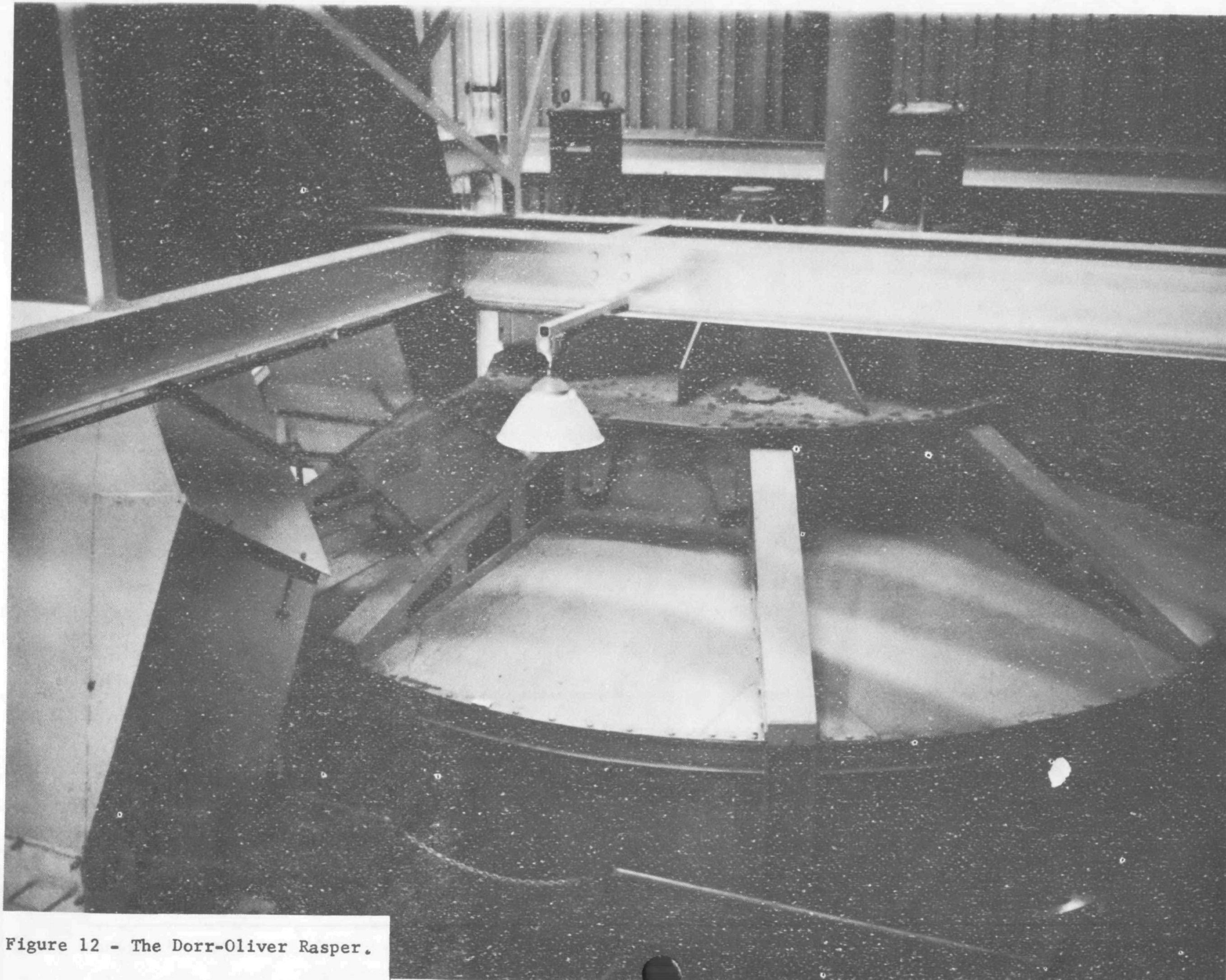


Figure 12 - The Dorr-Oliver Rasper.

forcing it through the perforations. The arms are driven by two 40 horsepower electric motors.

Refuse as received has an average moisture content of 39 percent. When using the rasper, water is added in the receiving hopper to presoften cardboard. Water is also added in the rasper. When the hammermill is used, water is added after grinding at a point ahead of the refuse-sludge mixer. The ground refuse or refuse-sludge mixture is adjusted to a moisture content of 50 to 60 percent by wet weight.

Raw or partially digested sludge containing 3 to 5 percent dry solids is pumped to the composting plant from the nearby sewage treatment plant. When using sludge from the same population generating the refuse, the water content is greater than that needed to obtain the 50 to 60 percent moisture content in the ground refuse-sludge mixture to be composted. Thus, especially with an operation using a rasper, sludge dewatering must be provided. For sanitary reasons it is impractical to add sludge to the refuse at any point in the process ahead of those places where the workmen must come into contact with the refuse.

Sludge is thickened in a Permutit Dual Cell Gravity (DCG) Solids Concentrator (Figure 13) to a moisture content of about 85 to 88 percent. This apparatus uses a revolving filter of fine-mesh nylon cloth. As a "plug" of sludge revolves inside the filter it becomes dewatered, rolls up, and is discharged. Special coagulants (polyelectrolytes) are used to condition sludge for filtering. The filtrate is returned with other liquid wastes to the sewage treatment plant where it is treated with incoming sewage. The thickened sludge is discharged to a conveyor belt which in turn discharges it to the mixer.

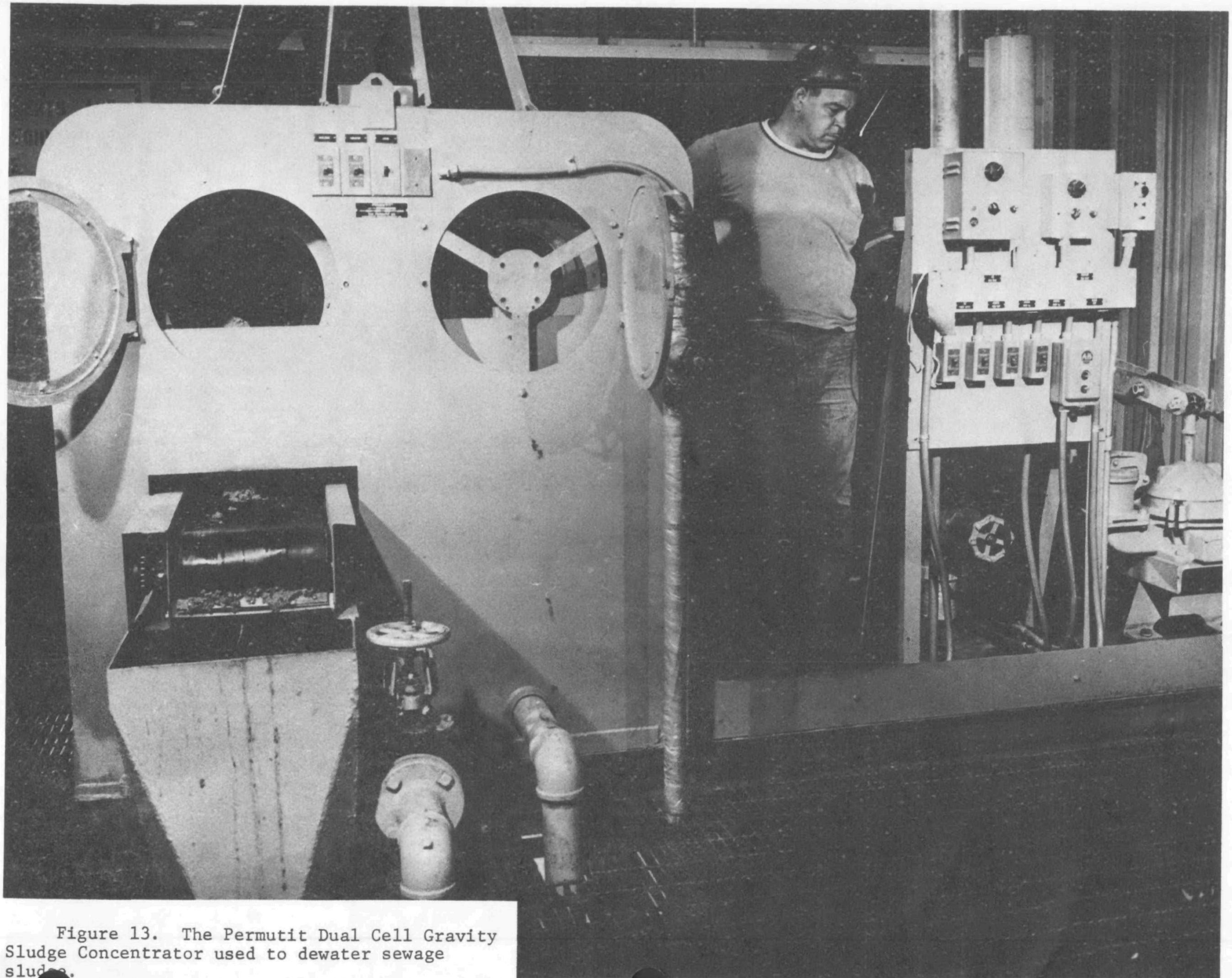


Figure 13. The Permutit Dual Cell Gravity Sludge Concentrator used to dewater sewage sludge.

Refuse and thickened sludge are mixed in a horizontal cylindrical mixing drum designed by TVA (Figure 14). As the drum revolves, internal vanes carry the mixture to the discharge end. From the mixer the material is carried to the ground refuse-sludge storage bin from which it is loaded into dump trucks and transported to the windrow area.

The ground refuse-sludge mixture is composted in windrows on a 4.8-acre area graded and stabilized with crushed rock. The windrows (Figures 9 and 15) are laid down so as to have a section as near to 9 ft wide and 4 to 4-1/2 ft high as possible. They can be as long as 230 ft. The "haystack" shaped cross-section will shed rain and the mass of a windrow so shaped will contain the heat of decomposition and can be aerated easily. The field is arranged to receive 34 windrows. As the plant operates 5 days a week and one windrow is laid down each working day, each windrow can remain on the field for a period up to 45 days. The active composting time in the field is 35 to 44 days.

During the time the material is being composted on the field it is turned 8 or more times with a special turning machine (Figure 16). This patented machine straddles a windrow, turning it with a rotating toothed drum as it proceeds from one end to the other. Turning aerates the windrows to supply the oxygen needed for aerobic decomposition. To maintain the desirable 50 to 60 percent moisture content, water can be added as needed before turning. Should rain cause the moisture content to rise above the optimum, the windrows are turned as often as necessary to dispel the excess moisture and return them to the proper wetness.

After the material has composted in the open field for a period of 6 to 7 weeks it is turned, taken from the field, and deposited in the

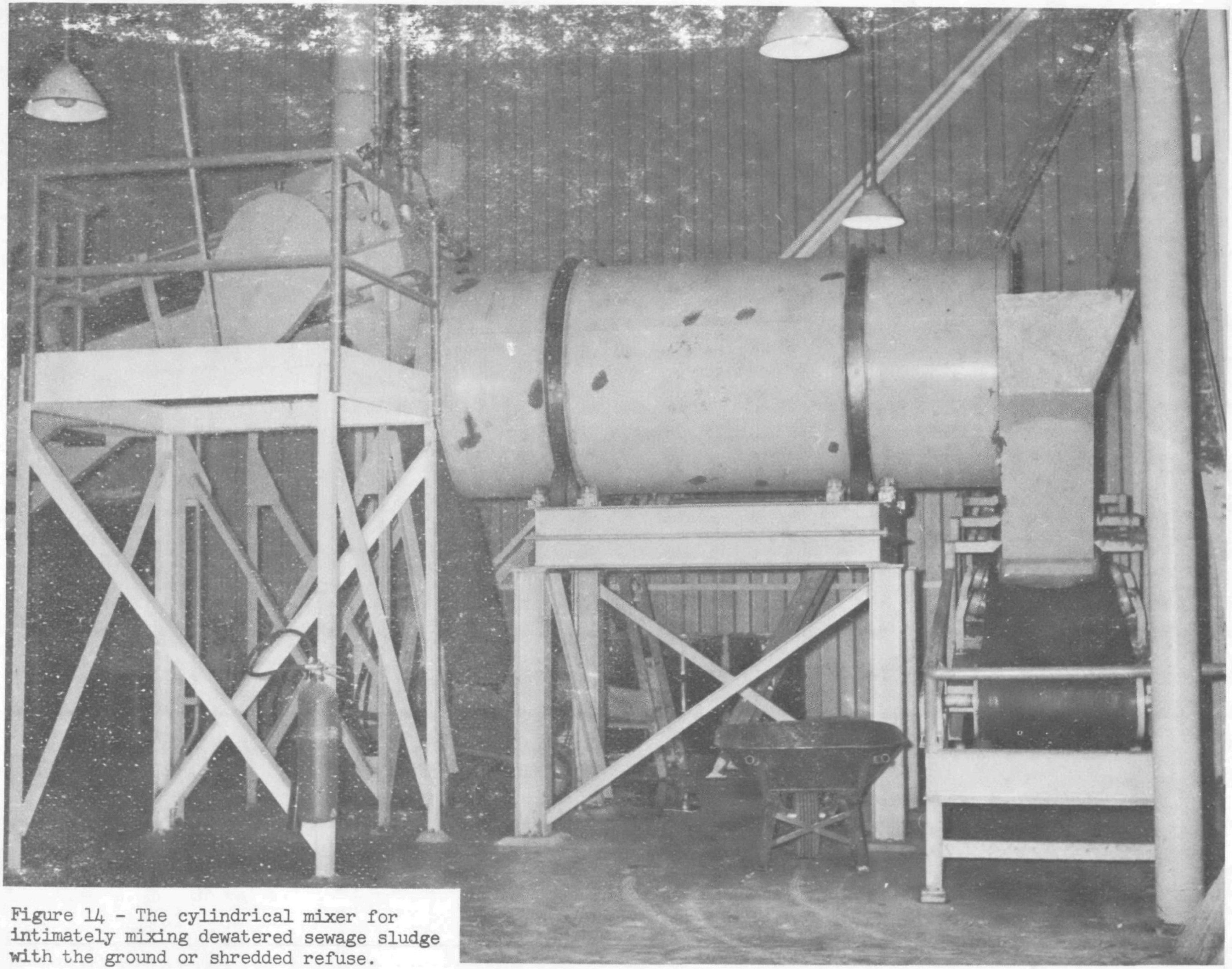


Figure 14 - The cylindrical mixer for intimately mixing dewatered sewage sludge with the ground or shredded refuse.

Figure 15 - A windrow of ground or shredded refuse.

Figure 16. The windrow turning machine. The machine straddles the windrow, turning it with the rotating drum as it passes through the windrow.

Cobey composter, front view.

curing and drying shed (Figure 17). This shed is 60 ft by 200 ft and provides a curing and drying period of 2 weeks, which is frequently insufficient to adequately dry the compost for screening.

Following the drying period, compost is screened and reground as required using a vibrating screen and a hammermill for this purpose. The screen is equipped with interchangeable wire mesh screens of 1/4 in. and 1/2 in. openings. The mill is of the swing-hammer type using hammers weighing approximately 2 3/4 lb each. A 100 horsepower electric motor drives the mill at 3,540 rpm and the rated capacity is 10 tons per hr. The screening installation is shown in Figure 18.

Compost is stored either in the unground and unscreened state or in the finished condition in stockpiles.

Construction Costs. Construction of the composting plant began on May 18, 1966, and was completed in June 1967. The total cost, including that of modifications made since startup, is $958,375. Constructed as a plant for both demonstration and research and including some duplicate equipment for comparison, the construction cost is somewhat more than would be required for a municipal plant.

Modifications Made Since Startup. Many modifications have been made to the plant since operations began. Important ones are tabulated below for the value they may have to future plant designers. They are given in the sequence of accomplishment rather than in the sequence of the process.

1. Repairing and strengthening the drive of the drum mixer and setting same in level position. Modification of vanes or flights inside the mixing drums. It was found that the

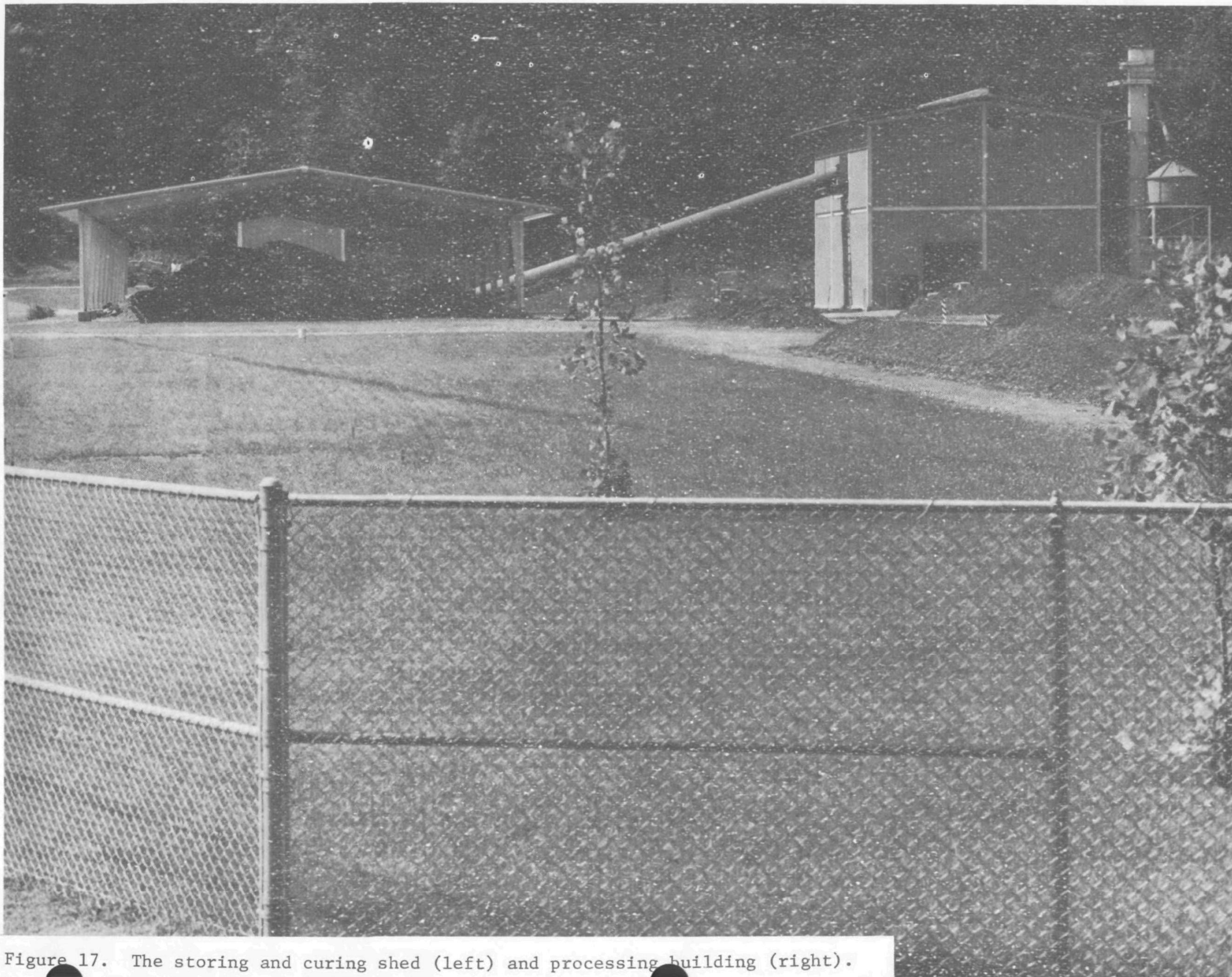


Figure 17. The storing and curing shed (left) and processing building (right).

Figure 18 - The final screening and grinding equipment. Compost is lifted by the bucket elevator and fed to the vibrating screen. Screened material is being collected in the truck. Material not passing through the screen is ground in a hammermill and re-cycled to the screen.

original inclination was not needed to carry the material forward. The level setting alleviated a side thrust on the supporting and rotating mechanism.

2. Addition of wipers to underside of conveyor belts and installation of drip or catch pans under the belts.

3. Addition of a curb or coaming around the floor which supports the DCG sludge filter and its appurtenances. Spillage in this area had caused cleanup problems.

4. Laying of plywood flooring over the grating floor at the picking station to prevent spillage to lower level. This also gives more comfort to men who must stand for long periods.

5. Covering conveyor belt drive motors to protect them from dust and spillage.

6. Applying thermal tape to pipes and valves in the process building to protect them against freezing. Installing heat lamps at end pulleys of certain conveyor belts to prevent freezing of belt to pulley during shutdown.

7. Removal of cover on cross belts from grinders to mixing drum. Covers over belt are not necessary except where they traverse an open area where the wind may cause a problem.

8. Installing a vertical pipe loop in the sludge pipeline between the metering pump and the sludge-flocculant mixing tank to equalize the hydraulic head of sludge in the holding

tank. It was found that the diaphragm sludge metering pump would not operate satisfactorily with the high positive head on the suction side resulting from the elevation of the sludge holding tank.

9. Removal of strut across receiving hopper at leveling gate end thus removing a cause for jamming. There should be no structural parts which catch refuse over or alongside a hopper.

10. Modification of chute under the leveling gate. A man must be able to dislodge refuse which may jam the flow at this point.

11. Installation of dual controls for the leveling gate and the plate conveyor at a station beyond the leveling gate. This gives the man beyond the leveling gate an opportunity to shut down this machinery when necessary.

12. Erection of targets or poles for aligning and positioning windrows. Ground refuse-sludge mix is deposited by trucks and the drivers need some guide in getting windrows in the correct position.

13. Adding pads to the bucket of a payloader to give clearance between it and the stabilized rock base of the field to prevent picking up rock with compost when it is being removed or when windrows are being shaped.

14. Correcting the slippage of the elevating conveyor belt by addition of weights for tension.

15. Adding skirts to the sides of the elevating conveyor belt to prevent spillage of refuse. This has saved much cleanup time.

16. Installation of a larger discharge gate for the reject bin. This bin discharges from the bottom. Gates must be as large as possible to avoid arching above the constricted lower part.

17. Installation of a larger discharge gate for the ground refuse bin. As in Item 16, gates must provide larger openings than those needed for grain, coal, or crushed stone.

18. Installation of a 12-ton-per-hr hammermill to replace the original 7-1/2-ton-per-hr mill. This is discussed later in the section on operations.

19. Back flow preventers were installed in the processing and receiving buildings and the composting field to protect the fresh water system from backflow from the sludge dewatering, washdown operations, and other possible sources of contamination. In the case of the sludge dewatering installation, the water supply piping was redesigned and reworked to enable one back flow preventer, located in a loop of pipe above the highest level of all other lines in the complex, to protect the portable water system from back-siphonage from this operation.

Staffing. For two years, the Division of Research and Development, Bureau of Solid Waste Management, maintained at the plant site a staff consisting of a Project Engineer, a Staff Sanitary Engineer, a Staff Chemist, a Staff Microbiologist, and a Staff Assistant. Thereafter, the technical staff was reduced to a Project Engineer and two part-time technicians. Laboratories, equipped for research and much more complete than would be needed for simple process control, were established on site for the chemist and the microbiologist.

The Office of Health and Environmental Science, TVA, is the official liaison between the TVA and the Bureau of Solid Waste Management. While this office has no resident staff at Johnson City, all interagency matters are handled through its staff. This office also maintains surveillance over the health of the TVA personsel at the plant with special attention to possible occupational problems specific to composting.

The plant is operated by the Division of Reservoir Properties, TVA, with the following on-site staff:

1 Foreman - in charge of daily operations.

1 Assistant Foreman - is in charge of the plant in the foreman's absence and also works as an operating engineer in some phases of the plant work.

2 Equipment Operators - these are classified as Operator B employees. One operates the windrow turner and the front-end loaders in addition to other duties. The other operates the sludge dewatering machinery and heavy equipment.

3 Truck Drivers - two work on the site or transport rejects to the landfill. One operates a truck equipped with spreading equipment and delivers compost to demonstration sites.

4 Compost Plant Laborers - one laborer is stationed at the leveling gate to do gross picking and to correct cloggings which occur here. Two work at the picking station. The fourth works where directed and presently performs the task of weighing incoming refuse, rejects, and outgoing compost.

If the Public Health Service staff now at the plant did not furnish this service, there would be a need for a clerk and laboratory technician, one man may perform both duties. This clerk would relieve the one laborer of weighing.

The Division of Reservoir Properties furnished higher-echelon supervision from its Morristown, Tennessee, office.

The Division of Agricultural Development, TVA, with headquarters in Muscle Shoals, Alabama, has the responsibility for the utilization and marketing studies and has one resident Agriculturist at the plant site.

Operations and Processes

Operating Schedules. At the start, the plant operated from 10:00 a.m. to 6:30 p.m. in the period of daylight saving time and 8:00 a.m. to 4:30 p.m. in the period of late fall, winter, and early spring. The warm weather schedule was adopted because of the lateness of the first delivery of refuse from the city. In colder weather, the last load of the day was held overnight to be on hand for the earlier start.

Later, changes were made in the city's delivery schedule to enable a truckload to arrive at about 8:30 a.m. each morning. Also, it was found that the last load of the day could be held over to the next morning even in warm weather if it was stored in the hopper and sprayed with an insecticide. Since then the plant has operated from 8:00 a.m. to 4:30 p.m. each day, summer and winter.

The plant does not usually process refuse after 3:00 p.m. The remaining hours of the day are devoted to the cleanup of the receiving and processing area.

Production. As previously mentioned, the plant is designed to process 10 tons per hr or 58 to 60 tons in 6 hr, leaving the remaining 2 hr for cleanup. It has been demonstrated that with refuse of favorable characteristics, the plant can process at this rate. The average capacity, however, is about 52 tons per day in 6-1/2 hr of grinding time.

The plant has been run as a research project. Although it normally takes all of the refuse delivered by the Sanitation Department of Johnson City, and there have been very few shutdowns, the plant has not been operated to full capacity for extended periods. Efforts are being made to extend the contributing area to a nearby city. At the present time, according to the city's Planning Office, the plant processes refuse from 31,200 persons.

Table 6 shows processing data for the period January 1968 through June 1969. The plant received an average of 34 tons per day. Based on the population served of 31,200, this is 2.17 lb per capita per day for the 5-day week and 1.55 lb per capita for a 7-day week. The 10 tons of commercial waste, routinely delivered directly to the landfill, brings the total tonnage collected to 44 tons per day. This indicates

TABLE 6

PROCESSING DATA FOR JANUARY 1968 THROUGH JUNE 1969
USPHS-TVA Composting Project

1968	Refuse received (tons)	Refuse rejected (tons)	Refuse received per day (tons)		Processing days
			Average	Maximum	
Jan.	554	142	26	48	21
Feb.	587	163	28	42	21
Mar.	698	178	33	53	21
Apr.	640	174	34	53	19
May	578	168	32	46	18
June	220	57	31	58	7
July	866	220	39	51	22
Aug.	932	214	44	55	21
Sept.	427	111	36	52	12
Oct.	544	154	39	61	14
Nov.	458	130	35	59	13
Dec.	661	178	31	45	21
1969					
Jan.	623	157	33	50	19
Feb.	573	150	29	39	20
Mar.	599	148	30	43	20
Apr.	775	213	36	48	22
May	758	218	36	50	21
June	773	226	37	53	21
Total	11,266	3,001*	34		333

*27 percent of incoming refuse.

a collection of 2.81 lb per capita per day for the 5-day week and 2.00 lb per capita per day for the 7-day week. As previously mentioned, this is low compared to the national average. Street sweepings and brush are not included in this quantity. Packing house and produce wastes are sold to piggeries. Much of the industrial waste of the city is hauled privately as is some of the household waste.

Of the incoming material, 27 percent was rejected as noncompostable and disposed of in the landfill.

A seasonal variation in refuse exists, as would be expected, and Figure 19 shows these variations.

Compost yield from the 11,266 tons of refuse received was about 5,650 tons (30 percent moisture content by wet weight). All of the compost removed from the field was not weighed. Two studies of yield, on which the above is based, are discussed in a following topic.

Receiving. The receiving hopper has a capacity equivalent to two trailer loads of refuse. When the hopper is empty, the 53 and 65 cu yd compaction trailers discharge a small part of their loads into the hopper and then pull away to deposit the remainder on the paved apron in front of the receiving building. A front-end loader is used to push refuse from the apron into the hopper. This procedure allows an inspection of the refuse, an opportunity to remove large items of noncompostables or those which interfere with the movement of the material, and the breaking up of compacted refuse. This latter treatment prevents serious bridging in the hopper. When the hopper contains refuse, the whole trailer load is deposited on the apron to be fed in as needed.

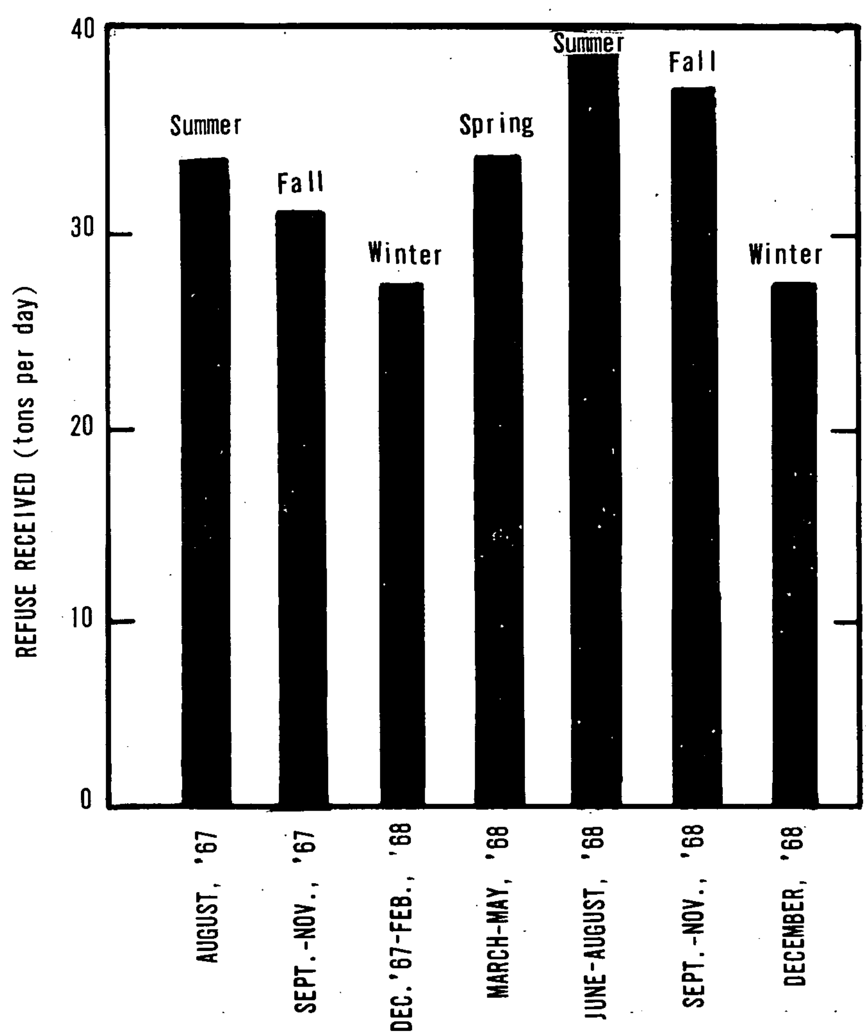


Figure 19. Quantity of refuse received at the USPHS-TVA Composting Project by seasons.

On one occasion, refuse failed to dislodge from the rear door of a 16-cu-yd packer truck as it was raised over the receiving hopper. This overbalanced the truck and the front end was lifted upward to almost a vertical position where it was caught by the eaves of the building. Both the truck's hood and the building were damaged. All packer trucks are now required to unload on the apron.

Gross picking is necessary at the receiving hopper and at the station behind the leveling gate.

Time records have been kept for the plate conveyor of the hopper and the main elevating conveyor belt. Table 7 shows that this machinery is capable of handling the design capacity of 10 tons per hr or more although the overall average for the last 6 months of 1968 was 9.3 tons per hr. On a day in which 58 tons of incoming refuse were processed, the machinery handled 9.9 tons per hr. On other days the rate of feed might be higher or lower depending on the characteristics of the refuse.

Operating difficulties since startup have been minimal. The drive motor of the plate conveyor required rewiring and a bearing has been rebuilt. Apparently the trouble was not caused by a condition of overloading with refuse. The 328 bolts which fasten the pans of the conveyor to the driving mechanism had to be replaced after some 26 months of operation. It was difficult to keep them tight and the repeated loosening ruined the threads. The new bolts have a finer thread and are installed with lock washers. An improved program of lubrication has been initiated to reduce heating of bushings, wear of bolts and other similar conditions.

TABLE 7

PERFORMANCE OF RECEIVING MACHINERY

1968	Hours of operation of receiving equipment and main feed belt	Tons of raw refuse moved to picking station	Tons per hour (average)
July	85	866	10
August	85	932	11
September	44	427	10
October	66	544	8
November	55	458	8
December	82	661	8
Total	417	3,888	9
June 5	6	58	10
October 30	7	61	9
November 27	6	59	10

Due to lack of stiffness the pans or segments of the leveling gate became bowed by the pressure of nonresilient items in the refuse. From time to time the clips attaching the segments to the drive chain broke and had to be rewelded. After processing about 17,000 tons of refuse during 26 months of operation, all of the pans were replaced with pans having heavier bar stiffeners.

The elevating conveyor belt has given no trouble since installation of the skirts to prevent spillage. Occasionally cardboard or other material jams under the cover but this is easily removed.

Grinding. The imported rasping machine has performed satisfactorily in the past 18 months of operation.

The manufacturer of the rasper states that it has a capacity of 7 tons by wet weight of picked raw refuse per hr. Time and tonnage records kept over a 6-month period show the rasper to be grinding an average of 5.6 tons per hr of refuse from which noncompostables and other objectionable material have been removed (Table 8).

The rasper must be run for about 10 min as refuse is fed to it before ground material is produced. It then builds up to a maximum production which can be maintained by keeping it full. After the feed belt is stopped, the machine must continue to run at a decreasing rate of production to process the grindable refuse remaining in it. If the rasper is emptied of grindable material at any time during the day, this cycle must be repeated. This characteristic of its operation is reflected in the average tonnage per hr given above.

The character of the refuse has an effect on the rate at which it can be handled. On one day when 61 tons of incoming refuse were processed,

TABLE 8

AVERAGE PERFORMANCE OF RASPER

1968	Hours of operation	Tons of sorted raw refuse ground*	Tons per hour (average)†
July	113	646	6
August	108	718	7
September	57	317	6
October	77	390	5
November	64	327	5
December	96	482	5
Total	515	2,880	6
Rasper Performance on Days of Maximum Runs			
June 5, 1968	6	43	7
October 30, 1968	8	44	6
November 27, 1968	6	43	7
One Hour Test Runs with Rasper Full			
January 15, 1969	1	7	
January 17, 1969	1	7	

*Tons of sorted raw refuse averaging 39 percent moisture by wet weight, or the weight of incoming refuse minus that of rejected material. Actual weight of ground refuse produced is greater than this due to water added to obtain a 60 percent moisture content.

†The rasper must be run for about 10 minutes as refuse is fed into it before it produces a ground material. It then builds up to a maximum production which is maintained if the rasper is kept full. After the feed belt is stopped, the rasper must be run for 20 to 25 minutes to finish processing the grindable material still in the machine. Due to the schedule of refuse deliveries or for other reasons the rasper usually cannot be kept full throughout the day and the average production figures reflect this situation. The character of the refuse can also affect the production of the rasper considerably.

the 44 tons of sorted (picked) refuse were ground at a rate of 5.3 tons per hr. On another day, when 59 tons of refuse were processed, the rasper's rate for the 44 tons of picked material was 6.9 tons per hr.

On test runs of one hr with the rasper full, a rate of 7.1 tons per hr of sorted material received with a moisture content of about 39 percent was observed. It appears that this machine can meet the manufacturer's claims.

Water must be added during processing to obtain a moisture content of 60 percent by wet weight in the material laid down on the field for composting. In practice it is added first in the receiving hopper to soften cardboard and again in the rasper as needed. The rasper is equipped with spray nozzles for this purpose and will not grind dry cardboard without operating difficulties. The actual weight of material entering the rasper is, therefore, greater than its weight when received at the plant. On the occasion of the rasper's grinding 7.11 tons per hr (39 percent moisture), it was discharging 10.8 tons of ground refuse with a water content of 60 percent.

At the end of the day, there always remains in the rasper some residue. This includes material such as metal cans, items of nonferrous metal, rags, bits of wood, and wire. This material must be removed at intervals either manually or through the rejection opening.

When the refuse is difficult to grind, the rasper can become overloaded by the buildup of material. To date this has not caused any mechanical trouble but it does consume time when it is necessary to remove the excess material by hand.

Very little maintenance has been necessary. Not long after startup a bearing in one of the American-built motors required repair which was done by the manufacturer. The main bearing of the shaft which carries the rotating arms became overheated soon after operations were begun. This was corrected by a modification of the lubrication of this part.

In March 1969, after 20 months of operation and the grinding of 8,720 tons of sorted refuse, the rasper bottom plates, pin plates, and wear plates were removed and replaced. The 8,720 tons of picked refuse represent nearly 12,000 tons of incoming refuse. In September 1969, after 26 months of operation, two of the rasping arms broke at the point where they are fastened to the rotor. These were rewelded with some steel reinforcement by plant personnel. Three others, not broken, were also strenghthened and such trouble is not expected to recur within 2 years.

The hammermill originally installed in the process building did not produce the particle size desired or achieve the specified capacity for grinding 7-1/2 tons per hr of raw refuse. Tests during the first 6 months of plant operation showed a capacity of 5.6 tons per hr. In late 1967 and early 1968, experiments were conducted with several grate size combinations to see if a better particle size could be obtained. The smaller the particle size produced, the greater were the operating difficulties and the smaller the grinding capacity. In March 1968, tests with the original grates showed a production of only 4.2 tons per hr.

On every occasion of operating the mill for grinding refuse, stoppages in the feed chute occurred. Before an arrangement was made whereby the mill could continue to run after the feed belt was stopped, the mill jammed and could not be restarted until it had been opened and cleaned out. After March 8, 1968, the use of the hammermill for grinding of refuse was discontinued.

From March through December 1968, the hammermill was used only for regrinding compost for use by the TVA agriculturist. Between March and October 1968, a total of 624 tons of compost at least 6 weeks old was ground at an average rate of 8.9 tons per hr. The range of production was from 3.7 tons per hr to 15.6 tons per hr. The dryness and other characteristics of the material and the speed with which it can be fed into the mill affect the rate of grinding. Compost with a water content over 30 percent by wet weight can give trouble by sticking and jamming. Material that is very dry can create a dust problem.

In mid-October 1968, the hammers were replaced with a set which had been refaced by a buildup of welding rod. A total of 288 tons of compost was subsequently reground at the rate of 13.6 tons per hr.

The hammers taken out of the mill in October 1968 had been installed in November 1967, and had been used for 102 hr. Of this time, 27.4 hr had been for grinding refuse. Total weight of refuse for this period of grinding refuse was not determined as it was the accumulation of several short experimental runs.

Experience had shown that the hammers of this mill required refacing after 40 hr of refuse grinding. After about 27 hr of grinding, they would have had 13 hr of remaining usefulness for this purpose. Thus, 13 hr for refuse grinding were good for about 74 hr of compost grinding. At this rate, a set of refaced hammers might serve for nearly 230 hr of compost grinding. This mill had ten 50-lb and four 15-lb hammers operating at 1,800 rpm, driven by a 125 horsepower motor. The grates were of the bar type. The mill recently installed for regrinding compost is a different type, having narrow hammers weighing about 2-3/4 lb each, designed to rotate at 3,450 rpm, and powered by a 100-horsepower motor. It is intended for grinding compost that has been rejected by the vibrating screen. Information obtained on the wearing of hammers on the larger mill is not applicable to the new final grinder.

In February 1969, a new and much larger hammermill for refuse grinding was installed. This mill is described in Table 5. During the month of March 1969, it had been operated for 47-1/2 hr, grinding 275 tons of refuse, when the hammers were taken out for rebuilding. The hammers were badly worn resulting in less efficient particle size reduction and indicating that removal after approximately 40 hr of operation seems to be necessary. Rebuilding after 30 hr will result in less difficulty in refacing.

The short experience with the new hammermill has shown that the pickers and the magnetic separator may miss large pieces of metal that will give trouble. In one case, a steel ball bearing almost 3 in. in diameter got into the mill. In another case, a large piece of metal was thrown about in the mill with such force that the 1/2-in. steel cover was bent. A tramp metal trap, which is quite heavy, was installed. This in turn necessitated the installation of a trolley hoist above the hammermill to assist in removing the trap and cover during hammer changes or for other reasons.

Experience to date has been insufficient to evaluate the cost of operating the new hammermill.

Addition of Sewage Sludge. On January 2, 1968, the routine addition of sludge was attempted.

Sludge is pumped from the primary sewage treatment plant adjacent to the composting plant into a 2,600-gallon holding tank. From this tank it is transferred to a mixing tank by a diaphragm metering pump. A anionic or cationic polyelectrolyte flocculant is introduced into the line ahead of the mixing tank by a positive displacement feed pump. After mixing, the sludge flows into the filter.

In January and February of 1968, subfreezing temperatures on eight occasions made it impossible to process sludge. The processing building was unheated and the freezing of pipelines and even dewatered sludge was experienced. Wrapping of pipelines with thermal tape and the installation of space heat in the building have corrected this problem.

When a breakdown of the sludge filter occurred, there was difficulty in disposing of unneeded sludge due to the arrangement of the sludge return lines. It was decided to add sludge on a 3-day-a-week basis in order to carry on the essential pathogen survival studies.

In July 1968, the plant again attempted to process sludge daily. Of the 103 days on which refuse was processed in the second half of 1968, dewatered sludge was incorporated into ground refuse on 75 days.

Of about 348,000 gallons of sludge received from the Johnson City sewage treatment plant, 261,000 gallons were processed through the filter. The average number of gallons processed per day of filter operation was 3,480. On 13 days the plant was unable to process sludge because of downtime on the filter. Of the 75 sludge processing days, the filter was operated only part of a day on 12 occasions on account of downtime. Over the 6-month period the added sludge solids averaged about 3.9 percent of the dry weight of the raw refuse-sludge mix laid down in windrows. On occasion, greater amounts were added for specific experimental windrows.

The DCG filter is capable of dewatering sludge from a water content of 96.9 percent to 85.0 percent of wet weight. The capacity (not necessarily raw sludge) is specified as 1,200 gallons per hr. The monthly average rate has ranged from 861 to 1,060 gallons per hr. The maximum amount of sludge processed on any one day has been 5,643 gallons. The equipment installed is not capable of handling all of the sludge generated by the 27,000 population served by the city sewer system.

The flash mixing tank, where the sludge is mixed with a flocculant before it enters the dewatering cells, is equipped with a DC motor, the speed of which is controlled by a rheostat. This rheostat burned out and the mixer was subsequently operated with an AC motor. This operation must be intermittent, however, because the motor runs at too high a speed. Permutit's attempts at obtaining a replacement rheostat have failed as the company that manufactures the speed control unit will not sell parts for it. An alternate solution is to install a gear reducer for the AC motor. Permutit is to supply parts numbers for such a reducer.

The sludge inlet piping to the dewatering cells splits the flow from a flash mixing tank into four parts by using a weir box. Rags and other large materials tend to clog this box, requiring continual attention to insure steady flow. The cause of this trouble lies partly in design, which Permutit intends to correct in future models, and partly in the fact that the Johnson City sewage treatment plant does not have comminution.

Trouble was experienced with the displacement of the sprocket idlers over the cells. When these came loose, the cell moved out of position and became deformed and jammed. The manufacturer recognizes this fault and will design a correction into a test machine being constructed; it is not known if this correction can be applied to the apparatus installed in the composting plant.

The nylon mesh filter medium is stretched between rubber seals which in turn are attached to a drive chain which imparts the rotary motion to the cells. The seals were not strong enough to stand the stress of being part of the drive mechanism and still support the weight of the sludge roll between them.

Metal inserts in the seals to which the drive chains are bolted proved to be too weak for the purpose. The machine was developed for dewatering digested sludge which forms a smaller roll than the raw sludge treated at the composting project. Raw sludge forms rolls in the order of two to three times the size of those for digested sludge, overloading the seals, and pulling out the inserts. Each time this happened the seal had to be replaced before the operation could be continued, a rather time consuming task.

Due to these troubles, the processing of sludge in the first half of 1969 was intermittent.

Permutit has redesigned the seals so that the new inserts have two horizontal projections instead of one, the web is incorporated into the new seal as it is poured instead of being glued on later, and the new seal is poured in one piece instead of several short pieces. The result is a unit construction which should be capable of carrying a much larger load than the original seals. The manufacturer supplied the project with a full set of these new seals in the late spring of 1969, and one unit of the filter was equipped with them. In July 1969, it was decided to temporarily cease the processing of sludge in order to devote time and funds to other investigations. The new seals have therefore not been tried in continuous operation.

From the above discussion, it can be seen that the sludge operation has fallen below expectations. In defense of the filter, which was still in the developmental stage, there were times when other operations in the plant or difficulties at the sewage treatment plant resulted in a short day's run. There were times when the quality of the sludge as received made it unmanageable and part of it had to be wasted back to the sewage treatment plant. As it is sometimes drawn from the digester and at other times directly from the primary settling basin, the quality of the sludge has been variable. Furthermore, since there is no comminutor at the sewage treatment plant, rags, sticks, etc., may come through and clog the troughs in the DCG. Raw sludge has better dewatering characteristics than digested sludge.

Handling and Storage. The ground refuse-sludge mixture is moved by conveyor from the mixer to a bucket elevator which lifts the material into a 12-ft diameter cylindrical storage bin. The bin was designed to hold several truckloads of material so that a truck could shuttle back and forth from this point to the windrow field. The bin discharged to the truck through a horizontal sliding gate in the bottom. The bottom third of the bin tapers toward this opening.

It was found that due to arching ground refuse would not flow through the gate after it builds up in the bin. A vertical screw feed was tried, but was unsuccessful. The gate has been enlarged and now a truck can load, make a short trip, and return to be loaded again without trouble. If the truck does not return shortly, however, the bin will clog. The conclusion is that bins should have straight sides and a live floor. A common ensilage wagon with such a conveyor floor has been tried with success in an experiment.

Windrow Maintenance. Although the windrow turning machine successfully mixes and aerates the composting refuse, structural and mechanical troubles have caused it to have considerable downtime, this being only the second such machine ever built by the manufacturer.

The machine as delivered tended to spread the windrows. The addition of teeth to the rotor and changes in their inclination to the center improved the capability to maintain the shape of a windrow. A vexing trouble was the frequent breaking of the drive chain. Overheating of fluid in the hydraulic transmission resulted in failure to transmit sufficient power.

In the spring of 1968, the manufacturer had a mechanical engineer design some improvements and sent a mechanic to the plant to make modifications. Work on the rotor teeth resulted in a machine capable of shaping windrows newly laid down by the dump trucks. A stronger drive chain with an improved idler sprocket arrangement was installed. The hydraulic drive system was improved including cooling of the fluid, some repairs were made to the rotor, and the chassis or frame was somewhat strengthened.

In August 1968, a shaft in the gear train broke on two occasions. Since the motor produces over 100 horsepower (BHP 122 by specification) and the reducing gear has a nameplate rating of 18 horsepower, TVA operations staff installed a torque limiter to protect the gear train.

Despite the torque limiter, gear train troubles have persisted. Some motor troubles were experienced but these had nothing to do with the design of the turner.

In December, the axle and king pin of one of the rear (steering) wheels broke. This was expected due to the light construction and the stress put upon it by an unsophisticated steering arrangement. The steering has been improved by the TVA and the stronger king pins installed.

After the modifications made by the manufacturer in April 1968, the machine moves over the ground at 0.27 miles per hr instead of the 4 miles per hr claimed by the manufacturer. This speed is not appreciably changed in working through a windrow and the machine appears to be able to aerate about 500 tons of compost per hr. Even at this slow rate, it is capable of turning the 34 windrows in 4 to 5 hr. Rarely would it be necessary to turn all windrows on the same day.

During composting, the windrows tend to slump. To maintain a desired windrow cross-section, they must be reshaped. Before turning, the margin or foot, where the side of the row meets the ground, must be picked up and placed on top or at the end of the windrow to assure that this part of the material will be subjected to the heat generated within the central mass.

Windrows must be kept at 50 to 60 percent moisture content at least until the 28th day. If they become too dry, they must be wetted and turned. Should they become too wet, turning can help to dry them. In the summer of 1967, wet weather gave some trouble. The summer and fall of 1968, were much drier than were these seasons in 1967. Added to this, Johnson City suffered a severe water shortage and asked users to practice conservation as far as possible. The watering of windrows was cut to a minimum and by the end of September, the use of domestic water for the complete daily washdown of the plant was discontinued. Portable irrigation pipe and a portable pump were brought in from a nearby TVA installation. The pump was set up near the plant on the bank of a creek entering the Watauga River and this supply was used for washing down operations. The city put a new filtration plant into operation in mid-1969 and there is now an ample supply of water.

Curing and Drying. As mentioned above, the water content of the digesting refuse is kept between 50 to 60 percent by wet weight throughout the first 28 days. By the 42nd day, the moisture content is usually between 40 and 50 percent. Trouble has been experienced in air drying this compost to the 25 to 35 percent moisture content desired for screening, regrinding, and final disposition. Except in very dry weather, the 2-week storage under cover of the curing shed does not accomplish this moisture reduction. In wet weather, the moisture content can be static for long periods. In dry weather, better results have been obtained by leaving windrows uncovered on the field exposed to the sunlight. Experience indicates that for commercial production of compost in a climate similar to that at Johnson City, mechanical drying equipment may be desirable.

Screening and Grinding. In the summer of 1968, regrinding was done in the hammermill originally installed for grinding raw refuse. No screening was done. In February 1969, a mill procured for regrinding and the vibrating screen were installed. The winter had been wet and extreme difficulty was experienced in obtaining material dry enough to screen or regrind. It was not until late April that compost was dry enough for real testing. None had reached the favorable moisture content of 25 percent.

The use of compost in agriculture is seasonal, in fall and spring. It appears that compost will have to be screened and reground in late summer and stockpiled for fall and spring use.

The compost as taken from the field is still quite hot but has been reduced to an inoccuous, earth-like material with no objectionable odor. The composting activity still goes on but at a slower rate. The heat is dissipated slowly from the inner mass of stockpiles, but is reduced. Drying reduces microbial activity and further enhances cooling. Decomposition is not complete, but for many uses, it has reached a practical point in large-scale composting.

Although the vibrating screen and a compost grinding mill were installed in February 1969, operating troubles and dry difficulties have prevented a full evaluation of this phase of the operations.

The compost is first screened and that material which does not pass through the screen is ground and then recycled to the screen. Considerable trouble was experienced due to blinding with the 1/4-in. and 1/2-in. woven wire mesh screens first installed. A perforated plate screen with 7/16-in. openings is now being used. This screen will pass about 50 percent of fresh compost when the moisture content is between 30 and 35 percent by weight. Production is 1 to 3 tons per hr, much less than the 10 tons per hr expected.

The hammermill installed for grinding compost has proven inadequate and has experienced excessive hammer wear. A set of hammers furnished with the mill lasted for only 8 hours grinding at the rate of about 2 tons per hr. Because of the excessive cost of replacing or rebuilding the hammers furnished with the mill, hammers fabricated from strap steel are now used and discarded when worn. About 80 tons are ground between changes.

Because of the disappointing performance of the small hammermill, consideration has been given to replacing it with the Williams hammermill formerly used for grinding refuse. This mill has shown a capability of grinding more than 10 tons per hr of compost. A rotary, drum-type screen is being considered to replace or supplement the vibrating screen.

Fly Control. On June 20, 1967, it became evident that flies were a problem.

Through the Regional SWP Chief, Region IV, an inspection by an entomologist of the National Communicable Disease Center was arranged. The Division of Health and Safety, TVA, also arranged for a TVA entomologist to visit the plant. It was the opinion of these two entomologists that although flies were breeding on the windrow field, the greater number had come to the plant in the refuse as eggs, larvae, and pupae. In the several days that it takes for a windrow to reach an elevated temperature, eggs hatch, and larvae migrate to suitable places for pupation. After windrows heated up and were turned twice a week during the first 14 days, breeding was lessened because of the heat destruction of eggs and what breeding appeared occurred mostly at the "toe" where turning is less efficient and temperature is low.

Before the inspections by the entomologists, the receiving and process buildings had been sprayed with a pyrethrum-piperonly butoxide space spray and Dibrom in solution had been used on the walls and on the windrows. Application was by a gasoline powered sprayer. Only partial control was obtained.

The CDC entomologist recommended Dimethoate in an emulsifiable concentration for space spraying and as a mist or fog in the windrow area to kill adults. For larvae, Dimethoate wettable powder suspension was recommended for a residual on the walls of the receiving and processing buildings. At the receiving building, larvae could be seen migrating from fresh refuse. He further recommended that Dimethoate wettable powder be incorporated into the ground refuse before it was laid down in windrows. This material was obtained and tried as a residual and a mist. The equipment on hand did not create a mist of the magnitude necessary and a spray was applied directly to the windrows. Some abatement was accomplished but flies continued to be a problem until cold weather set in. The recommendation for adding the insecticide to the ground refuse was not followed because of the unknown effects upon the flora carrying on the composting and upon the pathogen survival study.

The inspecting entomologists pointed out the fact that the once-weekly collection in Johnson City was related to the large number of larvae in every stage of development found in the incoming refuse. In their opinion, two collections a week would probably aid in the control of flies at the plant.

On July 5, the first significant fly population of the summer of 1968 was observed at the plant. Using a Dynafog Model 40 gph nonthermal fogger or mister and an emulsion of 12 gallons of 23.4 percent Dimethoate emulsifiable concentration in 38 gallons of water, control was effected. This dosage is equal to the recommended 6 gallons of 50 percent Dimethoate EC in 50 gallons of water. The speed of application was 4 miles per hr and it was found that only the four youngest windrows on the field needed fogging. The dosage was later reduced to 8 gallons of concentrate in 42 gallons of water with equal control being accomplished.

The receiving building and the apron were sprayed with a Dimethoate emulsion for the residual effect. Although fly larvae could be seen migrating from fresh refuse received at the plant, very few appeared to pupate. On the composting field, there was some breeding of flies in the toe of the windrows. This material is now picked up with a payloader and placed on the top of a windrow or at the end before each turning.

Interviews with county agriculturists and health officials disclosed that fly populations had been abnormally high on the refuse dumps in nearby Elizabethton and Jonesboro and in dairy barns in the summer of 1967, in contrast to abnormally low populations in the summer of 1968. The rainfall for the area in the period July through September in 1967, was 11.14 in. (normal being 11.97 in.) with 19 consecutive days of rain in July. In 1968, the precipitation for the area was 6.14 in. with a comparatively dry July. The experience of 1968, therefore, did not show to what extent the controls practiced would have been effective in 1967.

In the period July through September in 1969, the rainfall in the area was 14.60 in., as compared to the normal of 11.97 with 8.18 in. in July mostly occurring as thundershowers followed by sunlight. At the plant, where a rain gauge was being maintained, the rainfall was 9.65 in., with the July precipitation well below that for the area. At no time during that summer did flies become a problem, indicating that the control measures described above appear efficient.

Removal of Plastics and Glass. Plastics, particularly plastic film, present a problem. Shreds of plastic film persist through composting and are carried from the windrows by the wind, causing an unsightly appearance of the grounds. Regrinding and screening reduce the size and amount of the shreds to where they are unobjectionable in the finished product.

As it would be advantageous to remove plastic film before the refuse-sludge mix goes onto the field, TVA has conducted experiments for film removal. Several arrangements of apparatus have been tried, using the principle of separating the plastic film from the ground refuse solely by air currents. Although these showed promise, a significant amount of film has not been removed in this way.

Glass particles are objectionable if they are not ground fine enough or if sharp pieces remain after grinding. At Johnson City, when a rasper is used, glass is not reduced to fine particles as it is in the two or more stages of hammermill grinding used in most other plants.

Trials of a drum-type ballistic separator did not show sufficient removal of glass. This apparatus consisted of a revolving drum on which the ground refuse falls, the glass and other dense materials being bounced off with a trajectory different from that of the lighter organic materials.

TVA also unsuccessfully experimented with an apparatus consisting of a rotating cone on a vertical axis, mounted inside a cylindrical tank. The theory of operating this apparatus was that the refuse falling on the cone, which had an apex angle of about 152 degrees, would be slung off. An attempt would then be made to collect the glass and other dense particles which bounced off the wall of the tank at a trajectory different from that of the organic material. Beneath the cone, suction was to be used to remove plastic film loosened from the stream of refuse by the motion imparted by the cone.

PROJECT STUDIES AND INVESTIGATIONS

Composting Process Studies

Temperature Studies. In the first year of operation a considerable body of information was accumulated on temperatures attained in the composting refuse. Readings were taken with a portable single probe thermistor type telethermometer. Figures 20, 21, 22, 23, and 24 show the results of observations on 152 windrows at the 1-1/2-ft depth over the period June 20, 1967 to June 14, 1968. Temperatures over 140 F were recorded in all series for a number of composting days. For the series of windrows 1 C through 34 C, which spanned a period of very cold weather in January and February 1968, a shorter period of high temperatures was observed than for the other series of observations.

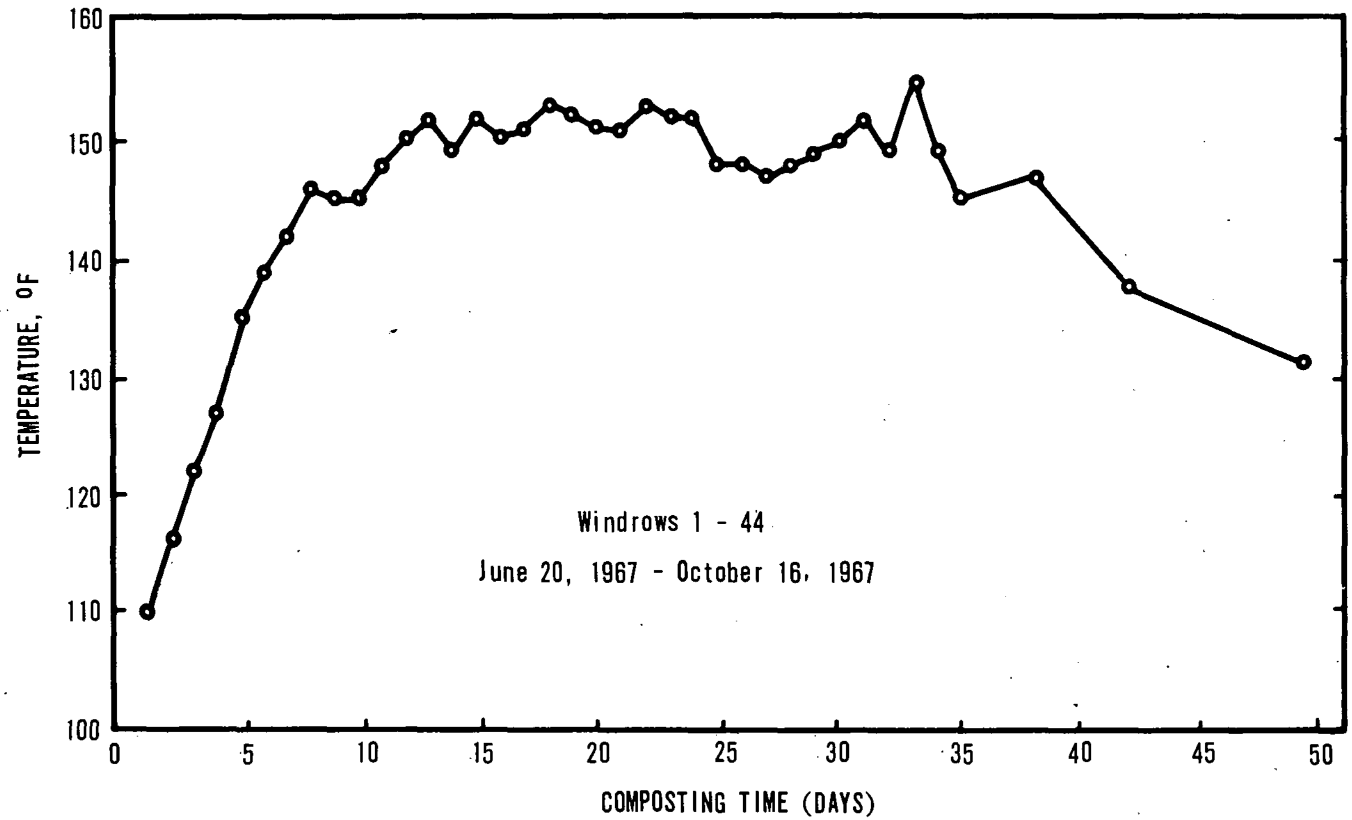


Figure 20. Average temperatures at the 1-1/2-ft depth in windrows 1 thru 44.

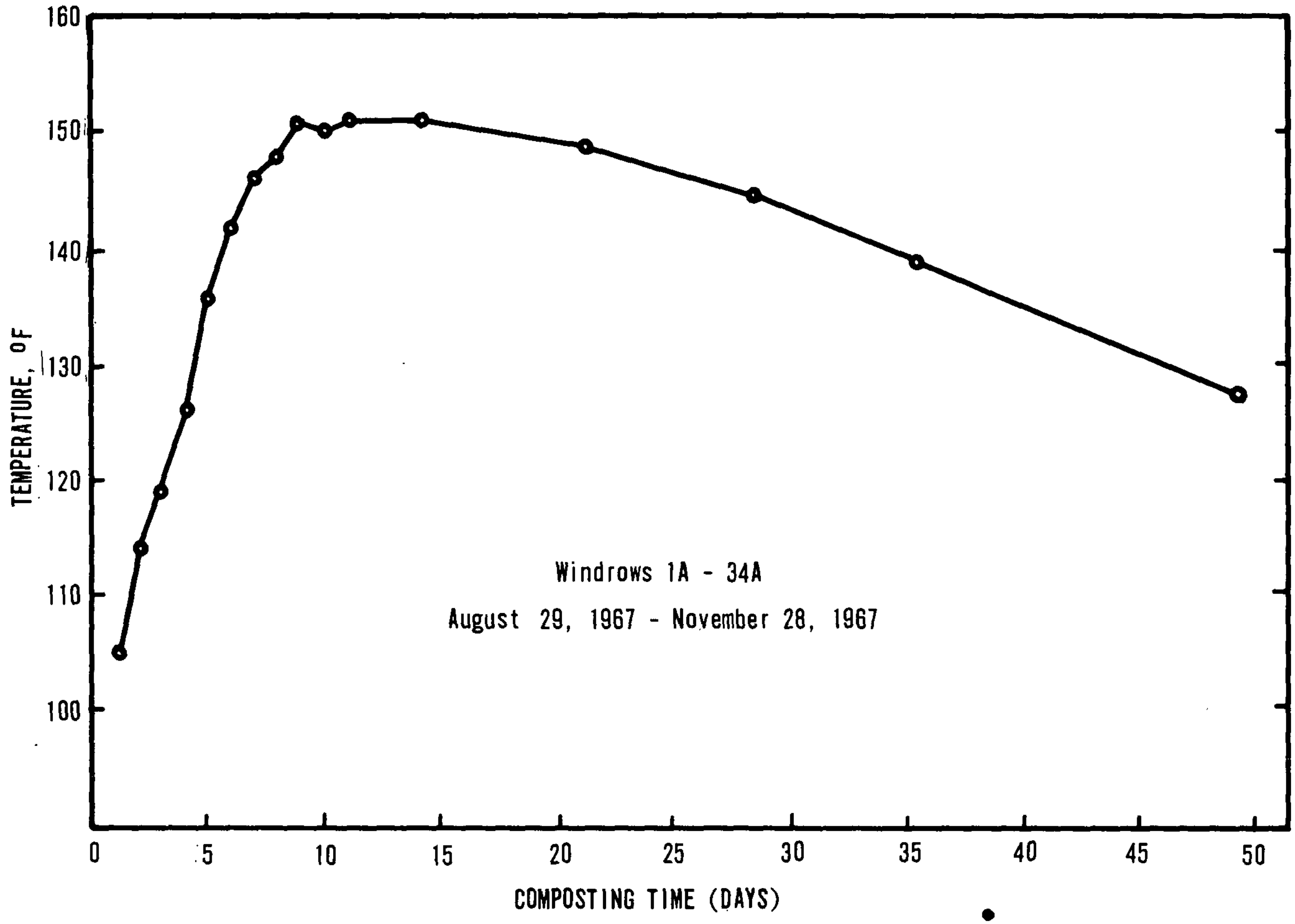


Figure 21. Average temperatures at the 1-1/2-ft depth in windrows 1A thru 34A.

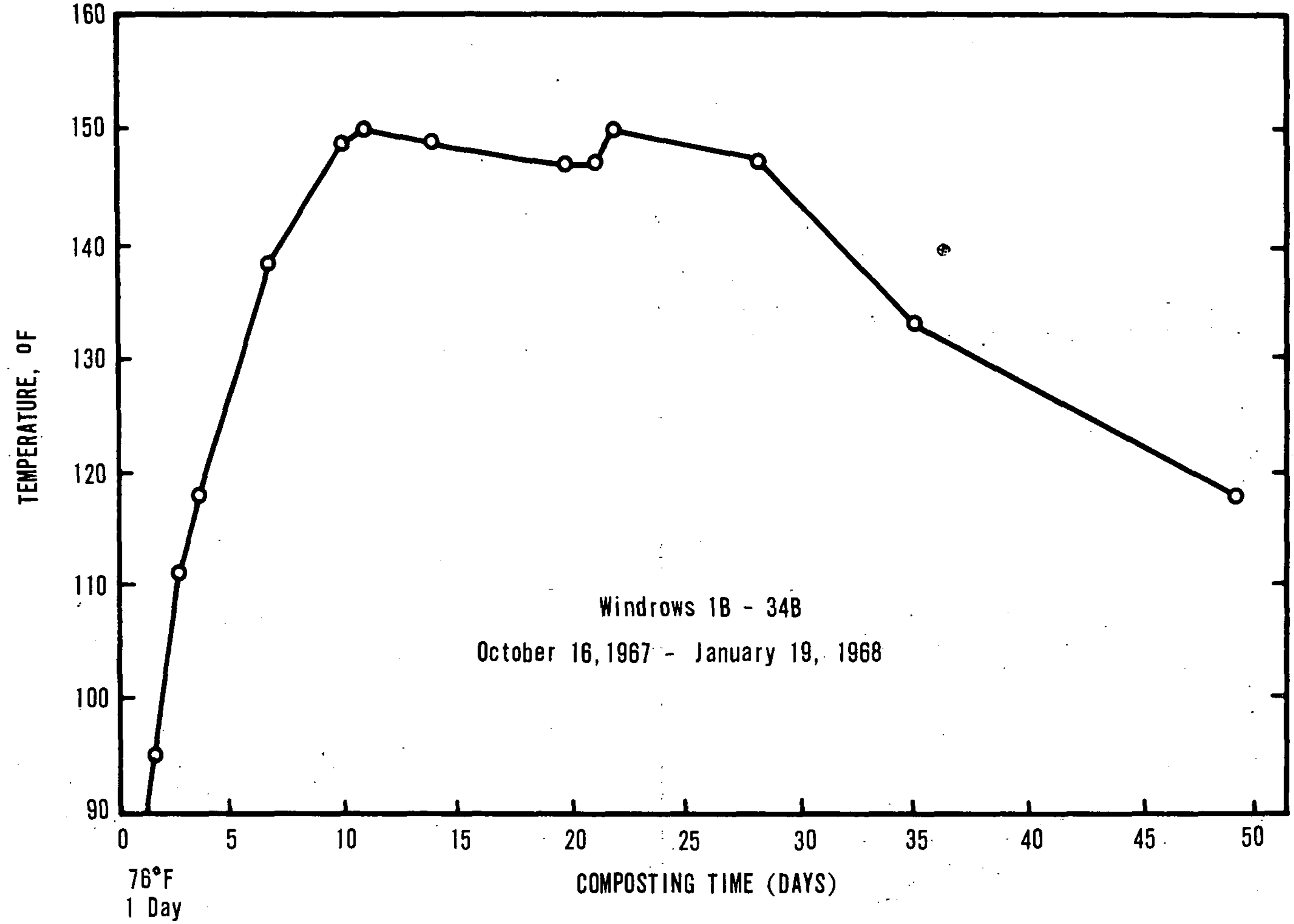


Figure 22. Average temperatures at the 1-1/2-ft depth in windrows 1B thru 34B.

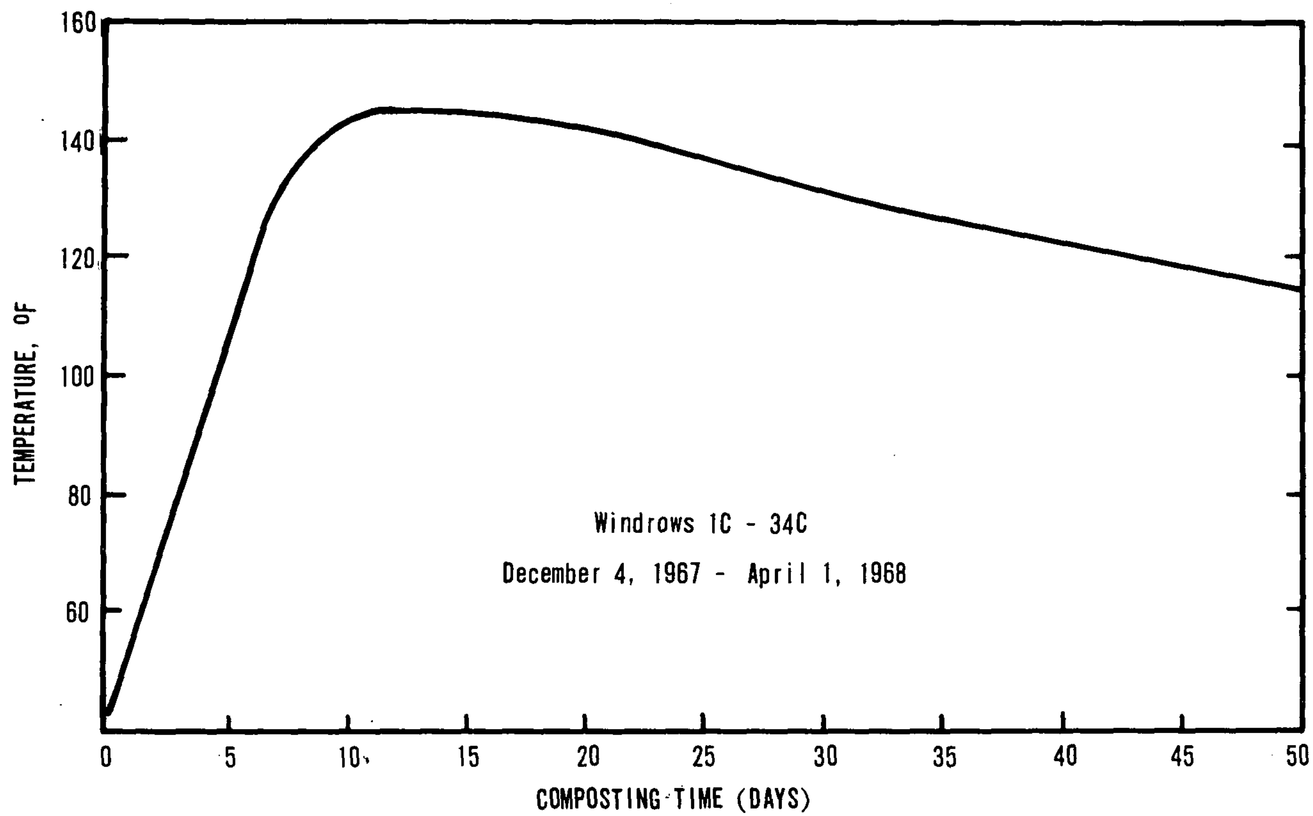


Figure 23. Average temperatures at the 1-1/2-ft depth in windrows 1C thru 34C.

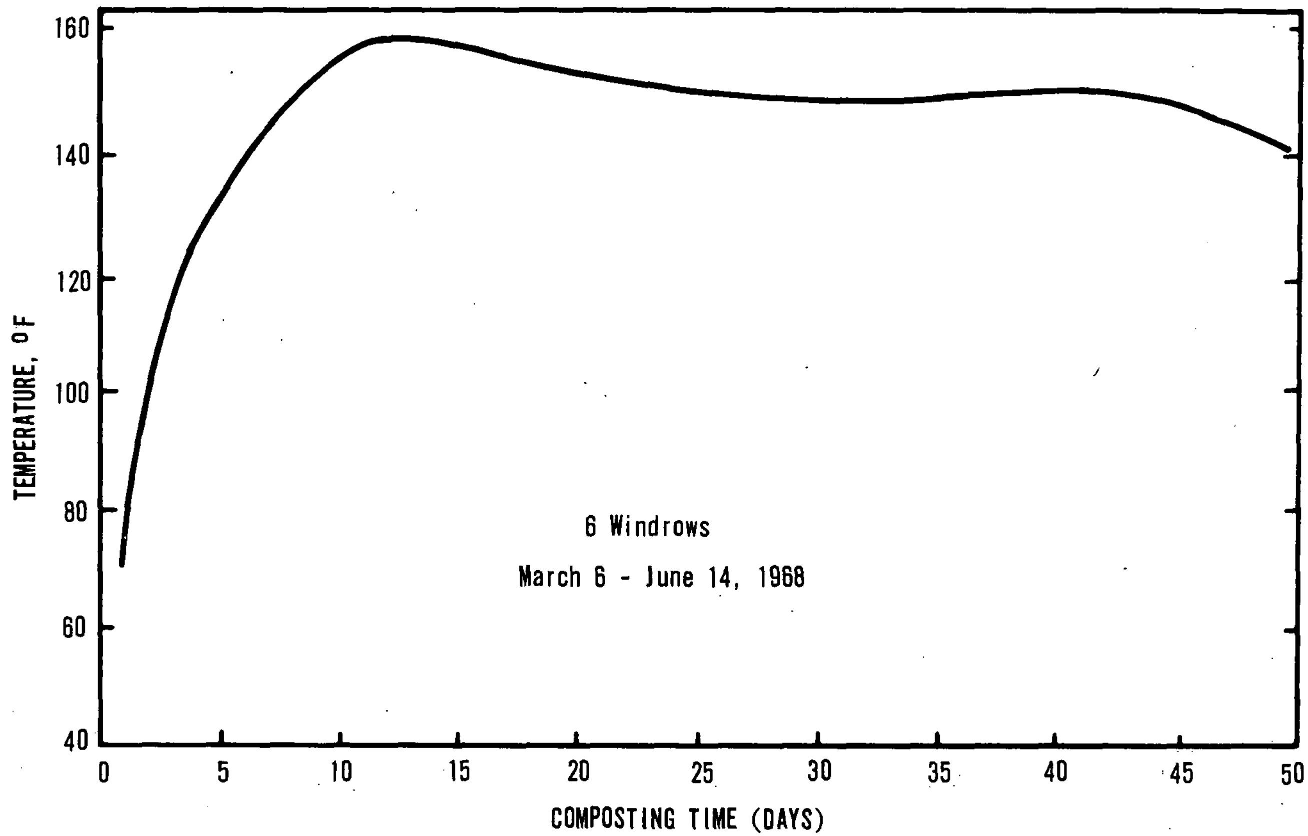


Figure 24. Average temperatures at the 1-1/2-ft depth of six selected windrows.

In the period April 26 through June 26, 1968, continuous temperature observations in a windrow were made with a YSI 12-point thermistor temperature recorder. The recorder monitored each point for 5 min--10 points within the windrow, one point for the ambient temperature, and a point for a register mark. The instrument cycled the 12 channels once every hr, recording about 11,000 points for the 42-day composting period. Temperatures were recorded at depths of 5, 13, 23, 32, and 41 in. at two stations 10 ft apart. The windrow height was 45 in.

The first 11 days of observations at Station 1 at various depths are shown in Figure 25. Station 2 showed a similar pattern of data. In this period the windrow was turned just before inserting the thermistor probes and again on the 4th, 7th, and 11th day. Immediately after a turning the windrow has a uniform temperature, after which the various depths reach different temperatures. This results in three groups of data over the period illustrated. Figures 26 and 27 show the temperatures recorded during the period 22 to 28 days for several depths for the two stations. Figure 28 shows the curve for the 22- and 32-in. depths at Station 1 over 42 days. Station 2 exhibited a similar pattern. Breaks in the curve show points of turnings. Interior temperatures change rapidly during the first 2 weeks of composting after which the interior temperatures show no great fluctuations. Surface temperatures, however, vary considerably during the entire composting period, depending upon season and weather conditions.

In the period November 4 through December 30, 1968, temperatures were continuously recorded for another windrow at two stations. Figure 29

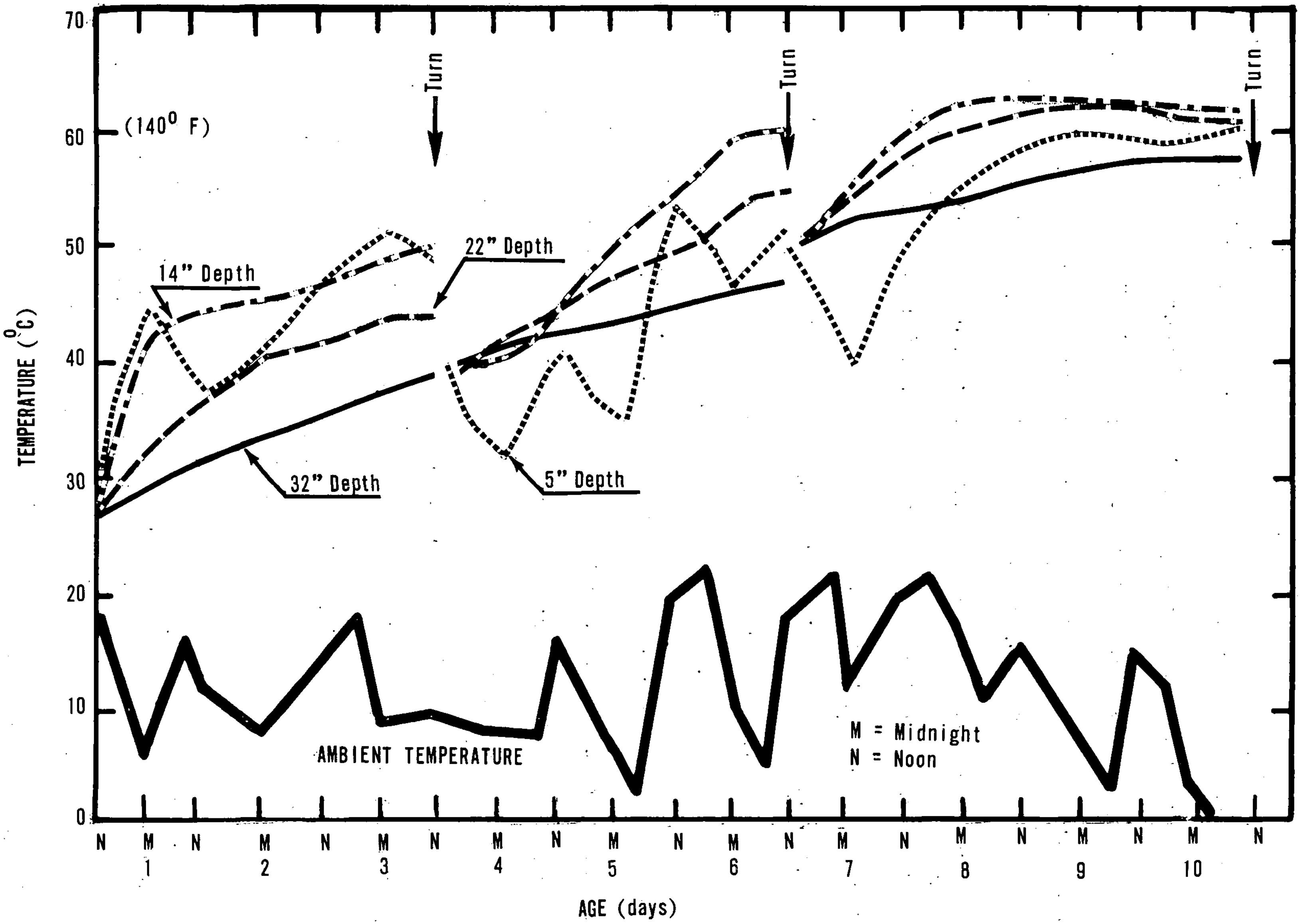


Figure 25. Temperature profiles of a selected windrow during the first 11 days of composting.

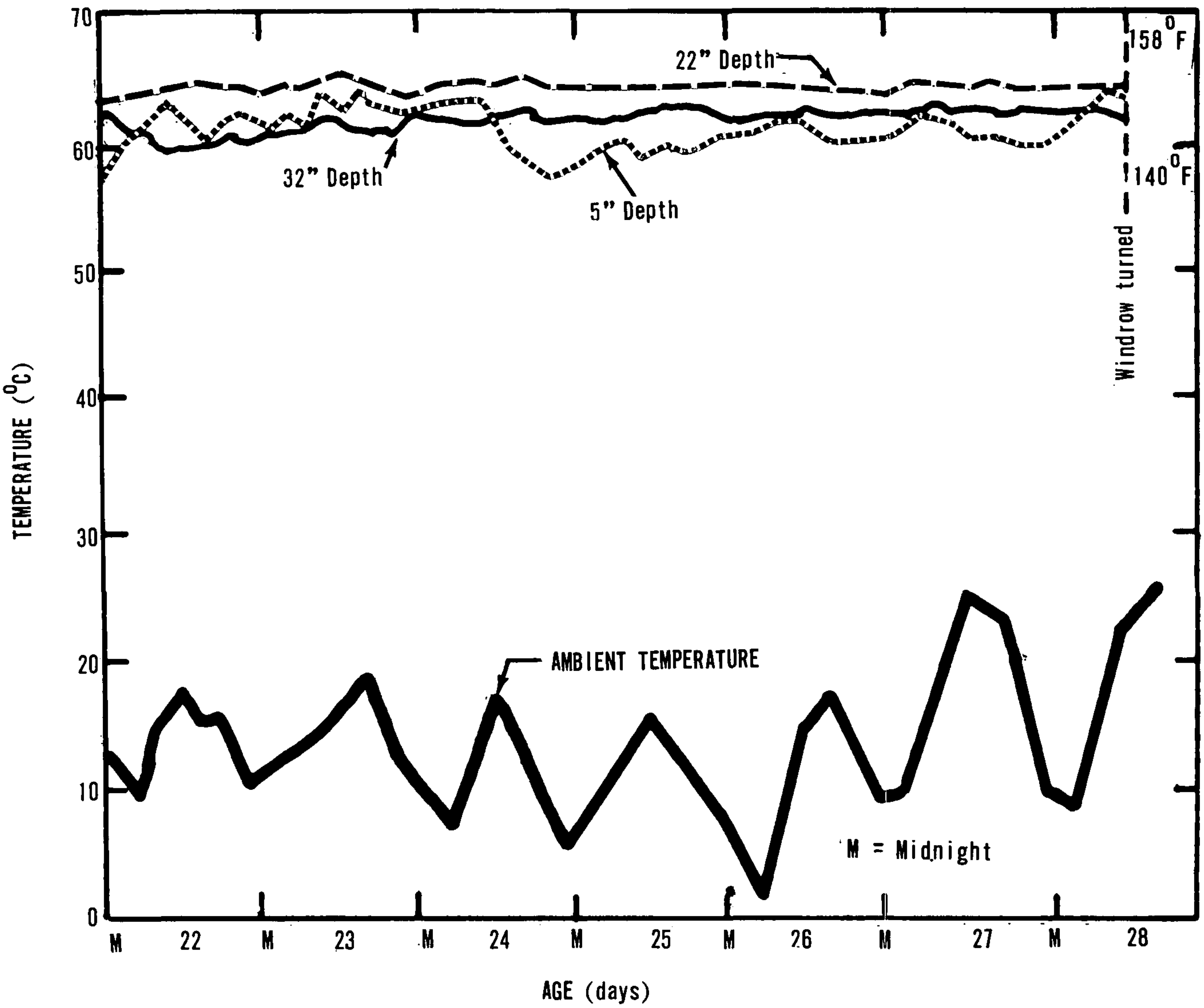


Figure 26. Continuous temperature record of windrow 17E, 22nd to 28th day (Station 1).

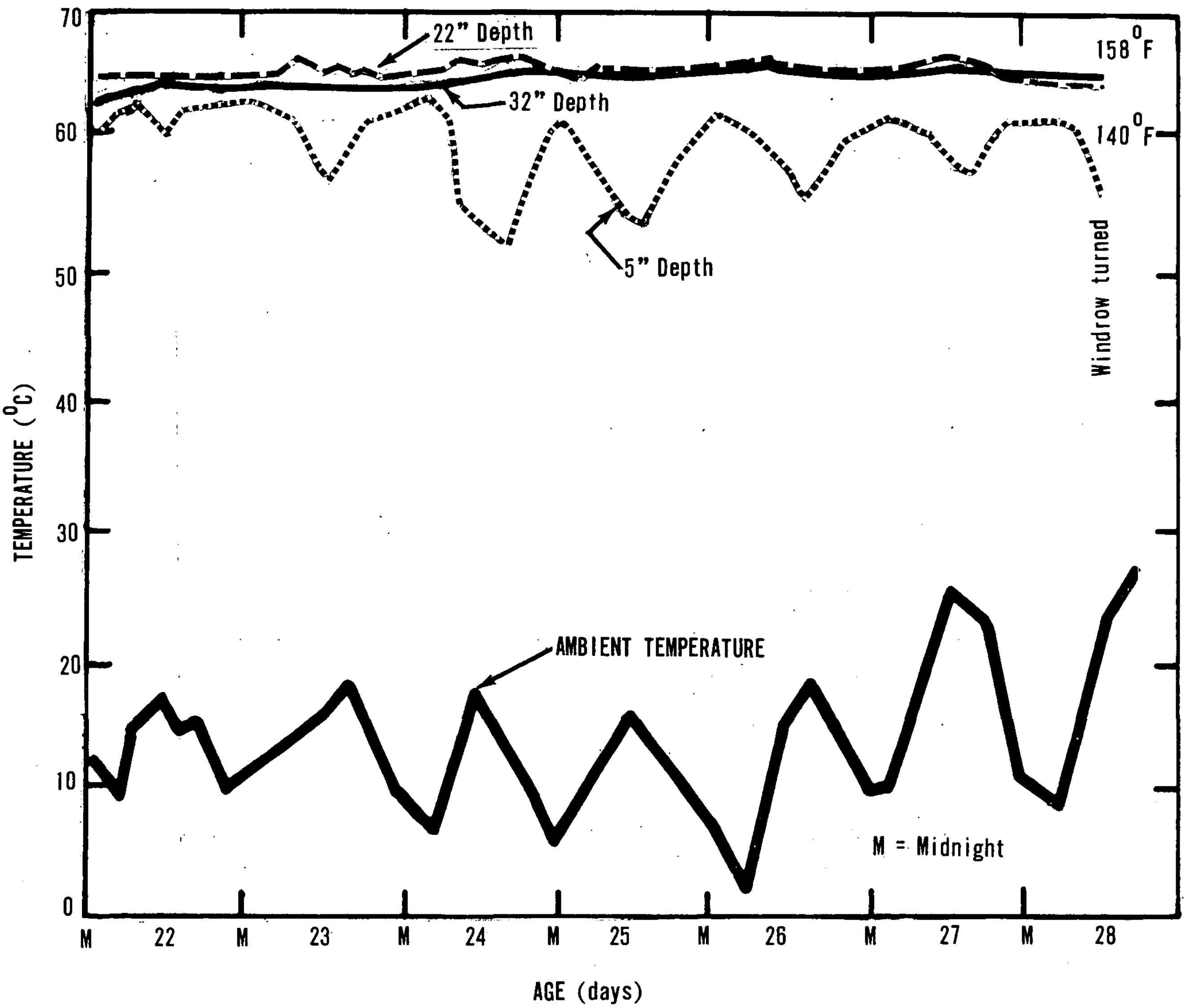


Figure 27. Continuous temperature record of windrow 17E, 22nd to 28th day (Station 2).

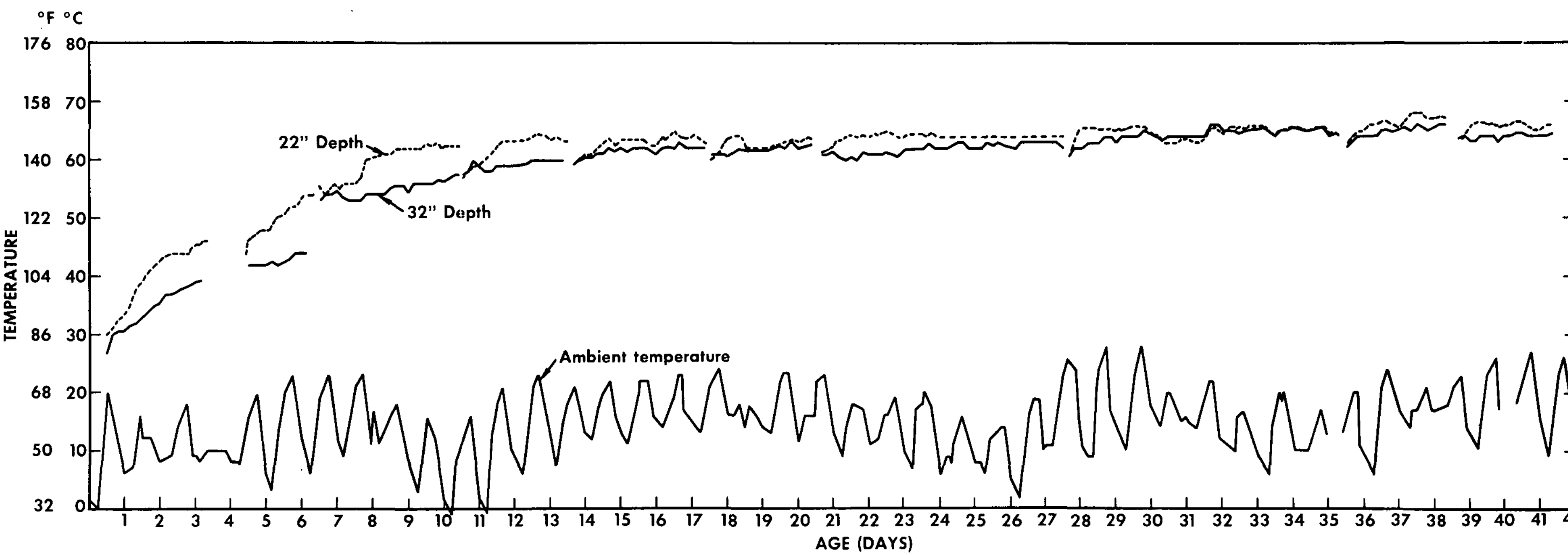


Figure 28. Temperature profile of windrow 17E.

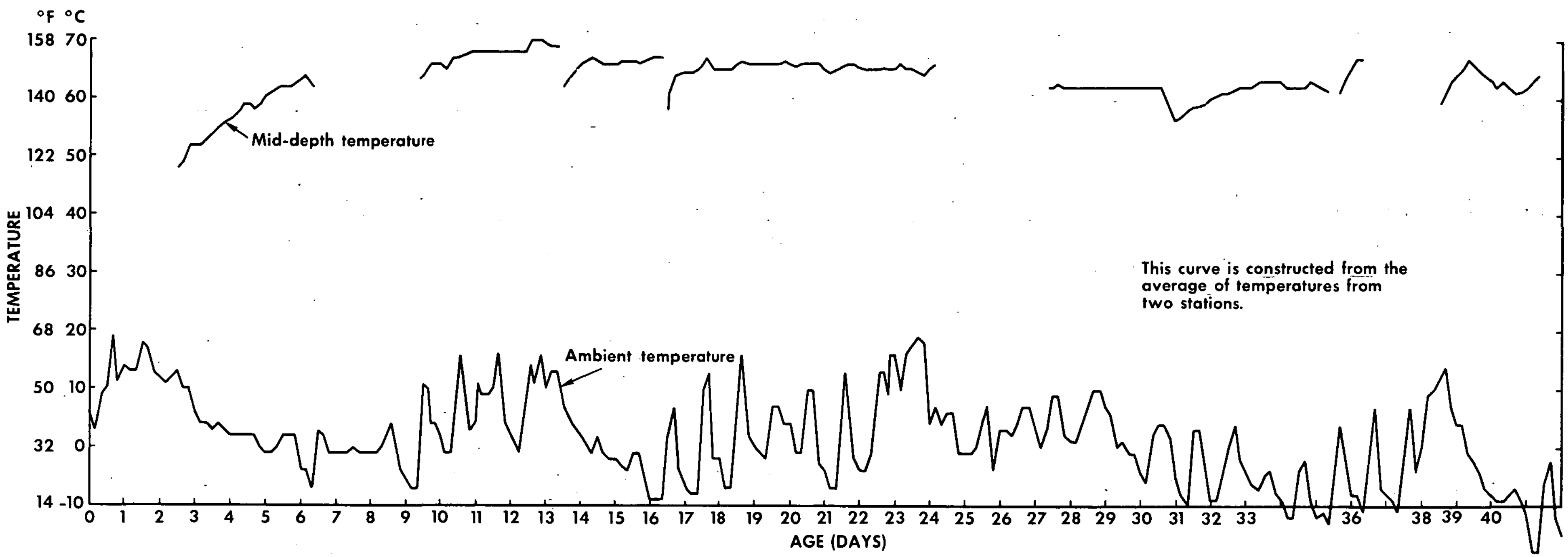


Figure 29. Temperature profile of windrow 17H.

shows the curve constructed from the averaged readings at mid-depth at the two stations over 42 days of composting. Ambient temperatures were low, reaching 5 F. The profile for this windrow, however, did not show the depressed temperatures exhibited in Figure 23. Figure 30 shows the relationship of position to temperature at various locations around this windrow at a depth of 8 in. and at mid-depth in the period of 31 to 35 days of composting. The higher temperatures in the upper parts of a windrow and the difference for the south and north sides are to be noted.

Conclusions to be drawn from these detailed observations of temperature are:

1. Temperatures vary with depth in all windrows. Temperatures above 140 F (60 C) are reached and maintained for significant periods of time in the inner mass of windrows.
2. These variations are more pronounced early in the composting cycle.
3. Immediately after turning, the temperature at all channels were found to be within 3.6 F (2 C) of one another.
4. After a turning, windrows quickly return to the temperature existing before the turning (Figures 25 and 28).
5. Excepting the outside 8 in. of material, weather conditions appear to have little effect on the windrow temperatures.
6. The surface temperatures at the apex of the windrows were often observed to be as high or sometimes higher than the mid-depth temperature.

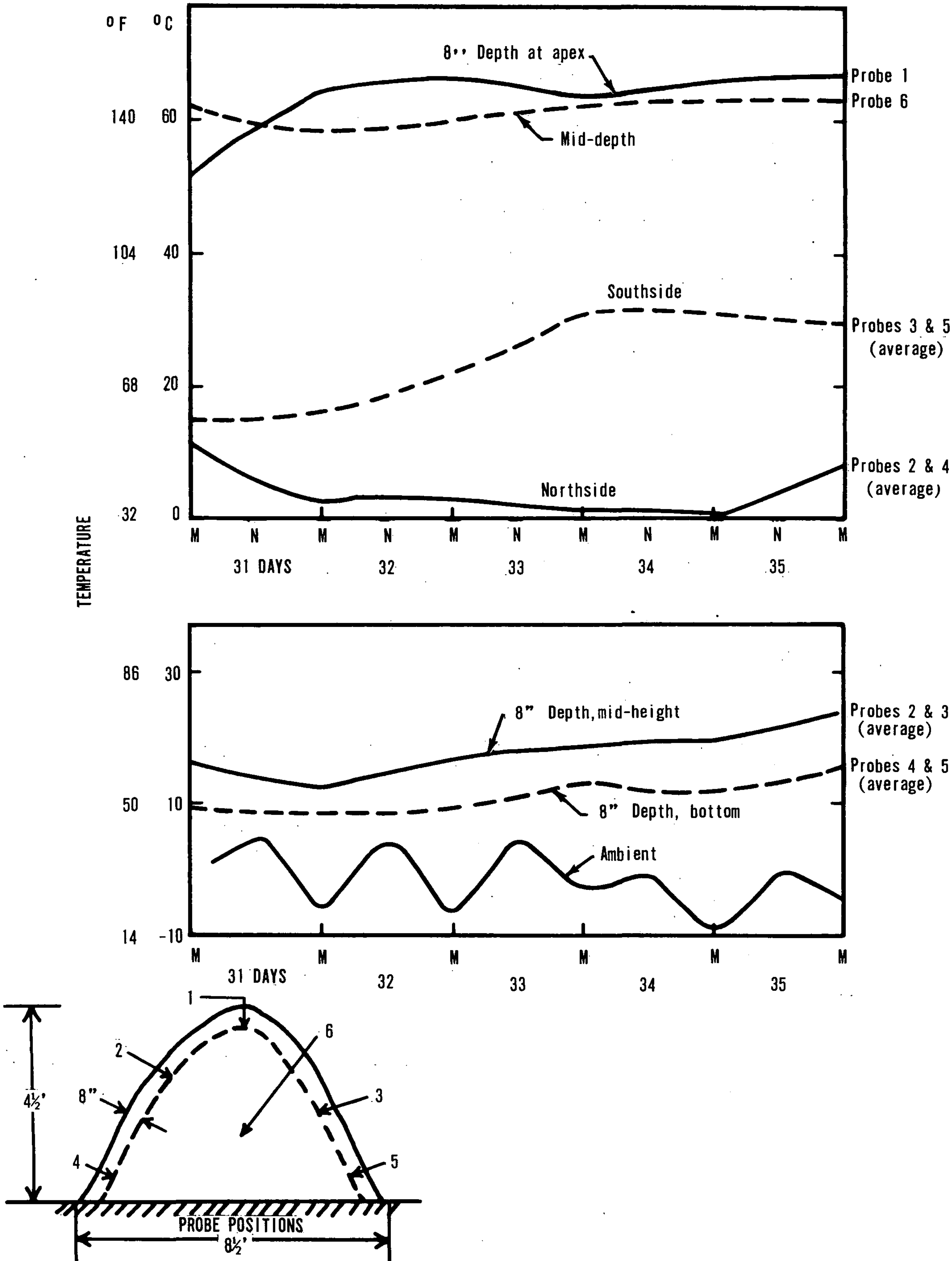


Figure 30. Temperature profiles at the 8" depth of windrow 17H (Nov. 4, 1968-Dec. 30, 1968).

7. The temperature on the outside 8 in. of the windrow decreased from the apex to the ground. This is considered due to convection currents rising from the bottom to the top inside the windrow. It is interesting to note that these may aid in the aeration of the compost.

8. The surface temperatures on the north or shady side of windrow 17H were observed to be lower than those on the south or sunny side.

Effect of Windrow Turning Frequency. Ten windrows were studied for the effect of various turning schedules. The number of turnings during the 49-day cycle for these windrows was 0 to 14. Temperatures were taken once a week throughout the test period. The relative degree of decomposition attained was judged on the basis of appearance, odor, and the amount of carbohydrate reduction.

The present windrow turning schedule is twice a week for the first 3 weeks and once a week thereafter. This routine was based on the higher temperature pattern reached with this schedule, compared with the greater cost of turning more often with lower temperatures resulting. The minimum number of turnings which will result in satisfactory compost is once a week for the entire cycle.

It was found that the best decomposition in the 49 days was obtained by turning the windrow twice each week throughout the cycle. This windrow did not show as good a temperature pattern as the one turned on the present schedule (which attained the highest overall temperatures). It did, however, attain temperatures higher than any windrows turned fewer times.

The windrow on the present schedule showed the next best decomposition and attained the highest overall temperatures.

Other windrows, turned less frequently, showed decreasing temperatures. After turning these windrows, however, the temperatures rose 20 to 30 F within 5 days and then declined. The temperature in the windrow not turned rose to about 130 F in 14 days, then dropped steadily throughout the remainder of the test.

Effect of Composting Sewage Sludge with Refuse. Assuming that:

1. a population generates refuse at the rate of 5 lb per day per capita (a figure near the national average) and that it is received at the compost plant containing 35 percent moisture by wet weight, and

2. that raw sewage sludge solids of the same population are generated at 54 grams or 0.119 lb per capita per day, dry weight, and

3. That rejected noncompostables will amount to 26 percent of the incoming refuse,

the percentage of dry compostable material (sludge and "picked" refuse) represented by the dry sewage sludge solids is:

$$100 \times \frac{0.119}{0.119 + (5 \times .65 \times .74)} = 4.7 \text{ percent}$$

or about 5 percent. This is the proportion of sludge to refuse to be normally expected from the same population producing the refuse.

At Johnson City, although the per capita production of refuse is lower than average, the available sludge handling equipment limits the amount added to refuse to between 3 and 5 percent of the total dry weight of the refuse-sludge mixture for normal operations. Obtaining a uniform sludge content has not been possible.

Using temperature as a parameter of composting activity, three pairs of windrows were closely observed. In each case a pair consisted of one windrow containing raw sludge and one of refuse alone. Figures 31, 32, and 33 show the temperature profiles for pairs having windrows containing 2, 3-5, and 9 percent sludge solids, respectively. Temperatures were taken at a depth of 1-1/2 ft. The conclusion drawn is that the amounts of sludge being processed, and even up to 9 percent sludge solids, had no significant effect on the temperatures reached in composting.

Figure 34 shows the pH profiles of a pair of windrows, one of which contained 2 percent of raw sludge solids by dry weight. No significant effect of sludge can be observed. Figure 35 shows the average pH values at various ages for a number of windrows with 3 to 5 percent raw sludge solids and a number of windrows without sludge. Figure 36 shows curves for a pair of windrows, one of which contained 9 percent raw sludge solids. Here a difference in the pH of the masses was observed, the value being higher in the earlier stages in the windrow containing sludge. The effect of the addition of sludge solids in amounts greater than would normally be the case is treated below in a discussion of a special study.

Assuming 0.85 percent nitrogen in fresh ground refuse and 3 percent in sludge solids, the use of sludge in the amount of 5 percent of the

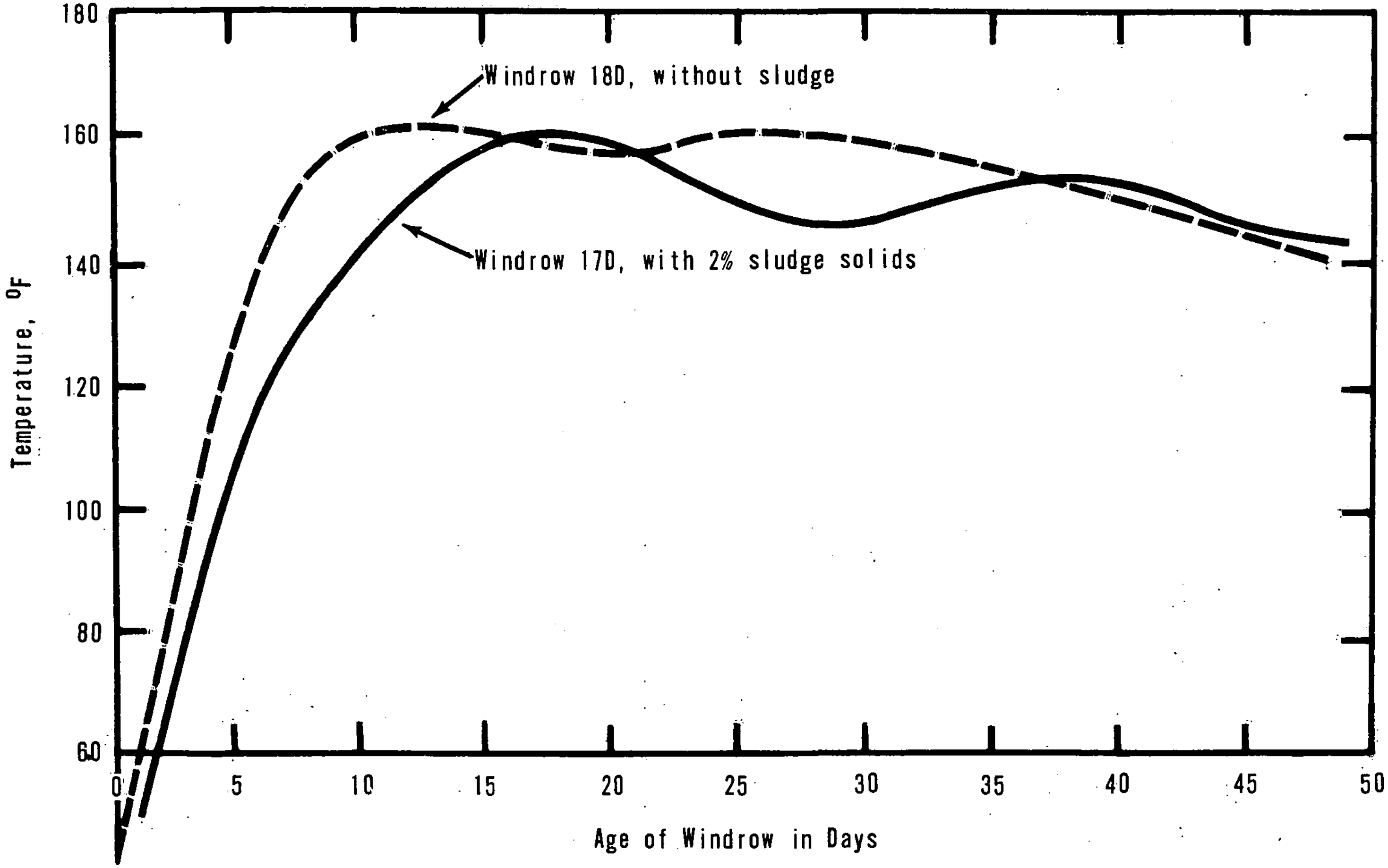


Figure 31. Temperatures in windrows with 2 percent sludge solids (1-1/2-ft depth).

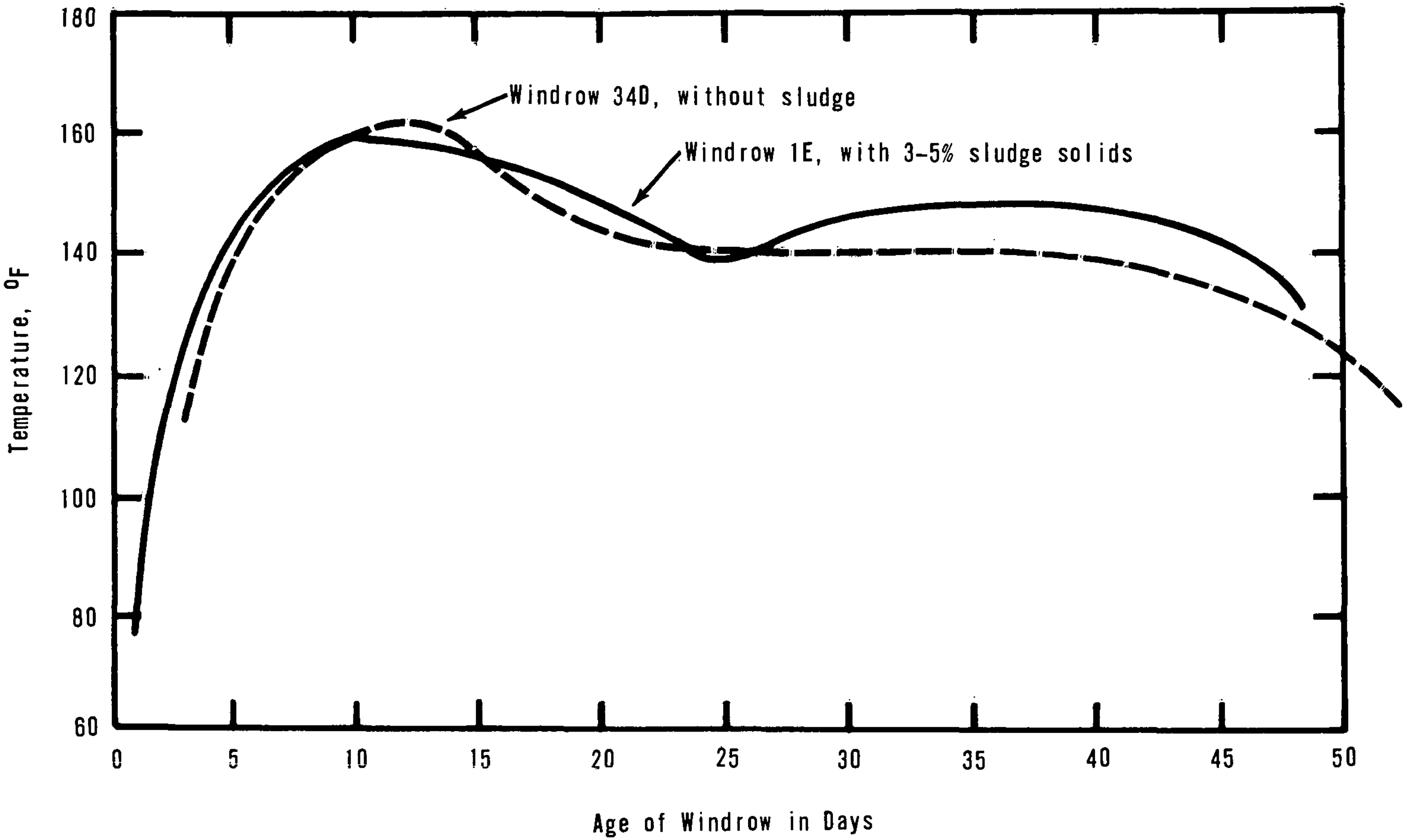


Figure 32. Temperatures in windrows with 3-5 percent sludge solids (1-1/2-ft depth).

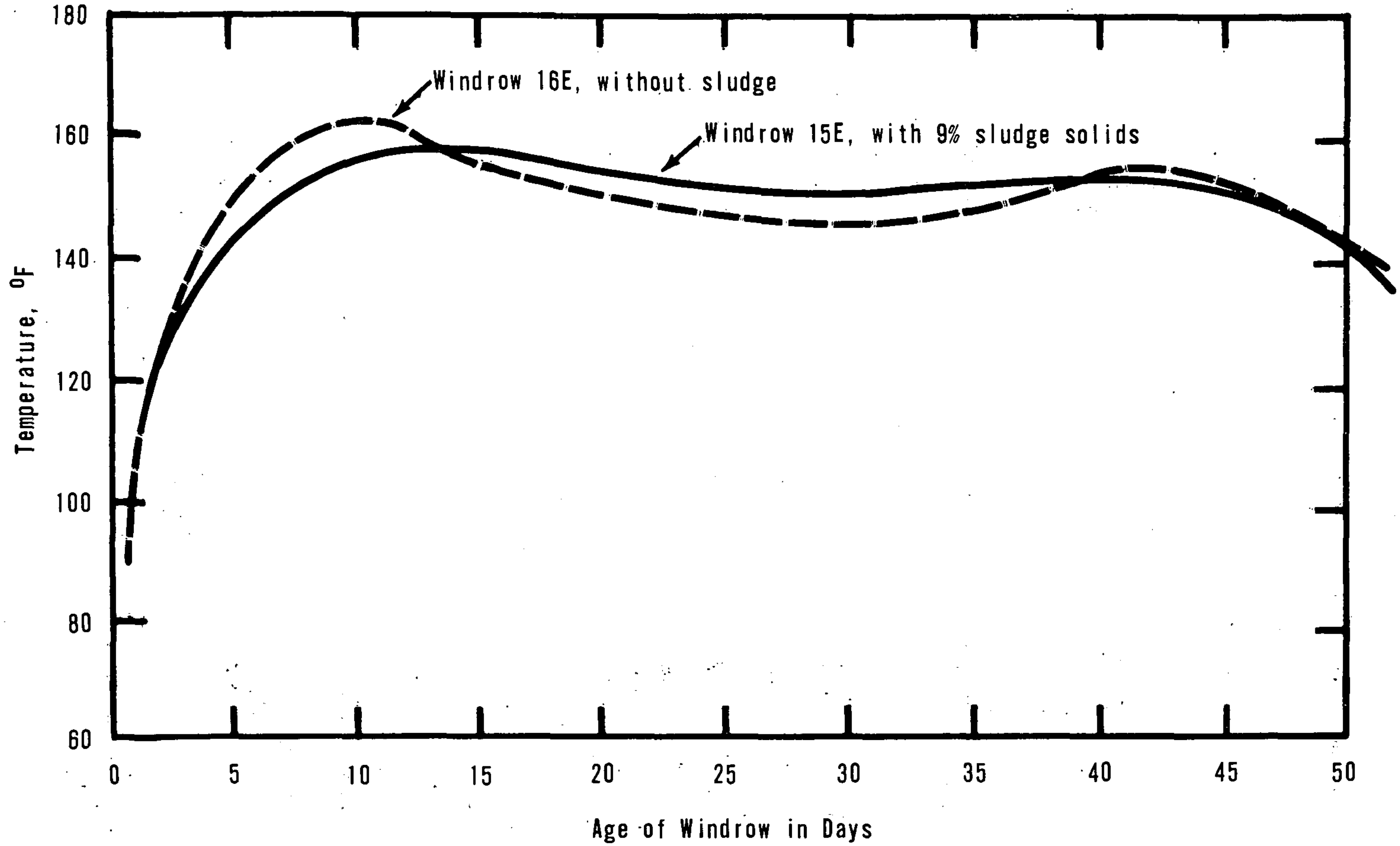


Figure 33. Temperatures in windrows with 9 percent sludge solids (1-1/2-ft depth).

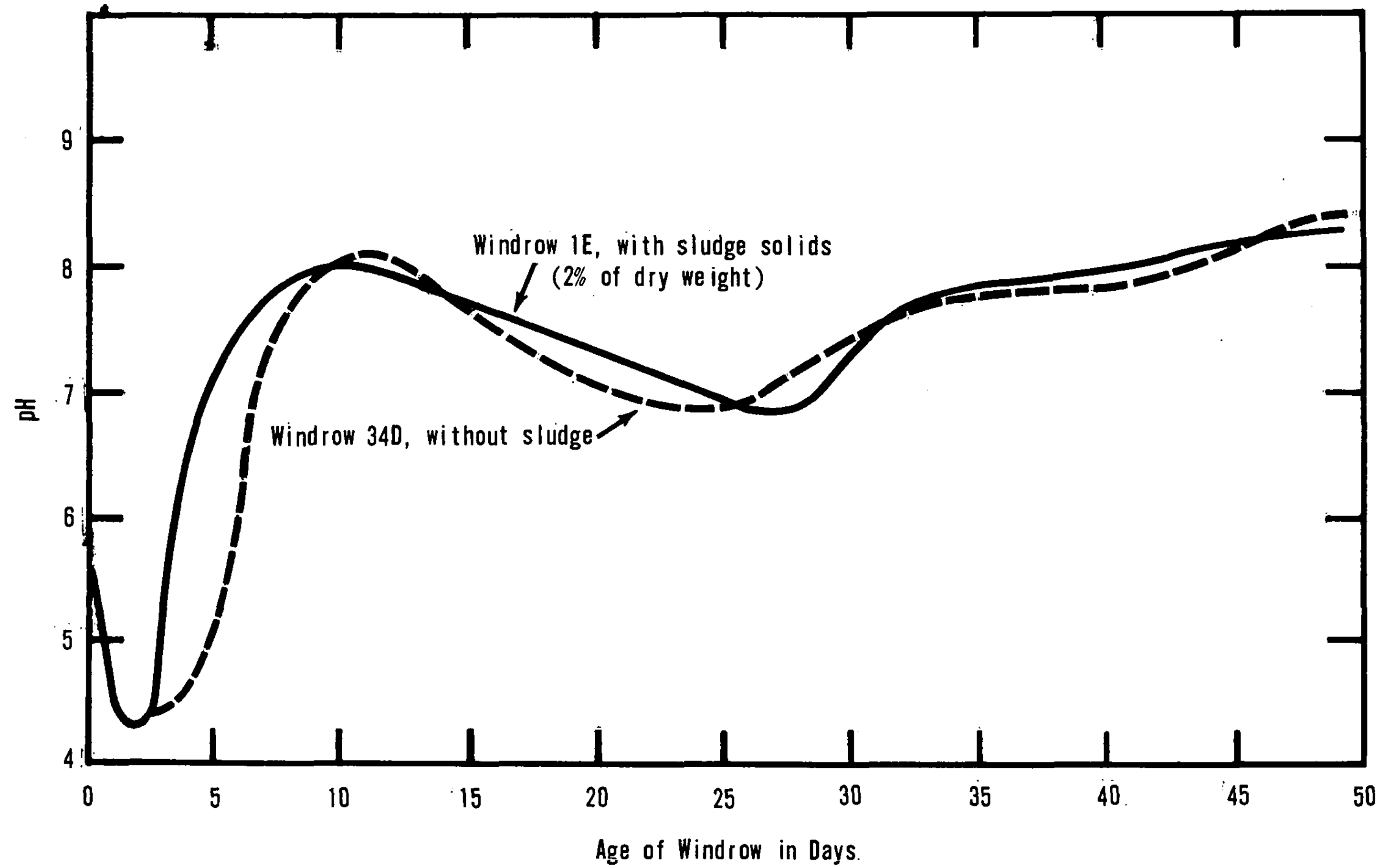


Figure 34. pH of windrows with 2 percent sludge solids (1-1/2-ft depth).

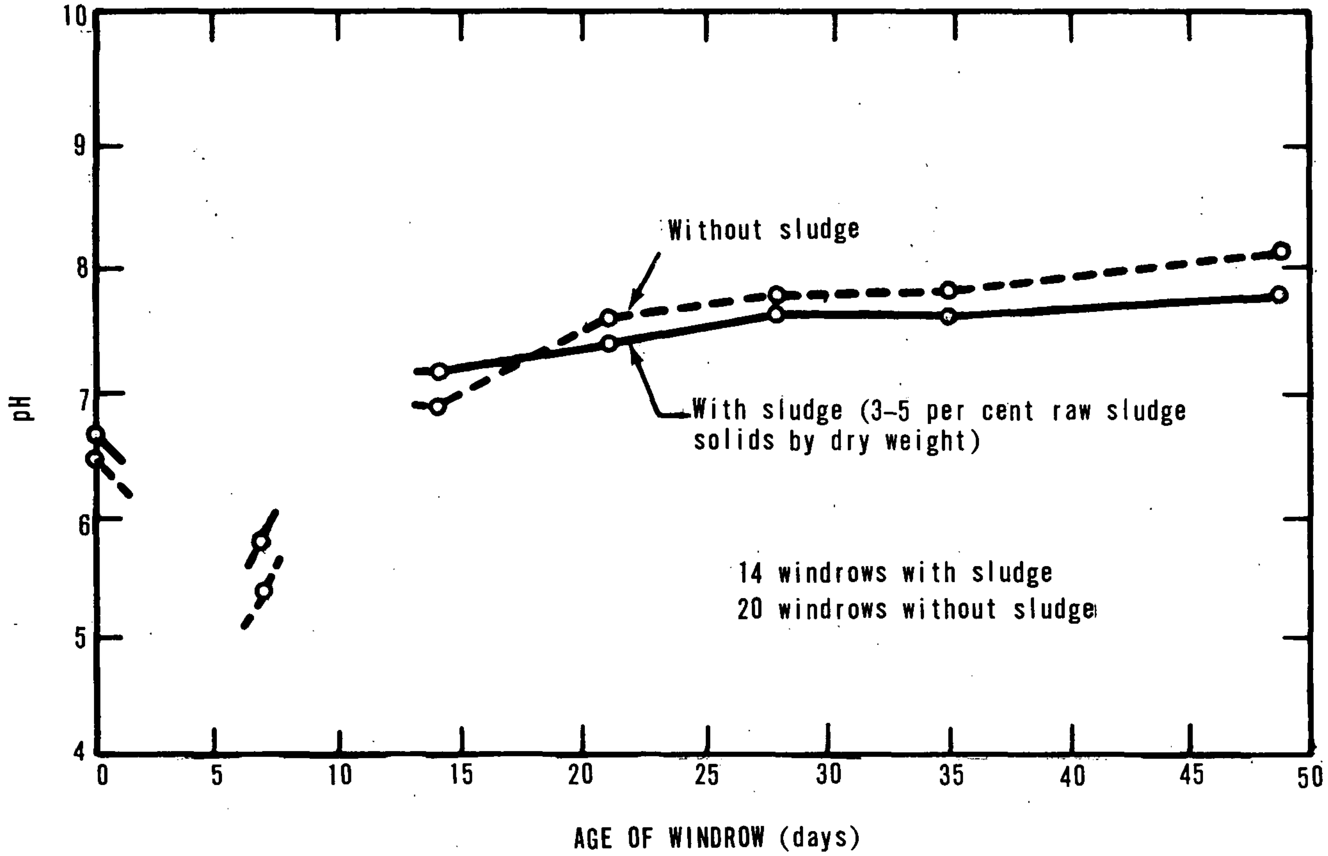


Figure 35. Average pH of windrows with 3-5 percent raw sludge solids (1-1/2-ft depth).

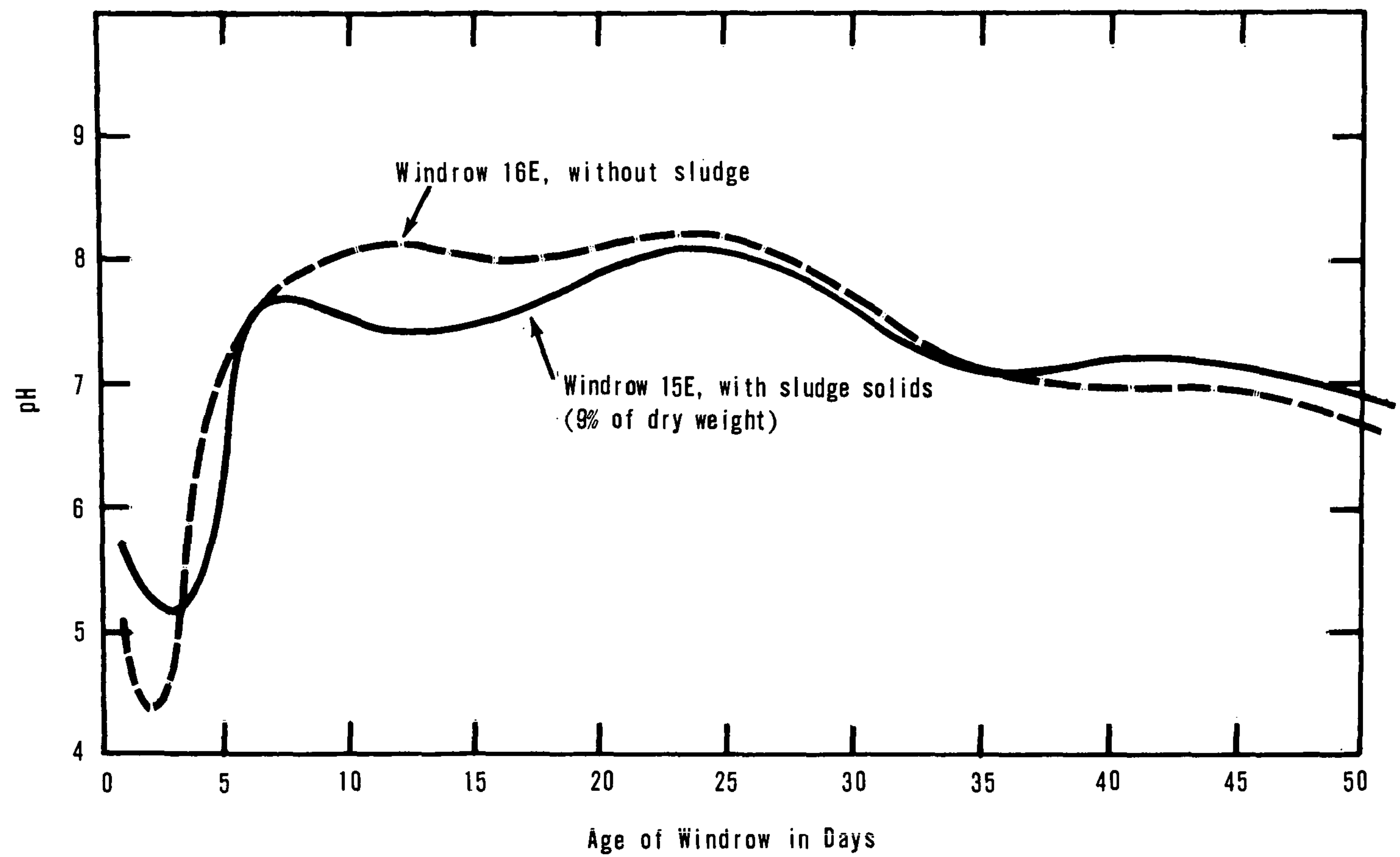


Figure 36. pH of windrows with 9 percent sludge solids (1-1/2-ft depth).

sludge-refuse mixture (dry solids basis) would result in a finished compost containing 1.05 percent nitrogen. This calculation assumes that the loss in nitrogen and the loss in weight from sludge during decomposition is similar to the loss from refuse.

The addition of sludge in the quantities used does not significantly add to the quality of finished compost as gauged by the nitrogen content. At Johnson City, actual observations show the compost made of refuse and sludge to have a nitrogen content averaging about 1 percent by dry weight.

Although the carbon to nitrogen ratios of refuse and compost are discussed under a subsequent heading, the observed effect of sludge solids on this important relationship should be mentioned here. The initial C/N ratios of a group of seven windrows containing 3 to 5 percent sludge solids showed an average of 44.4. At 42 days of composting a similar group of five windrows showed an average of 33.9 and at 49 days two of these showed an average of 31.9. A special test windrow prepared without sludge showed an initial ratio of 44.4 and at 49 days a ratio of 33.0.

The observations of the rate of heating, the pH profile, and the C/N ratios lead to the conclusion that the addition of sludge in the amounts which would normally be available has no appreciable effect on the composting process for refuse similar to that collected in Johnson City. For refuse with a low organic content, the effect of the addition of this amount of sludge may be greater.

Several experiments were made with sludge in appreciably greater quantities than would normally be available.

Sludge solids were added in the amount of 12 percent of the dry weight to a portion of a windrow. The heating pattern was observed to be normal. The initial nitrogen content of the control was 0.79 percent and that of the test portion 0.86 percent. The 49th day nitrogen content was 0.97 for the control and 1.02 for the test material.

Despite the low nitrogen content in these observations, the C/N ratio at 49 days was 25.4, lower and more favorable than normally observed at Johnson City. The texture and appearence of the compost was improved.

Another windrow was prepared with portion containing 33 percent in raw sewage solids from a neighboring city which uses a vacuum filter for dewatering. Initial nitrogen content was 1.64 percent for the test portion and 0.75 for the control portion. The final nitrogen content for the sludge-refuse compost was 1.58 percent and 0.88 for the control. Figure 37 shows that the temperatures rose along with those of the control for the first week, dipped, and then again reached those of the control in three weeks. Figure 38 shows the pH profiles of the test and the control. The initial pH was high at 9.0, then fell and gradually rose to well above that of the control at the same age.

The chemical oxygen demand (COD) of the control and the test portion were:

Day	Test	Control
1	940 mg/g	890 mg/g
28	710	775
56	590	670

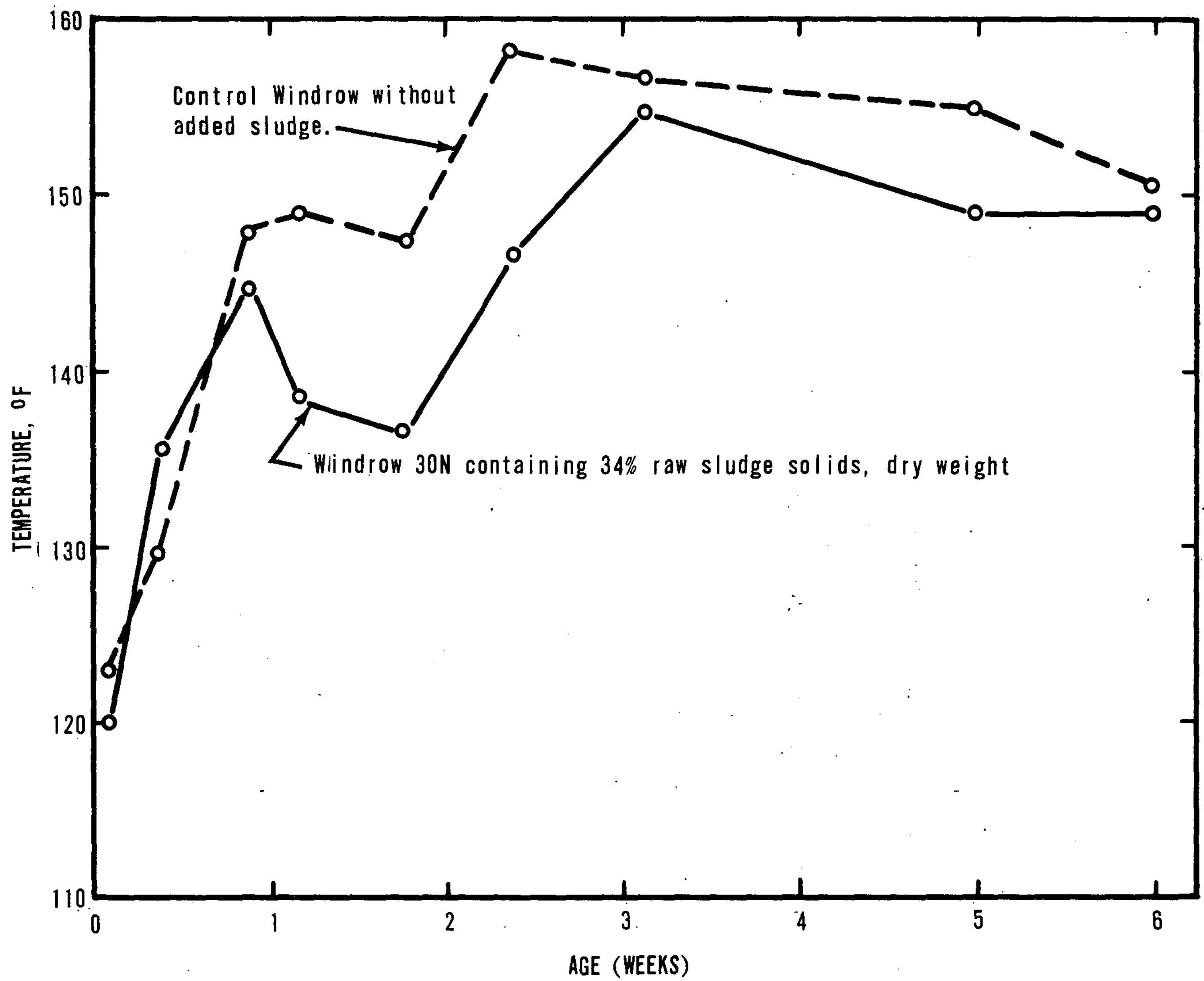


Figure 37. Temperatures of a windrow with 34 percent sludge solids (1-1/2-ft depth).

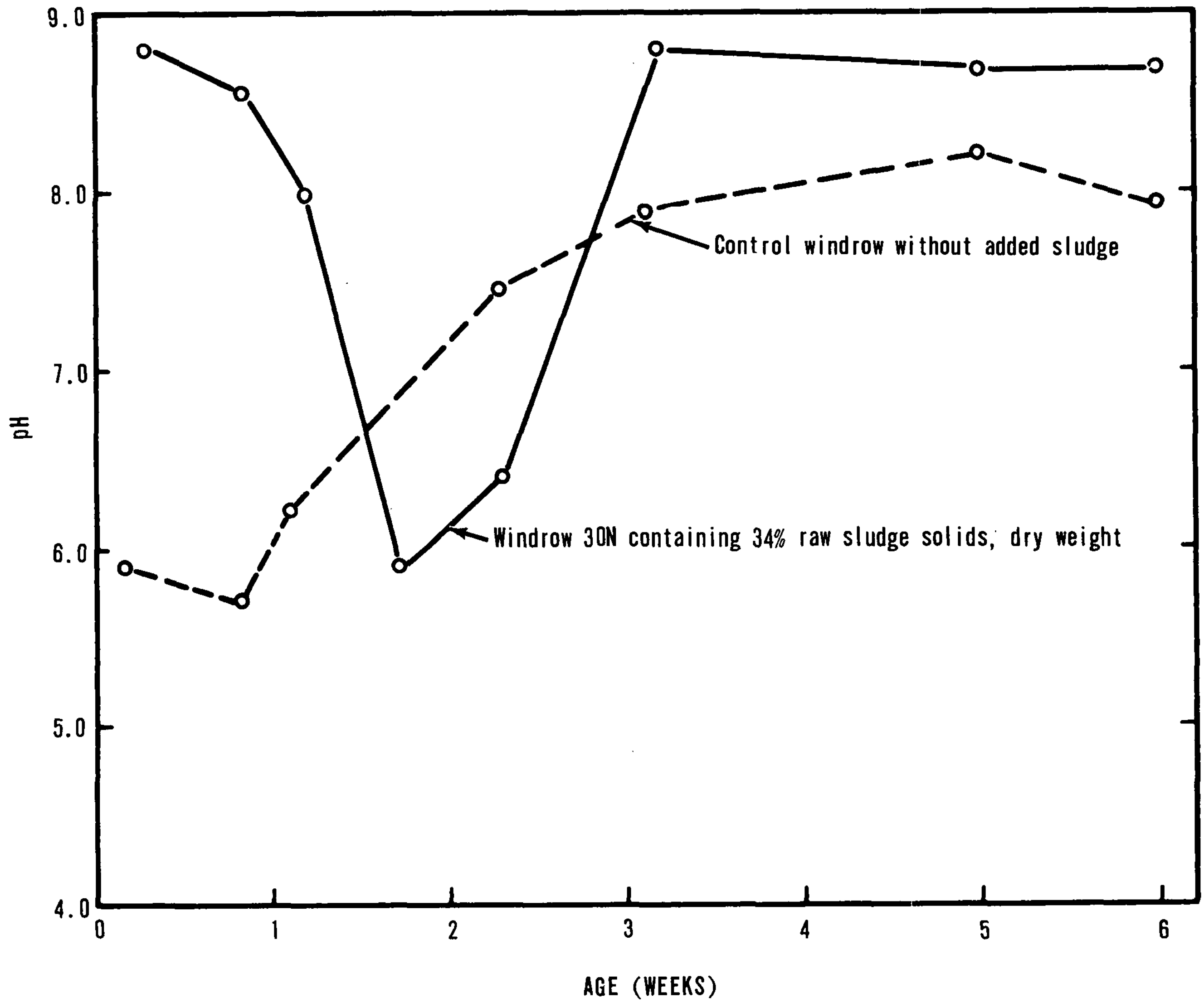


Figure 38. pH of a windrow with 34 percent sludge solids (1-1/2-ft depth).

The rates of decomposition did not differ greatly as measured by the reduction in COD. The final product benefited in nitrogen content from the sludge but some nitrogen had been lost in the process. The compost had a rich appearance.

A windrow was prepared with 50 percent partially digested sewage sludge solids taken from a dried up sludge lagoon. The temperature profile was similar to that of the control to the 2-week point after which temperatures of the test portion lagged. Satisfactory temperatures were, however, attained. The pH of the mass of test material showed a departure from that of normal refuse on composting. No nitrogen determinations were made (Figure 39).

It is concluded that sewage sludge solids can be successfully composted with municipal refuse. In the amounts normally available, the proportion of sewage solids to refuse will not greatly affect the rate of decomposition or the quality of the finished compost as measured by nitrogen content. Where greater amounts are available, the nitrogen content and appearance of the compost can be improved.

Effect of Adding a Nitrogen Compound to Composting Refuse. Under the supervision of the TVA agriculturist, urea-ammonium nitrate containing about 27 percent nitrogen was incorporated into composting refuse in several tests. The windrows were kept under observation for temperature as a parameter of composting activity and the chemist performed the chemical tests and the moisture determinations. The observed effects are discussed as follows:

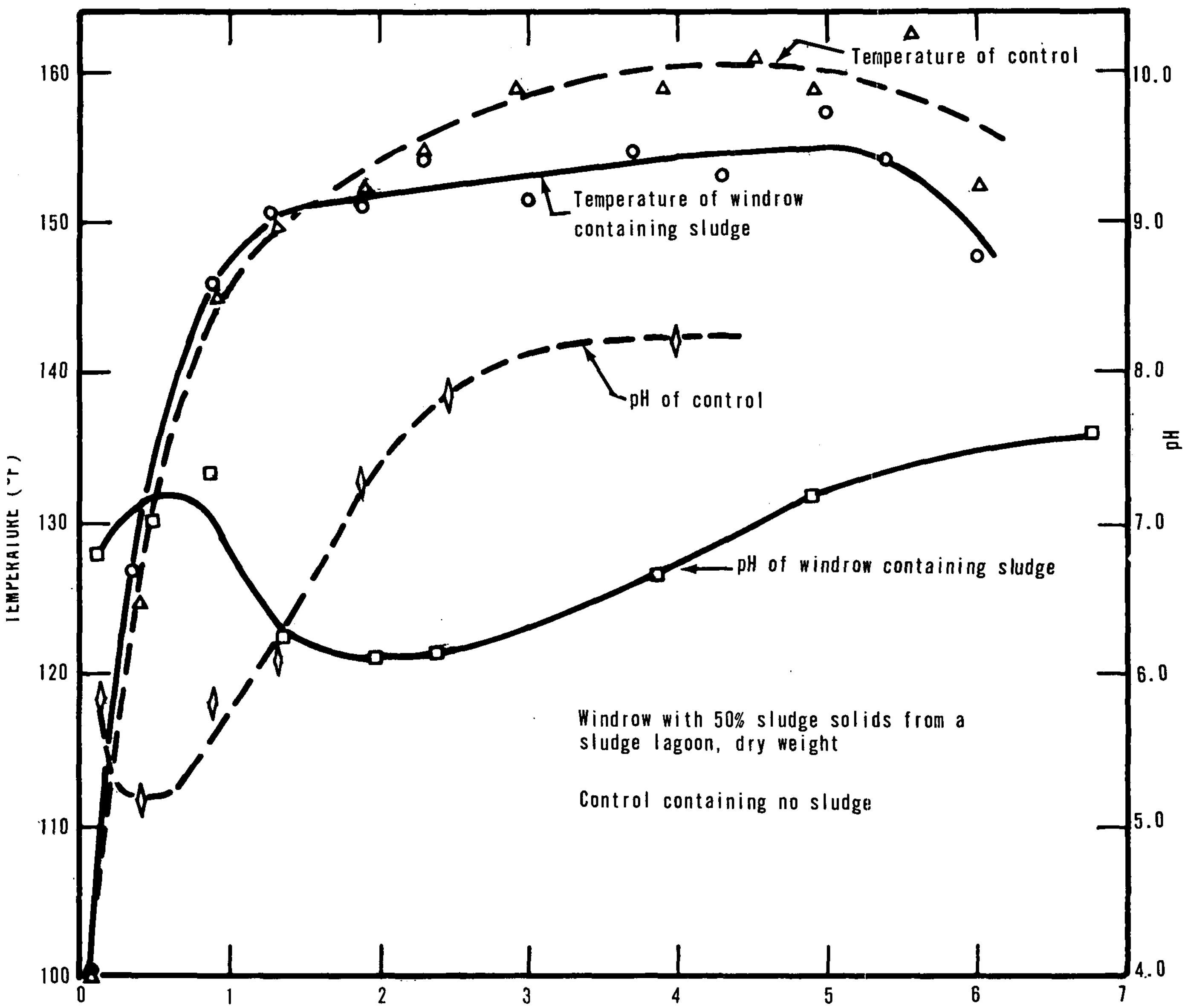


Figure 39. Temperature and pH of a windrow containing 50 percent sludge solids (1-1/2-ft depth).

Test 1. Enough urea-ammonium nitrate was added to a section of windrow 8G on day 1 to bring the nitrogen content from 0.94 to 3.5 percent by dry weight of the mass. This windrow contained raw sewage sludge and had a moisture content of 62.1 percent by wet weight. The second section was left as a control. It was immediately noted that the pH of the test portion was 8.2 against the normal 6.6 in the control. The pH did not thereafter drop to the low normal obtained in the control. At the 11th day, when the control was at pH 5.00, the test row showed a pH of 7.55. By the 14th day the test row pH was over 8 while the control was barely over 7. After 21 days the two remained close together with a pH slightly over 8. This change in pH appeared to be linked with the microbiological activity as the temperature in the test row lagged well behind and never reached that of the control.

Table 9 tabulates the data and Figure 40 shows the temperature curves. Decomposition was slowed and although the test windrow contained more nitrogen than did the control at 42 days, there had been a significant loss.

Test 2. Urea-ammonium nitrate was added to a section of windrow 17G to bring the initial nitrogen content from 0.93 to 2.46 percent by dry weight. This windrow contained raw sewage sludge. Again the initial pH was elevated as in Test 1 but by the end of 8 days was nearer that of the control than was observed in the case of Test 1. By 18 days the control reached a pH of 7 but the test portion was above 8. As in Test 1, the

TABLE 9

COMPOST FORTIFIED WITH NITROGEN
(Urea-Ammonium Nitrate)

Test 1 - Windrow 8G (8/8/68)

Age in Days	% Nitrogen Control	% Nitrogen Test	Turning No.	% Moisture Control	% Moisture Test	pH Control	pH Test
0				61.1	62.1		
1	0.94	3.50	1			6.60	8.20
4			2				
5						4.70	7.10
8		3.47	3			4.68	6.08
11			4			5.00	7.55
14			5	43.2	43.2	7.08	8.08
15		3.68					
18			6				
21		3.11	7			8.50	8.35
28			8			8.30	8.25
34			9				
35		2.70				8.22	8.17
39			10				
42	1.14	2.75	11	49.6	38.6	7.90	8.18

Test 2 - Windrow 17G (8/20/68)

Age in Days	% Nitrogen Control	% Nitrogen Test	Turning No.	% Moisture Control	% Moisture Test	pH Control	pH Test
1	0.93	2.46	1			6.22	8.10
3			2	72.3	72.3		
7			3				
8	1.01					4.60	5.30
10			4				
11		2.34					
14		2.51	5	58.5	57.0	6.00	7.90
17			6				
18						7.00	8.40
21		2.04	7				
28		1.85	8				
35		1.82	9				
38			10				
42		1.52					

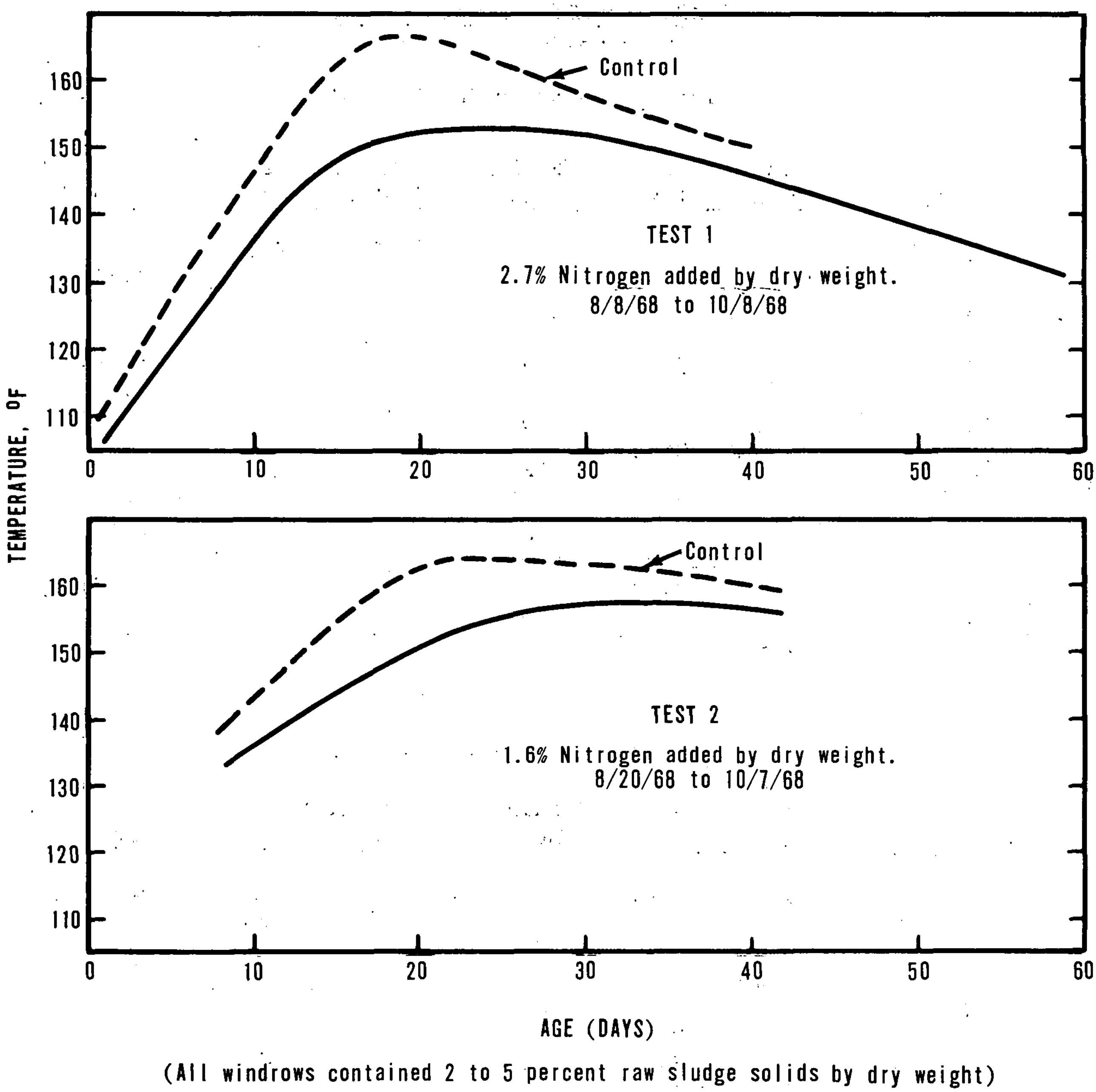


Figure 40. Temperature of windrows containing urea-ammonium nitrate.

temperature of the test portion lagged and was not falling at the rate of the control at 42 days. As in Test 1, nitrogen was lost and microbiological activity was slowed as indicated by the temperature (Table 9 and Figure 40).

Test 3. In this test the urea-ammonium nitrate was added on the 21st day of composting in two windrows, 11M and 12M. Neither of these contained sewage sludge. In 11M, where the nitrogen content was raised to 2.35 percent by dry weight, the pH was immediately elevated and the temperature of the windrow dropped radically. By the 26th day the temperature had risen to about 150 F and was about normal thereafter. The final nitrogen content was 1.41 percent, showing a loss. In windrow 12M, the nitrogen content was brought up to 4.63 percent by dry weight. The pH reacted similarly to that of 11M but the temperature fell and remained low. The final nitrogen content was 3.35 percent, showing a loss (Table 10 and Figure 41).

Nitrogen had been added in an earlier test to windrow 1H on the 23rd day of composting, raising the nitrogen by about 1 percent of the dry weight of the mass. This windrow had reacted similarly to windrow 11M and 12M.

It is concluded from these tests that the addition of urea-ammonium nitrate in the amounts used appear to inhibit microbiological activity and result in a loss of nitrogen.

Effect of Adding a Buffering Agent to Composting Refuse. The pH of fresh refuse or refuse containing normal amounts of sewage sludge is about 6 and may drop to between 4 and 5 soon after being laid down for composting.

TABLE 10

COMPOST FORTIFIED WITH NITROGEN
(Urea-Ammonium Nitrate)

Test 3 - Windrow 11M (7/10/69)

Age in days		Percent Nitrogen Content	pH
20			6.8
21	Nitrogen added	2.35	8.1
24			8.0
28			7.8
35			7.8
42		1.41	8.1

Windrow 12M (7/11/69)

Age in days		Percent Nitrogen Content	pH
20			6.2
21	Nitrogen added	4.63	8.3
24			8.2
28			7.9
35			8.0
42		3.35	8.2

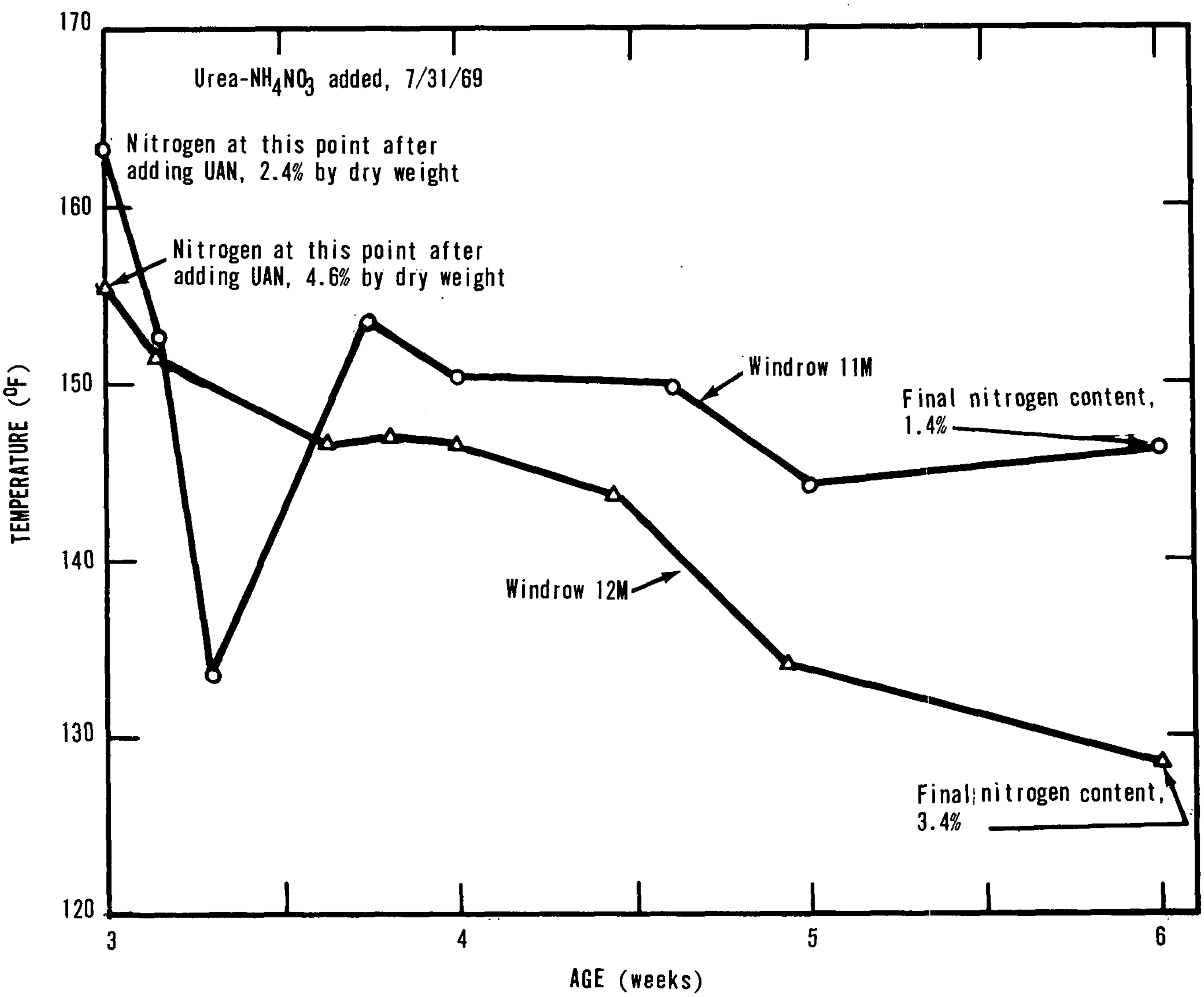


Figure 41. Temperature of windrows with urea-ammonium nitrate.

Often in farm and gardening practice crushed oyster shells, crushed limestone, or even lime is added to raise the pH at the start to accelerate decomposition. At Johnson City, three trials were run using limestone.

In the first trial, 3/16 in. crushed limestone was added in the amount of 21.2 percent of the total dry weight of the refuse-sludge-limestone mixture. The pH was raised initially to 7.5 but fell to 6 by the 16th day, after which it rose slowly to 8.5 on the 42nd day. The control was also atypical with respect to pH but exhibited the normal immediate drop from an initial 6 to 5.2 in 3 days after which it slowly rose to 8.5 on the 42nd day. The temperature of the test windrow rose more sharply than did that of the control but dropped after 10 days due to a deficiency of moisture. Water was added and the temperature rose again but not as quickly as would have been expected. The data for pH and temperature are shown in Figures 42 and 43.

Limestone dust was added at the rate of 9 and 16 percent by dry weight to two portions of a test windrow prepared from fresh refuse only. Figures 44 and 45 show the pH and temperature profiles of the test and control sections. The effect in each case was to raise the initial pH and both test sections showed an atypical rise and dip in pH in the first week. Again the attainment of high temperature was accelerated.

Analysis for nitrogen showed the following:

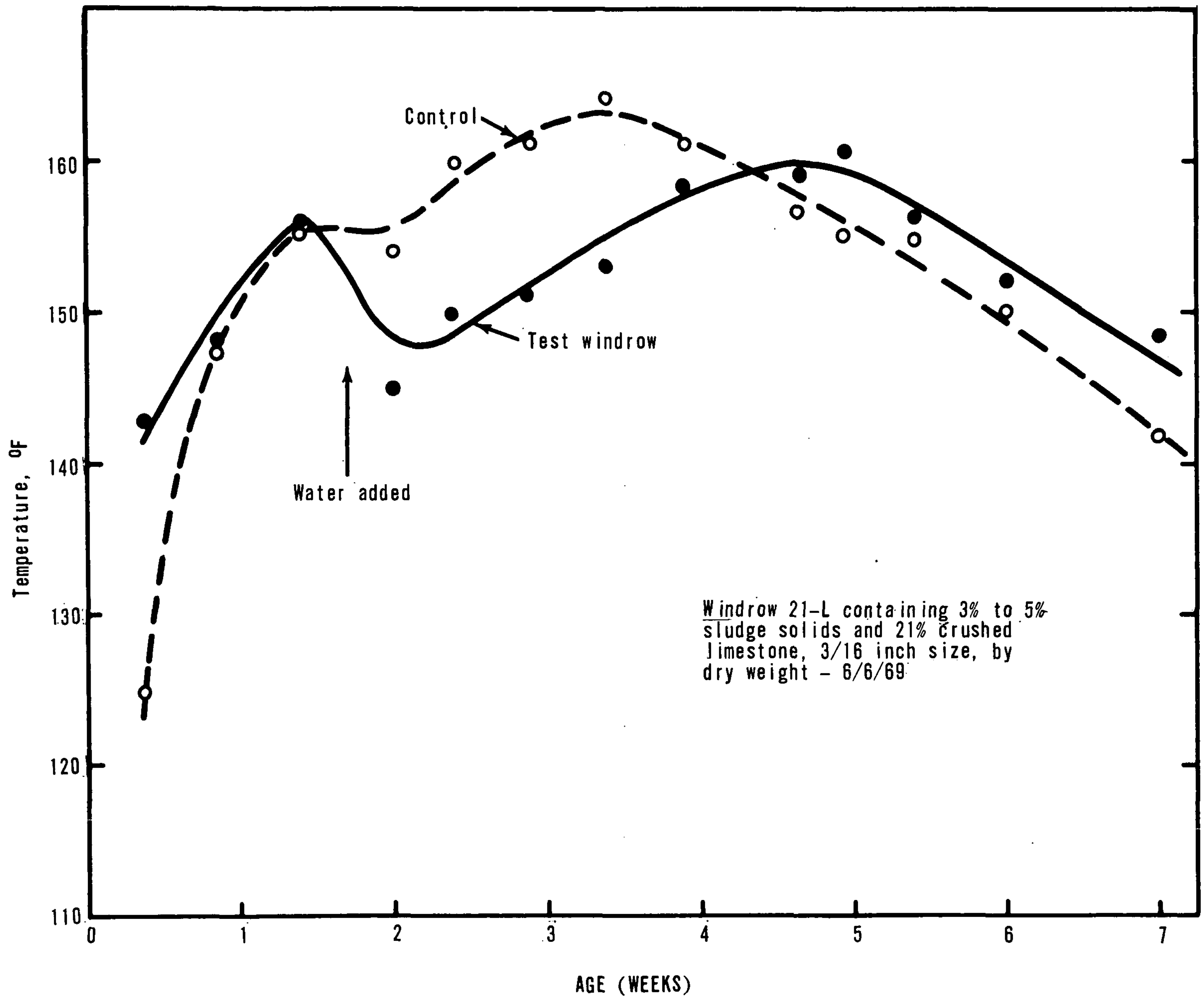


Figure 42. Temperatures of windrows with limestone and sludge added.

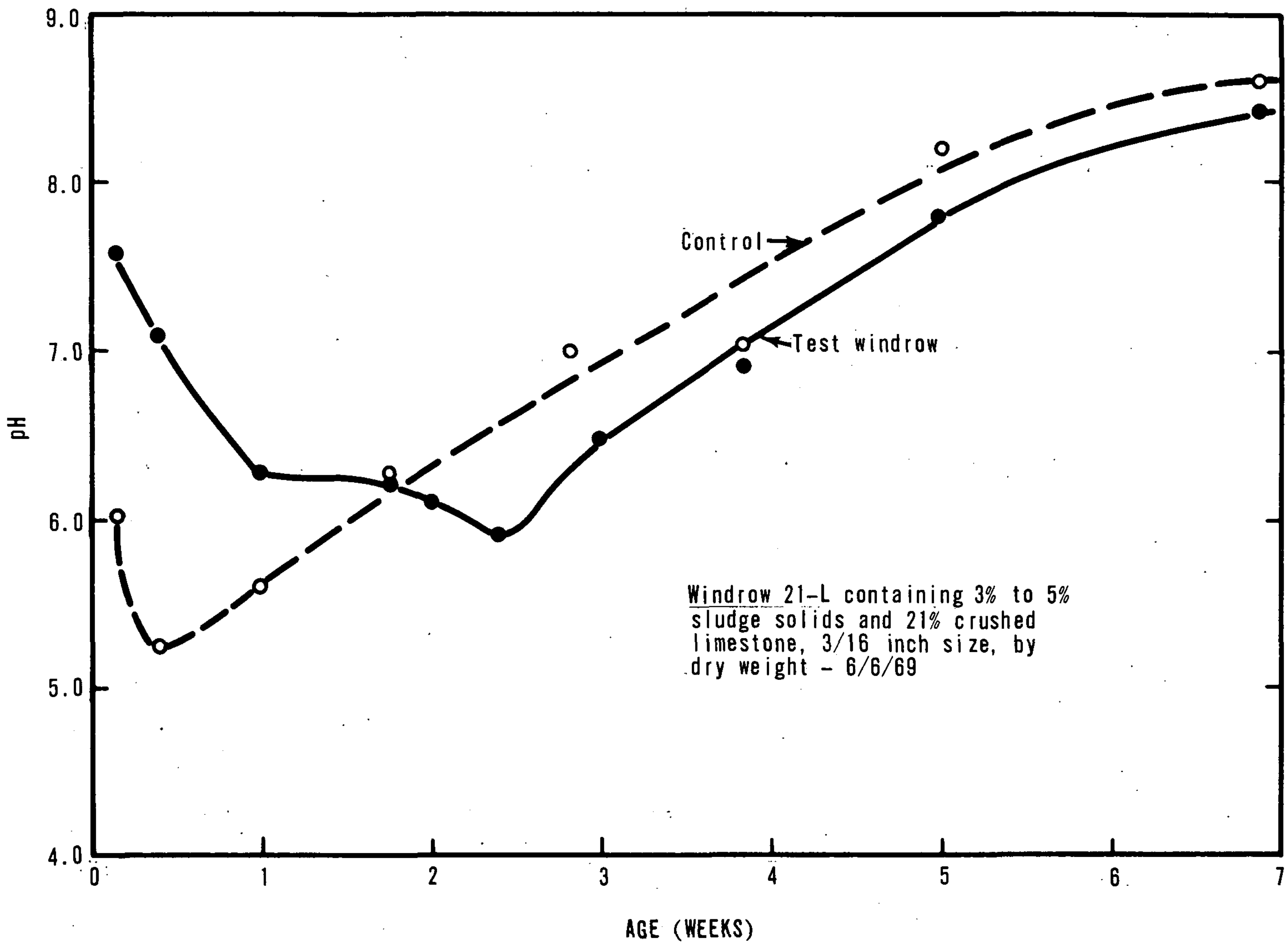


Figure 43. pH of windrow with limestone and sludge added.

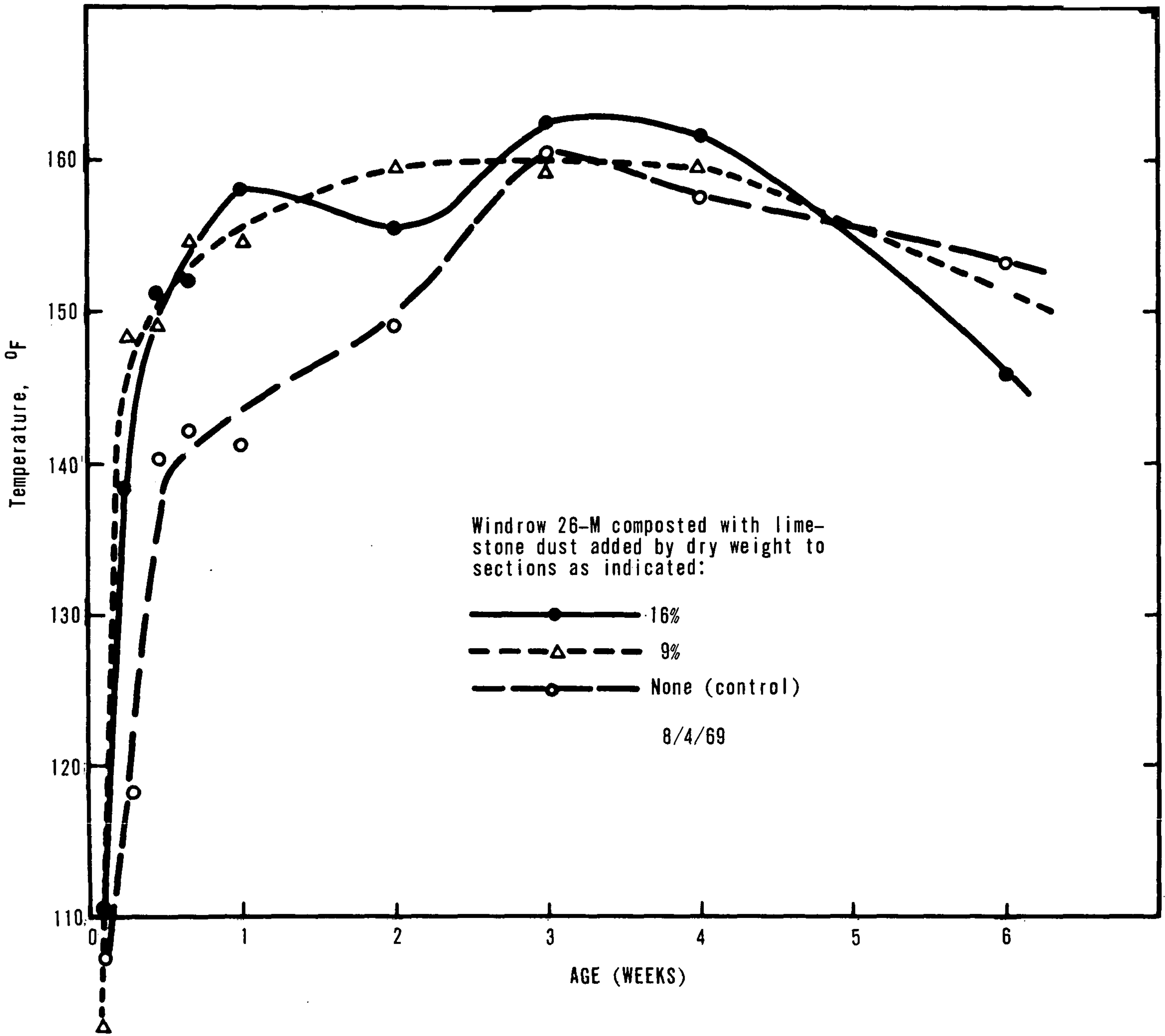


Figure 44. Temperature of windrow with limestone dust added.

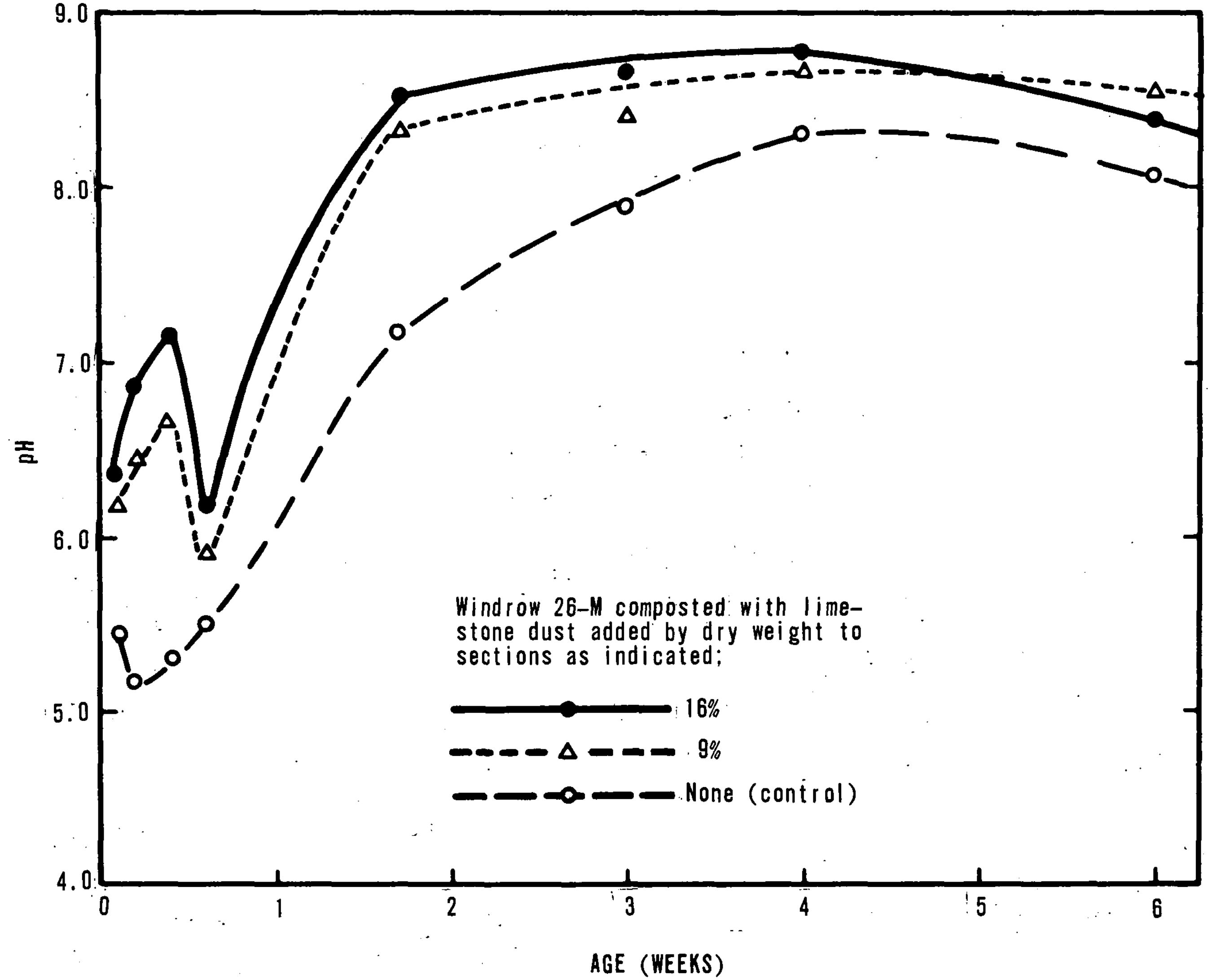


Figure 45. pH of windrow with limestone dust added.

Windrow	Additives	Nitrogen content by % of dry weight 0 day	21st day	49th day
Test No. 1				
Control	3 to 5% sludge solids	0.81		1.02
Test	Same as above with 21.2% 3/16" crushed limestone	0.74		0.57
Test No. 2				
Control	None	0.84	0.82	0.96
Test	9% limestone dust	0.73	0.76	0.66
Test	16% limestone dust	0.64	0.61	0.49

Although the temperature rise was accelerated, there was a considerable loss of nitrogen which resulted in a poorer compost. The results of these field tests are similar to those of the laboratory tests conducted by the University of California at Berkeley.[2]

Effect of Composting Other Wastes with Refuse. The TVA agriculturist obtained quantities of cow manure, paunch manure, aged poultry (chicken) manure, animal blood, and pepper canning wastes for incorporation into composting refuse to investigate the possibilities of this method of disposal of such wastes and to see if the finished compost was improved by addition of them. As with the windrows to which urea-ammonium nitrate was added, temperature was used as the parameter of composting activity. Tests with the several wastes are discussed as follows:

1. Cow manure, in an amount making it 15.4 percent of the mixture of manure and refuse by dry weight, was added on day 1 to a section of windrow 17N. No sewage sludge was incorporated in this windrow.

The initial nitrogen content of the mixture by dry weight was 1.12 percent and of the control 0.80 percent. Final nitrogen content for the composted mixture was 1.14 percent as against 0.93 percent for the control. Temperature was slow to rise, reaching in 4 weeks what had been reached in 2 weeks by the control (154 F). The pH of the mixture initially was lower than that of the control, 4.4 to 6.2. The pH of the control dipped then rose characteristically to nearly 8 in 2 weeks at which time the mixture also had reached the same value. Decomposition of the mixture in this proportion, as indicated by temperatures, appeared to be slowed and the mixture would have to remain on the field longer than refuse alone (Figure 46)

2. Paunch manure from a local slaughterhouse, in an amount equal to 14.9 percent of the mixture by dry weight, was added on day 1 to a portion of windrow 13G. This windrow contained between 2 and 5 percent raw sewage sludge by dry weight. The initial nitrogen content of the mixture was 1.22 percent against 0.97 percent for the control. The paunch manure itself contained 2.48 percent nitrogen by dry weight. The temperature curves for the 42 days of composting were identical for the test and control portions. The 42-day nitrogen of the test row was 1.26 percent and of the control 1.04 percent. Figure 47 gives the temperature curve.

3. Chicken manure, in an amount equal to 21.2 percent of the mixture by dry weight, was added on day 1 to a portion of

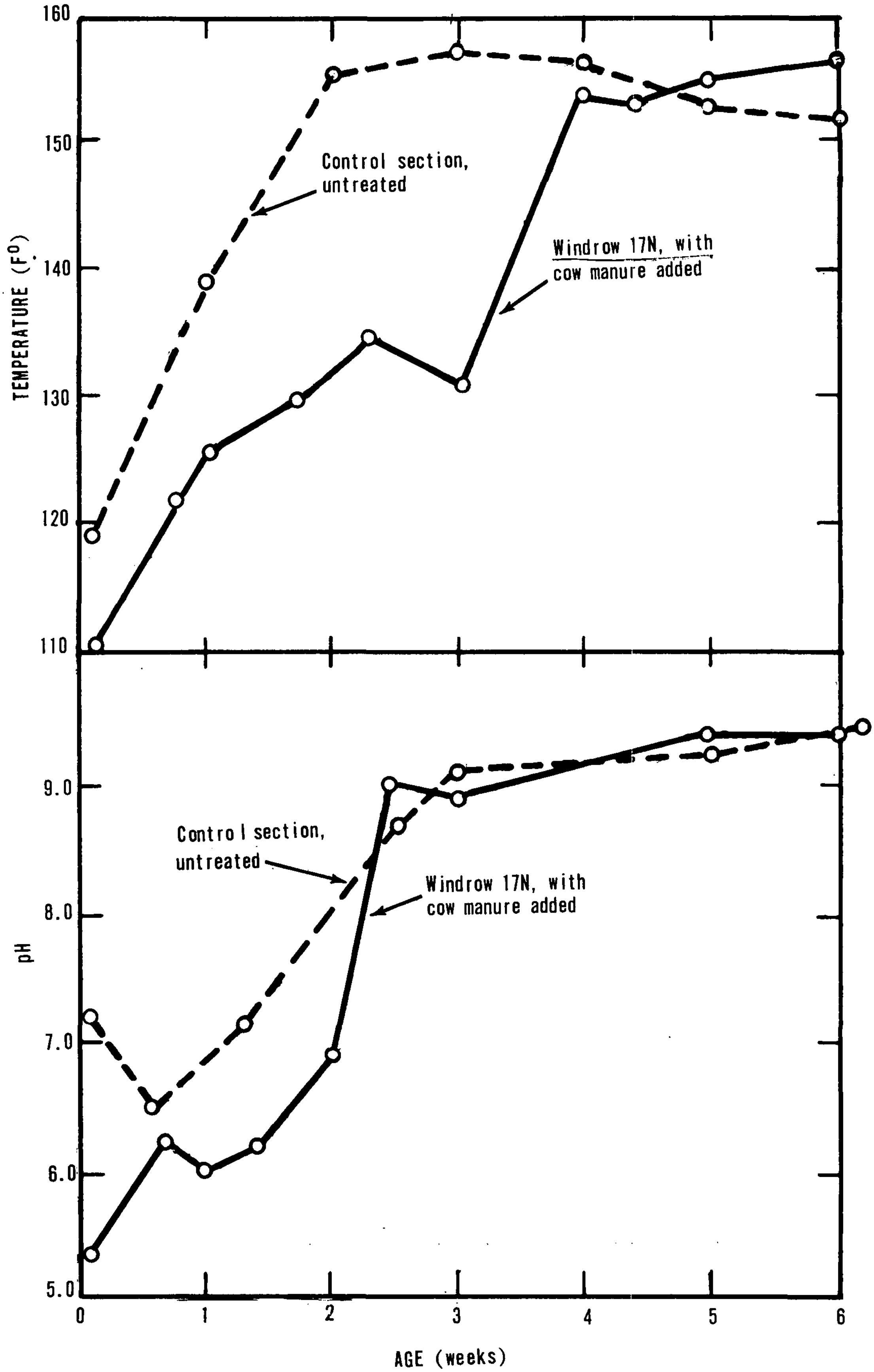


Figure 46. Temperature and pH of refuse composted with cow manure.

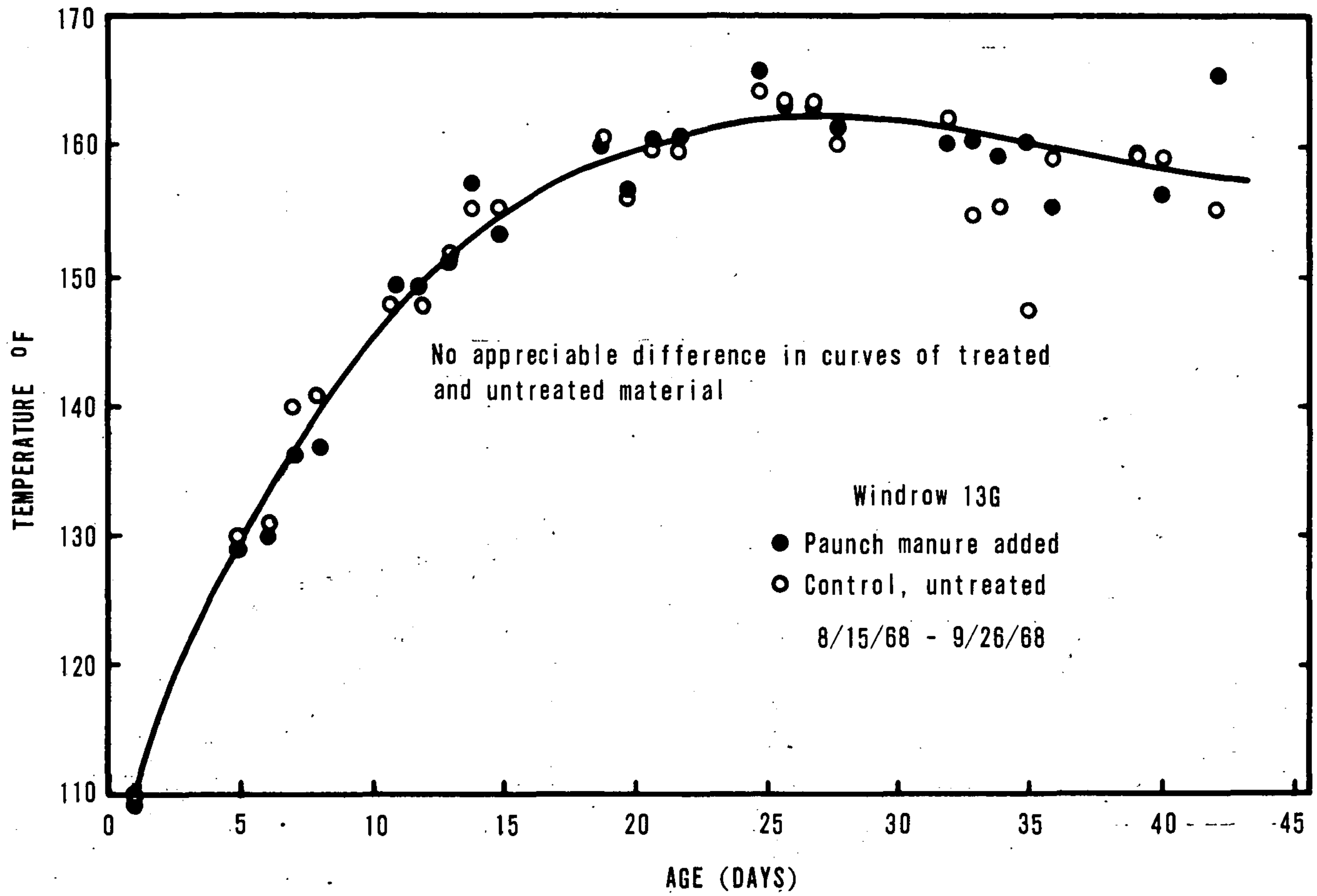


Figure 47. Temperature of refuse composted with paunch manure.

windrow 19G. The chicken manure had been made available to the project on the occasion of a cleanout of droppings from a local farm. A portion of it had undergone decomposition for as much as 6 months. Its nitrogen content was 2.40 percent, similar to that of paunch manure, and the initial nitrogen content of the mixture was 1.37 percent and of the control 0.84 percent. The raw refuse contained between 2 and 5 percent sludge solids. Although the initial nitrogen content of the two portions was not greatly different from those of the paunch manure test, the test portion reached its maximum temperature more quickly than did the control. On day 16 the test portion had reached 165 F while the control showed only 150 F (Figure 48). In this experiment the control did not act normally but the chicken manure hastened the activity in this particular batch of compost. The 42-day nitrogen content of the test portion was 1.25 percent against the 1.05 percent for the control.

The experiment was repeated with fresh chicken manure in windrow 15N with a concentration of 20.1 percent. This windrow contained no sewage sludge. Initial nitrogen content was 1.19 percent for the mixture and 0.73 percent for the control. Final nitrogen contents were 1.32 for the experimental portion and 0.99 percent for the control. The temperature of the portion containing the chicken manure approximately followed that of the control to about the third week when the profile for the test row fell below. By four and a half weeks the test portion was about 12 degrees

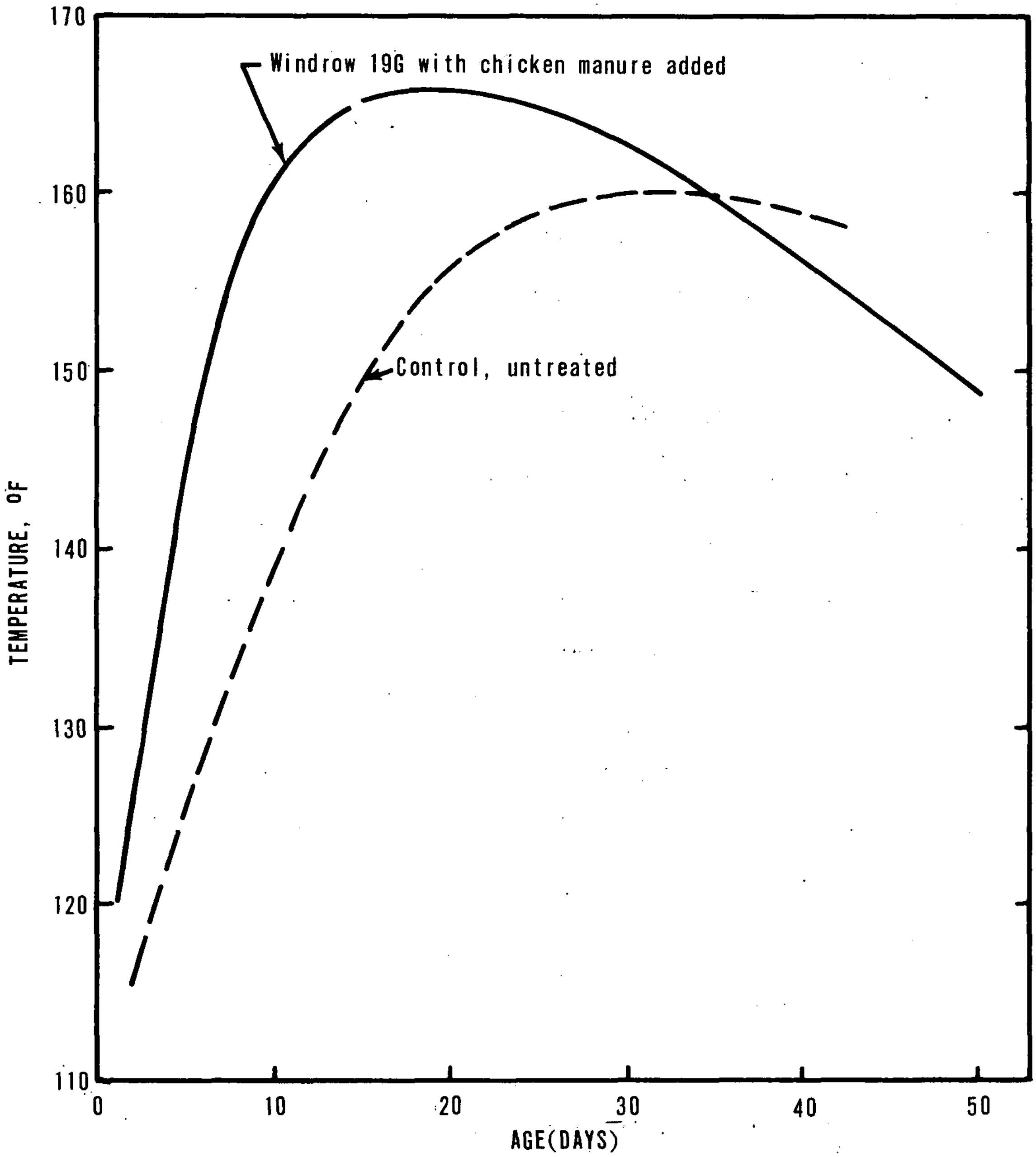


Figure 48. pH of refuse composted with aged chicken manure.

below that of the control. It then began to pick up and at the end of 6 weeks was again approximately that of the control. The pH of the mixture reached 8.8 when the control had reached 8. At 6 weeks the pH of the mixture was still somewhat higher than that of the control (Figure 49). The fresh manure and the composting mixture released large amounts of ammonia which accounts for the high pH and the lower temperatures observed.

4. Beef blood from a small slaughtering establishment was added on day 2 to a portion of a windrow containing about 3 percent sewage sludge solids. The 40 gallons of blood, weighing 354 lb, contained about 110 lb of solids. The mixture of refuse, sludge, and blood contained about 1.3 percent blood solids by dry weight. Blood is high in nitrogen, 10 to 14 percent by dry weight,[4] and this rather small addition was estimated to raise the nitrogen content of the windrow from 0.91 percent to about 1.0 percent.

The addition of blood appeared to retard heating, as compared to the control portion, in the first 25 to 27 days. After that, the test portion exhibited temperatures exceeding those of the control (Figure 50). The 42-day nitrogen content for the test portion was 1.25 vs. the 1.05 of the control. This experiment showed that slaughterhouse blood can be composted with refuse without trouble and may have some value in enriching the compost. The experiment was not repeated due to the difficulty in obtaining blood.

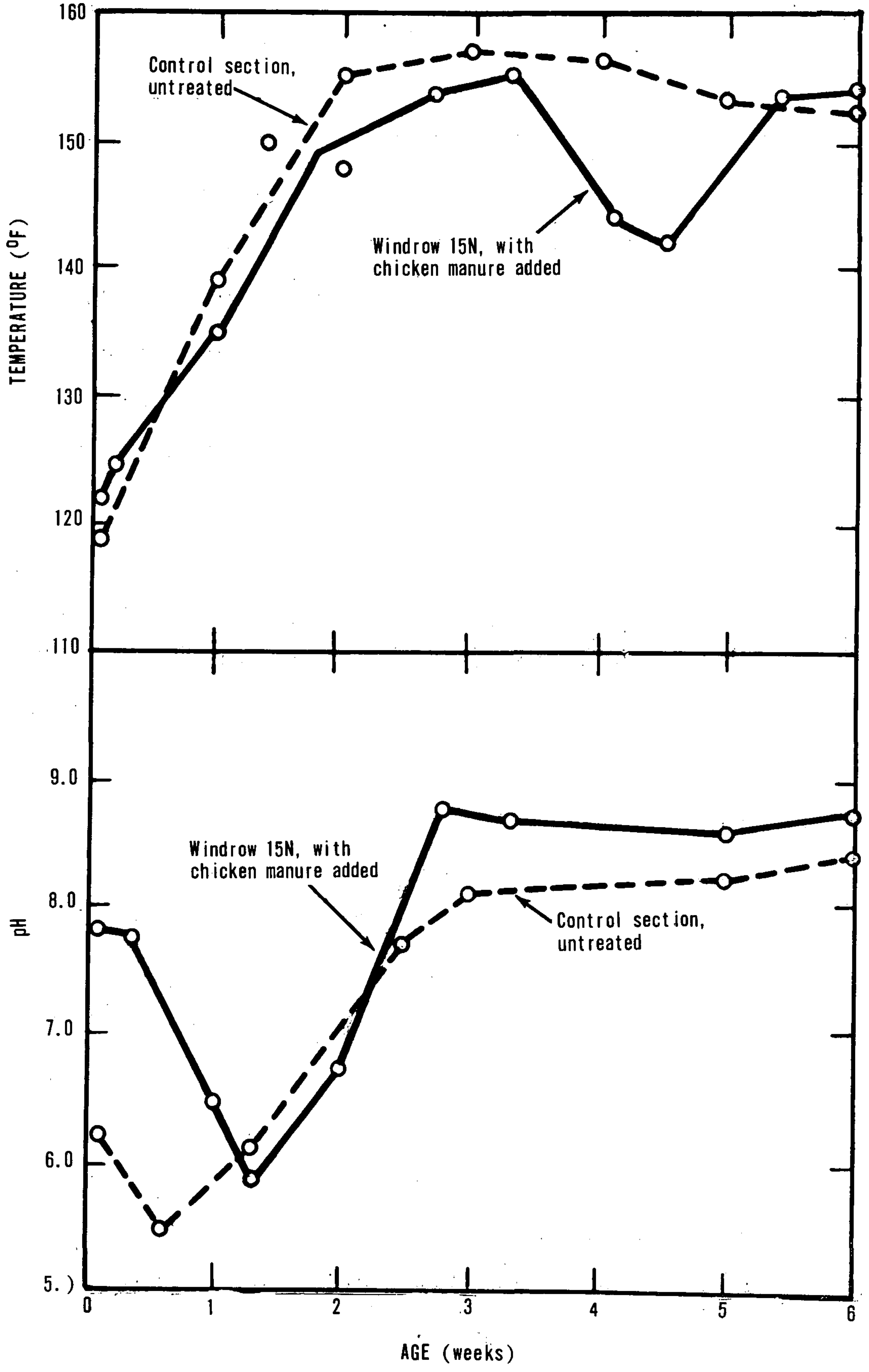


Figure 49. Temperature and pH of refuse composted with fresh chicken manure.

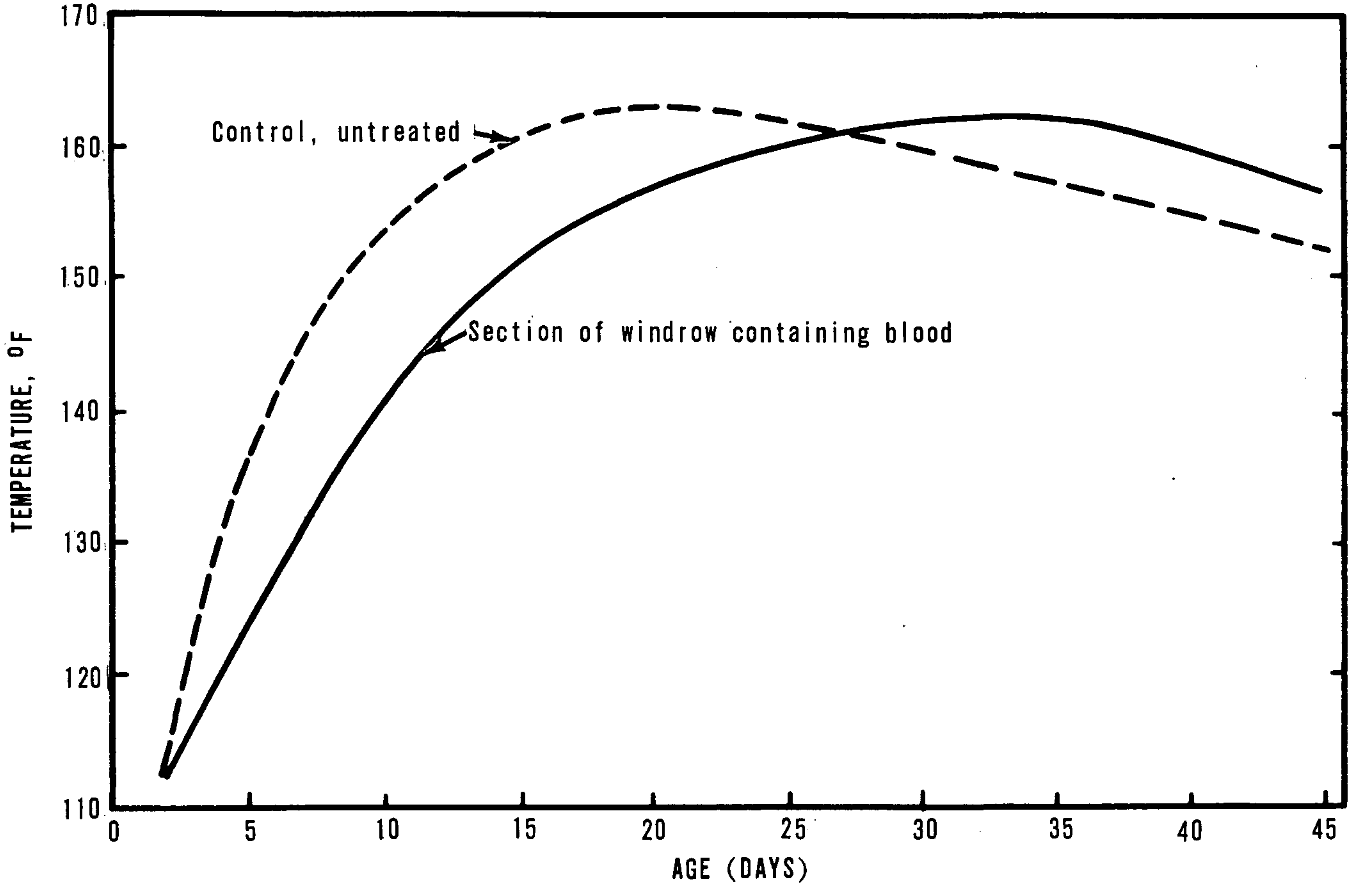


Figure 50. Temperature of refuse composted with slaughterhouse blood.

5. A batch of the wastes of a pimento pepper canning factory, consisting of the pepper cores, rejected peppers, and skins, was incorporated into a portion of a windrow of refuse containing about 3 percent sewage sludge solids on day 3. The pepper waste represented 14 percent of the total dry weight of the mix. The pepper wastes contained 2.82 percent nitrogen on a dry basis and the initial nitrogen content of the mix was about 1.1 percent. The temperature profiles of the test and control portions of the windrow were identical during the composting period. The final nitrogen content of the test portion was 1.3 percent.

This test was repeated using pepper canning wastes in the amount of 6.3 percent of the total weight of the mixture of refuse and pepper wastes. The pepper wastes contained 2.68 percent nitrogen in this case and the refuse (control portion) showed a nitrogen content of 0.89 percent. The initial nitrogen content of the refuse-sludge-pepper mixture was 1.04 percent. Figures 51 and 52 show the temperature and pH profiles during composting. The final nitrogen content (at 42 days) was 1.10 percent for the test row and 1.01 percent for the control.

Effect of Covering a Windrow with Plastic Sheeting. Half the length of a windrow was covered with plastic sheeting in April 1968 and the other half was left uncovered. The plastic was removed for turning and replaced immediately after turning. Temperatures were taken of both parts in the center and near the surface at a depth of 4 in. Some of these data are listed below.

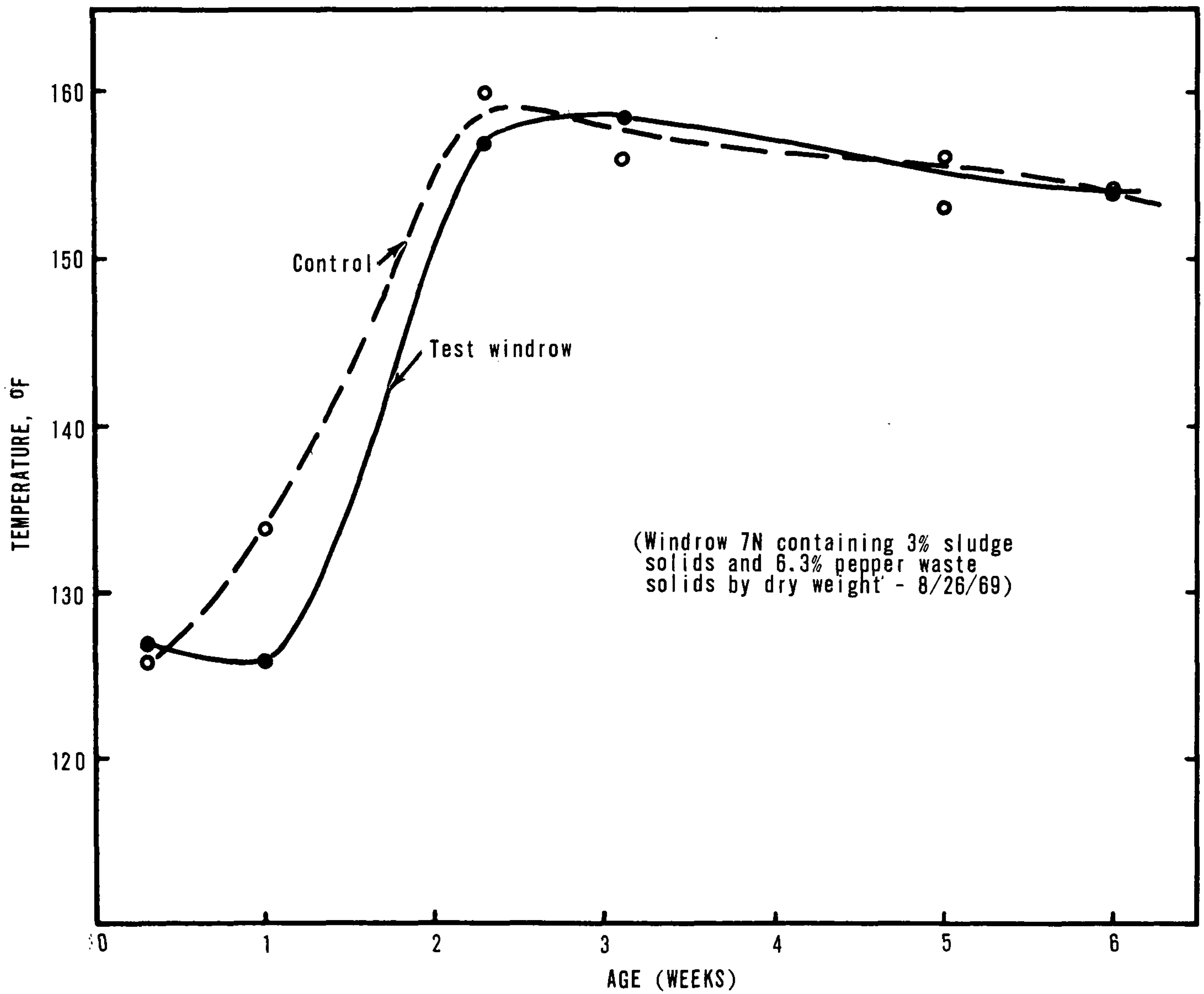


Figure 51. Temperature of sludge-refuse mixture composted with pepper canning wastes.

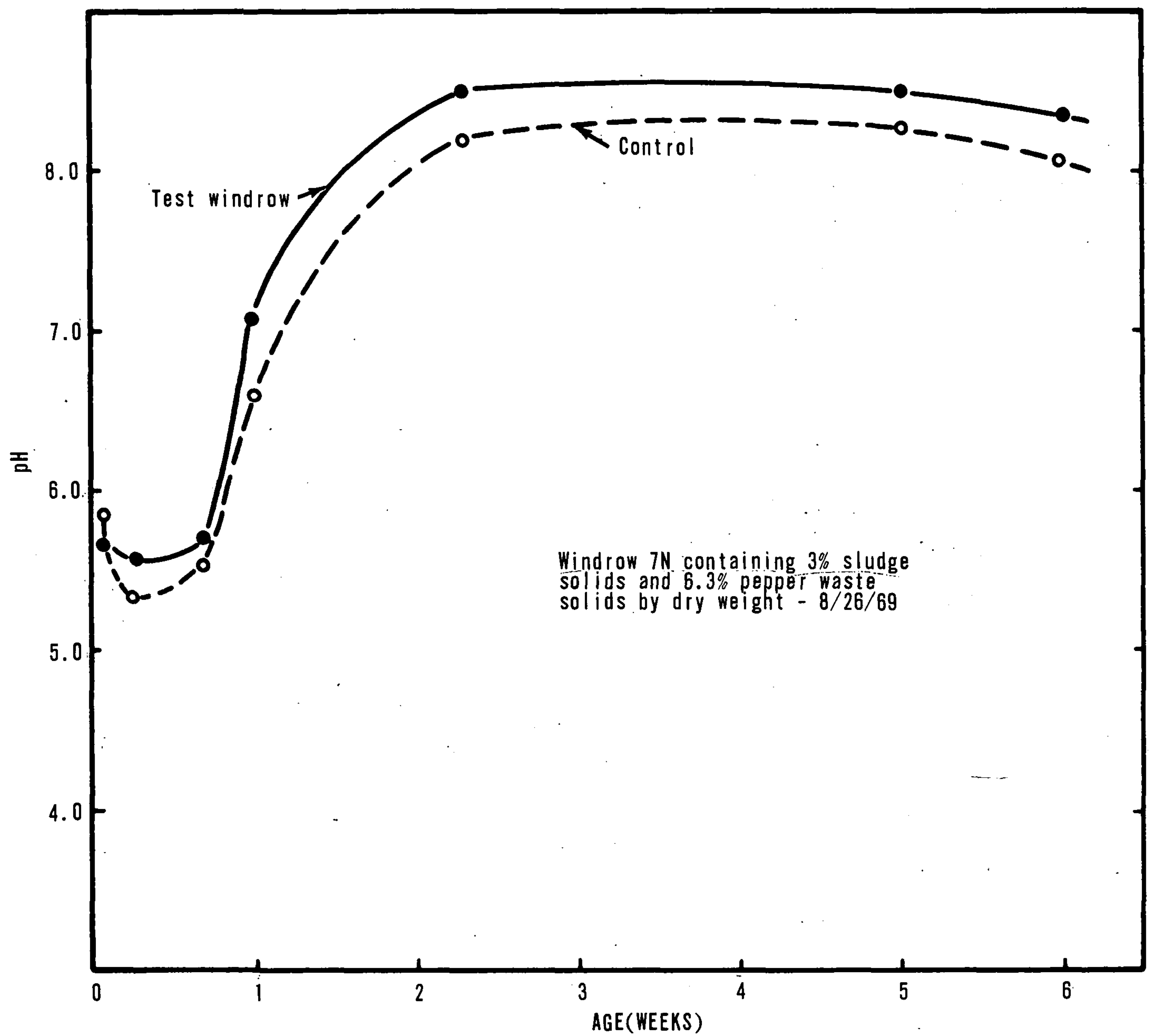


Figure 52. pH of sludge-refuse mixture[illegible]mposted with pepper canning wastes.

Age of windrow in days	Covered		Uncovered	
	Center	At 4" depth	Center	At 4" depth
0	65°	65°	65°	65°
7	116°	114°	144°	139°
14	125°	124°	145°	120°
21	135°	133°	150°	112°
28	137°	134°	149°	131°
35	143°	140°	152°	135°

As can be seen from this tabulation, in the covered portion of the windrow the temperatures in the center of the mass lagged substantially behind those in the uncovered portion. However, after 7 days the surface temperatures were considerably higher in the covered portion due to the greenhouse effect of the plastic. The pH of both parts was about the same. The odors of both parts after turning were about the same, the part under the plastic not being offensive.

The effect of plastic covering for fly control could not be evaluated as the fly population at the composting plant was nil and remained so through the period of the experiment.

Effect of Covering Windrows with Old Compost. In cold weather a retardation of heating has been observed in the windrows. To evaluate the usefulness of covering the new windrows with old compost, three windrows were thus treated.

Windrow 14J was covered with a 12-in. layer of old compost for half its length on zero day. The covered portion showed a steeper rise in temperature at the interface between the old and new than did the control near the surface. It reached 106 F in 3 days, while the control required 4 days to reach this temperature. At 5 days, the control had reached

116 F against the 108 F of the covered portion. On the seventh day, the control was at 112 F and the covered portion at 108 F. Thereafter they both cooled, the control to 107 F and the covered portion to 98 F, by the ninth day, showing need for a turning.

In the center of the mass, windrow 14J reached a higher temperature, 108 F, than the control by the third day. It thereafter became cooler. The center of the control reached a temperature of 110 F in 5 days, 142 F at 9 days, and then began to cool for lack of aeration.

Windrow 16J was covered similarly on the third day. On that day, immediately after covering, the test portion showed 56 F and the control 48 F at the interface and surface, respectively. On the fifth day, the uncovered portion had reached 118 F against the test portion's 103 F. At 10 days, the control was at 102 F against the test portion reading of 104 F.

The center of the mass of uncovered portion of 16J was 13 F lower than that of the test portion on the day they were covered. By the fifth day, the test portion had reached 95 F against the 114 F of the control. By the seventh day, the test portion was only 92 F at its center while the control was at 135 F. Both cooled thereafter for need of a turning.

Windrow 13J was similarly covered on the seventh day. Starting at 4 degrees apart on that day, they both had reached about 120 F on the next day at the interface. From there on, the covered portion showed an increase in temperature at the interface to the fifteenth day, when it was at 131 F. The control showed only 109 F.

In the inner mass, the control steadily rose from 116 F to 151 F on the thirteenth day while the test portion had declined from 114 F to 104 F.

The ambient temperature during this period was about 32 F. All rows were turned before being covered.

It is apparent from these studies that covering windrows at these times has an adverse effect on the temperatures in the center of the windrow, with no significant advantage being gained with surface temperatures. This was observed when they were covered with plastic, and is apparently due to preventing the windrow from "breathing" although the effect of the cover in compacting the underlying refuse may also be a factor. Extrapolating from the results of the windrow covered at 7 days, it appears that the time to cover a windrow to achieve thermal kill at the surface is after it has reached its maximum temperature (2-3 weeks). Such a procedure is under consideration but will require investigation.

pH Observations. Observations of pH changes with age revealed the characteristic curve as shown in Figure 53.

The pH showed an acid condition for the first week generally with some values below 5.0. As the pH rose above 6.0 to a range of 7.5 to 8.0 during the second week, the temperatures also increased. The pH leveled off in a range of 7.8 to 8.5 for the rest of the composting and curing time.

Microbiological and Fly Population Studies

Bacteriological Statistical Experiments. A series of experiments was undertaken by the microbiologist to determine the variability of the bacterial population counts of compost samples due to the inherent heterogeneity of the material itself.

Experiment 1. This experiment was performed to evaluate variation due to error in laboratory procedure. Ten grams of

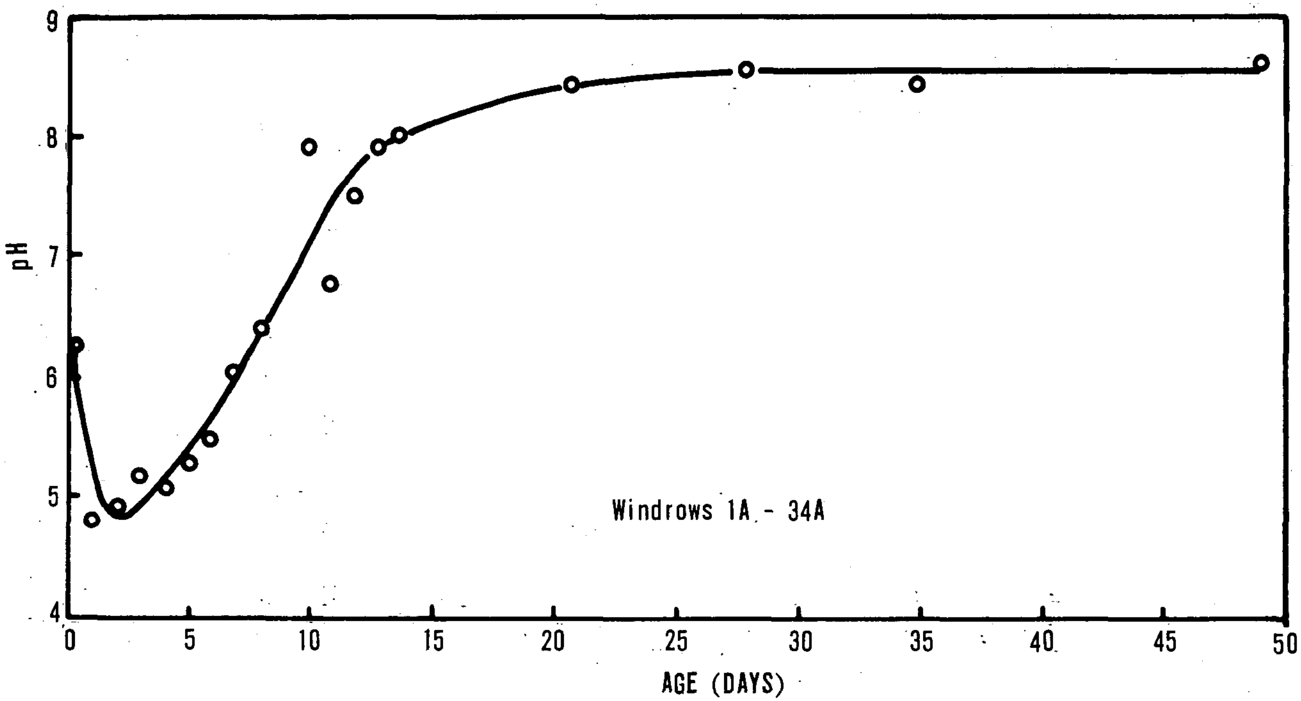


Figure 53. Average pH in windrows 1A thru 34A (1-1/2-ft depth).

zero day compost were homogenized in a 100 milliliter phosphate buffer (pH 7.2). Five 1 milliliter aliquots were removed from this homogenate, each was serially diluted, and the appropriate range of dilutions was incorporated into pour-plates of tryptone glucose extract agar. Plate counts were made at 48 hrs. Results were as follows:

Sample	1	229 x 10^4 cells per ml of homogenate
	2	243
	3	249
	4	248
	5	233

average = 240 x 10^4 cells per ml of homogenate

Since cell distribution should theoretically be Poissonian, the standard deviation should be ± 15.5 cells per plate of the average count, if the laboratory technique is adequate. None of the five counts exceeded this range.

Experiment 2. A set of five 10-gram samples was drawn from a zero day windrow; each was homogenized in 200 milliliters of sterile phosphate buffer. Plate counts were made on each of the five homogenates. In addition, the fifth homogenate was plated in triplicate to determine plating variation. A set of five 5-gram samples was drawn from another zero day windrow, homogenized in 100 milliliter aliquots of sterile buffer, and plated as above. Results were:

Sample 1	51 x 10^5	per ml homogenate for the five 10-gram samples
2	65	
3	150	
4	137	
5a	105	
5b	126	
5c	122	

Std. deviation = ± 42 percent for samples 1-5a

Sample 1	66 x 10^6	per ml homogenate for the five 5-gram samples
2	49	
3	182	
4	62	
5a	42	
5b	66	
5c	28	

Std. deviation = ± 73 percent for samples 1-5a

The above experiments were repeated with 49-day compost using the same experimental procedure. The results were as follows:

Sample 1	62 x 10^4	per ml homogenate for the five 10-gram samples
2	56	
3	71	
4	33	
5a	93	
5b	80	
5c	81	

Std. deviation = ± 35 percent for samples 1-5a

Sample 1	52 x 10^5	per ml homogenate for the five 5-gram samples
2	32	
3	281	
4	33	
5a	30	
5b	22	
5c	25	

Std. deviation = ± 140 percent for samples 1-5a

The value of determining the standard deviation in this regard is that the range in which 67 percent of the sample counts should fall is defined. It is clear from the limited data presented here that choosing 10-gram samples would give a more accurate and reproducible estimate of the actual cell counts than the choosing of 5-gram samples. Samples of up to 200 grams were used in the project laboratory at Johnson City.

Survival of *Mycobacterium phlei.* The Staff Microbiologist conducted studies of the survival in composting of *Mycobacterium phlei* Strain 41 obtained from Dr. George Kubica, National Communicable Disease Center, Atlanta, Georgia. This strain, which is rather thermophilic, was used rather than *Mycobacterium tuberculosis*. A non-virulent strain of the latter was concurrently being used in survival studies by another investigator.

During preliminary experiments in the project laboratory, attempts at the isolation of *Mycobacterium phlei* from seeded raw ground refuse samples by classical published methods proved unsuccessful. Therefore, all insertions were of necessity made with cultures grown on Lowenstein-Jensen (L-J) agar slants at 45 C for 3 days. All insertions were prepared in duplicate and inserted on either zero day or day 14 at depths of 2 in., mid-depth, and in the toe of the windrow. At selected time intervals, the duplicate slants were removed from the windrows. Subcultures were made by washing each slant with 0.5 milliliters of sterile phosphate buffer. The buffer-cell suspension was then transferred to a new L-J slant and incubated for at least 10 days at 37 C. Viable cultures would usually produce detectable growth within 3 days. A total of 136 sets of duplicate sample (224 tubes) was inserted into 12 windrows.

Table 11 gives the findings. No samples inserted at mid-depth on zero day or day 1 were found to contain viable cells after 14 days of composting. For the insertions at the depth of 2 in., viable cells were found after 49 days where the temperature reached only 92 F. In other windrows none were found at compost ages over 21 days where temperatures subsequently reached 118 F. Where temperatures reached 128 F or over at the 2-in. depth, no viable cells were found. This condition was usually obtained by the 14th day. For samples inserted in the "toe" of the windrow, viable cells were found to the point at which temperatures reached 134-136 F. In one case, viable cells were found at mid-depth at a temperature of 138 F on the seventh day of composting. Samples retrieved at greater ages were not viable.

From the data obtained in these studies it appears that temperatures as low as 128 F are sufficient to kill *M. phlei* provided the time of exposure is sufficient. Seven days at 128 F should be sufficient with shorter times for temperatures over 130 F. Insertions were made under artificial conditions due to the fact that they were slant cultures and not directly exposed to the compost. Temperature, therefore, was the sole factor in their destruction. Where proper mixing is practiced and temperatures of 140 F or over are obtained, *M. phlei* would be destroyed.

Pathogen Survival Studies under Contract. The intensive studies on the survival of pathogens and parasites in the windrow composting of refuse and sewage sludge were carried out under two contracts (PH-86-67-112 and PH-86-68-143) with East Tennessee State University in the period July 1967 through June 1969.

TABLE 11

MYCOBACTERIUM SURVIVAL IN COMPOST
(*Mycobacterium phlei*)

Insertions into Windrows 18H (11/19/68) and 28H (12/10/68) on Day 14

Exposure Time (days)	Viable Cells Detected		Temperatures, °F		Insertion Location
	18H	28H	18H	28H	
0	(++)	(++)	120	132	2" and mid-depth
1		(+-)		152	2"
		(--)		162	mid-depth
2		(--)		146	2"
		(--)		160	mid-depth
3	(--)	(--)	128	144	2"
	(--)	(--)	158	152	mid-depth
7	(--)	(--)	148	148	2"
	(--)	(--)	158	156	mid-depth

All samples removed after 14 and 21 days exposure were negative

Insertions into Windrow 21 (12/10/68) on Day 0

Exposure Time (days)	Viable Cells Detected	Temperatures, °F	Insertion Location
0	(++)	34-40	2", mid-depth, and toe area of windrow
3	(++)	46	2"
	(++)	40	mid-depth
	(++)	44	toe area
7	(++)	98	2"
	(++)	78	mid-depth
	(++)	50	toe area
17	(--)	152	2"
	(--)	160	mid-depth
	(++)	126	toe area
21	(--)	142	2"
	(--)	150	mid-depth
	(--)	114	toe area

Insertions removed from all three insertion depths at 35 days were negative.

TABLE 11 (CONT'D)

Insertions into windrow 19I (1/7/69) on Day 0

Exposure Time (days)	Viable Cells Detected	Temperatures, °F	Insertion Location
0	(++)	38	2", mid-depth, and toe area of windrow
7	(++)	26	2"
	(++)	30	mid-depth
	(++)	46	toe
14	(++)	92	2"
	(++)	108	mid-depth
	(++)	92	toe
21	(++)	102	2"
	(--)	142	mid-depth
	(++)	98	toe
28	(--)	118	2"
	(--)	142	mid-depth
	(--)	116	toe

Insertions into windrow 22I (1/13/69) on Day 0

Exposure Time (days)	Viable Cells Detected	Temperatures, °F	Insertion Location
0	(++)	34	2", and mid-depth
7	(++)	52	2"
	(++)	50	mid-depth
21	(++)	76	2"
	(--)	130	mid-depth
24	(++)	90	2"
	(--)	140	mid-depth
28	(++)	96	2"
	(--)	148	mid-depth
35	(++)	104	2"
	(--)	132	mid-depth
49	(++)	92	2"
	(--)	126	mid-depth

TABLE 11 (CONT'D)

Insertions into windrow 29I (1/22/69) on Day 0

Exposure Time (days)	Viable Cells Detected	Temperatures, °F	Insertion Location
0	(++)	36	2", and mid-depth
7	(++)	102	2"
	(++)	122	mid-depth
14	(++)	88	2"
	(++)	110	mid-depth
28	(--)	144	2"
	(--)	152	mid-depth
35	(--)	122	2"
	(--)	142	mid-depth
49	(--)	110	2"
	(--)	142	mid-depth

Insertions into windrow 24J (3/5/69) on Day 0

Exposure Time (days)	Viable Cells Detected	Temperatures, °F	Insertion Location
0	(++)	62	2", and mid-depth, and toe area of windrow
7	(++)	96	2"
	(+-)	130	mid-depth
	(--)	146	toe
14	(--)	128	2"
	(--)	152	mid-depth
	(--)	134	toe
21			

All samples removed after 21 and 28 days exposure were negative

Insertions into windrow 26J (3/7/69) on Day 0

Exposure Time (days)	Viable Cells Detected	Temperatures, °F	Insertion Location
0	(++)	40	2", mid-depth, and toe area of windrow
7	(++)	122	2"
	(--)	142	mid-depth
	(+-)	110	toe
14	(--)	140	2"
	(--)	150	mid-depth
	(-*)	118	toe

All samples removed after 21 and 28 days exposure were negative

* Insertion culture contaminated

TABLE 11 (CONT'D)

Insertions into windrow 4M (6/30/69) on Day 0

Exposure Time (days)	Viable Cells Detected	Temperatures, °F	Insertion Location
0	(++)	92	2", mid-depth, and toe area of windrow
2	(++)	134	2"
	(++)	120	mid-depth
	(++)	126	toe
7	(--)	134	2"
	(--)	148	mid-depth
	(--)	134	toe
10	(--)	144	2"
	(--)	152	mid-depth
	(--)	136	toe

Insertions into windrow 8M (7/7/69) on Day 0

Exposure Time (days)	Viable Cells Detected	Temperatures, °F	Insertion Location
0	(++)	86	2", mid-depth, and toe area of windrow
2	(++)	118	2"
	(++)	118	mid-depth
	(++)	118	toe
7	(+-)	136	2"
	(++)	138	mid-depth
	(+*)	134	toe
10	(--)	142	2"
	(--)	146	mid-depth
	(--)	136	toe

* Insertion culture contaminated

TABLE 11 (CONT'D)

Insertions into windrow 17M (7/22/69) on Day 0

Exposure Time (days)	Viable Cells Detected	Temperatures, °F	Insertion Location
0	(++)	88	2", mid-depth, and toe area of windrow
2	(++)	118	2"
	(++)	120	mid-depth
	(++)	116	toe
7	(--)	142	2"
	(--)	142	mid-depth
	(--)	150	toe
10	(--)	120	2"
	(--)	148	mid-depth
	(--)	144	toe

Insertions into windrow 19M (7/24/69) on Day 0

Exposure Time (days)	Viable Cells Detected	Temperatures, °F	Insertion Location
0	(++)	92	2", mid-depth, and toe area of windrow
4	(+-)	142	2"
	(++)	132	mid-depth
	(++)	134	toe
7	(--)	134	2"
	(-*)	146	mid-depth
	(--)	128	toe
10	(--)	140	2"
	(--)	152	mid-depth
	(--)	132	toe

* Insertion sample contaminated

The first contract studied the occurrence and survival of pathogens and parasites. The second covered the actual insertion of organisms with the compost. The findings of the two studies have not yet been published by Dr. William L. Gaby, under whose supervision they were made.

The organisms for which the search for occurrence was made included:

- Coliforms
- Fecal coliforms
- Fecal streptococci
- Coagulase positive staphylococci
- *Salmonella* species
- *Shigella* species
- Enteroviruses (such as polio)
- Pathogenic fungi
- Parasitic organisms (protozoa, cestodes, and nematodes)

In this phase, 602 samples were taken from 30 windrows and from the fresh refuse, sewage sludge, and fresh sludge-refuse mix on the days those particular windrows were laid down. The sludge was raw or in a partially digested state. The duration of the composting process at Johnson City is 49 to 56 days, 35 to 42 days of which are on the composting field and the remaining 2 weeks in the curing stage, either in the open or under a shed. Samples were taken from windrows at various intervals during the process and on the terminal day. The samples also were taken from several positions within the windrows.

The studies showed that there was a consistent, inverse relationship between the number of total and fecal coliforms in compost and the windrow temperature. Temperatures of 120-130 F (49-55 C) were sufficient to reduce coliform populations significantly, often to levels lower than the minimal level of detection by the Most Probable Numbers Method. However, the temperature decrease occurring at the latter stages of the composting process allowed reestablishment of significant numbers (10^2-10^5/g) of coliforms. Fecal streptococci did not appear to be as heat sensitive and maintained populations as high as 10^6/g even when temperatures reached 130-140 F (55-60 C).

Salmonella species were frequently isolated from the raw sewage sludge; however, no *Salmonella* or *Shigella* species were isolated from samples of windrows over 7 days old. Coagulase positive staphylococci were isolated only from raw refuse, never from sludge, and found in only one windrow on the 49th day. All other samples were negative for coagulase-positive staphylococci after the first day on the field. The studies under the ETSU contract did not give conclusive results for pathogenic fungi. No enteroviruses were ever isolated from sewage sludge, raw refuse, or any compost sample at any time. In the parasite detection studies, 3 percent of the total number of samples (total of 602) of fresh to 49-day compost were positive for one or more parasitic ova or cysts. Of the 49-day samples taken, 8 of 135 (6 percent) were positive for parasites. It is of importance here that these positive findings are based on the identification of parasitic forms which were morphologically intact and not upon actual viability tests.

Organisms used in the insertion studies included:

Bacteria: *Escerichia coli*
Salmonella typhimurium

	Salmonella typhimurium
	Shigella sonnei
	Staphylococcus aureus (coagulese positive)
Parasites:	*Endamoeba histolytica*
	Ascaris lumbricoides (viable ova)
	Endolimax nana
	Necatur americanus
Fungi:	*Histoplasma capsulatum*
	Blastomyces dermatitidis
	Aspergillus fumigatus
	Geotrichum candidum
Viruses:	*Polio* virus, Type II
Spirochoetes:	*Leptospira philadelphia*

A total of 1,137 samples of bacteria, fungi, parasites, and viruses was inserted in 24 windrows in the second phase. In conformity with the first phase of the work, the samples were planted at various positions within the compost and withdrawn at intervals during the process. Insertions of bacteria were made both in sealed ampules and in such manner that the cultures were in contact with compost. This was done to determine if bacteria could survive the process despite the elevated temperatures and the possible presence of antibiotic substances. Other organisms were inserted in test tubes with screw caps.

In the insertion studies, all bacterial samples in the form of impregnated discs in contact with compost removed after 25 days in the windrows were rendered nonviable. All samples of *Shigella sonnei* and *Staphylococcus aureus* removed at 14 days and thereafter were nonviable.

Samples of *S. sonnei* inserted in sealed ampules removed after 25 days were nonviable and those of *S. aureus*, similarly prepared, removed after 35 days were destroyed. Only two samples of 18 of *S. aureus* in ampules removed between 25 and 29 days in the compost were positive. One sample of *Salmonella typhimurium* in an ampule was positive after 49 days and showed a reduction of cells from 2×10^8 to 1.6×10^2. This was a sample inserted and kept in the bottom 6 in. of a windrow where temperatures are lower. On turning, the compost was moved from the bottom but the sample was reinserted in this cooler part of the windrow.

Of the 38 samples of the fungus *Histoplasma capsulatum*, inserted in capped test tubes, three were found to be positive on withdrawal. Withdrawals were made from the seventh day to the 28th day. One positive had been in the compost for 14 days, another 24 days, and the third for 26 days. The 14th and 24th day samples had been kept at the midpoint of the composting mass and the 26th sample in the outer layer at the 2-in. depth.

All samples of the fungus *Blastomyces dermatitidis*, withdrawn at intervals up to the 28th day, were rendered nonviable.

Thermophilic fungi such as *Aspergillus fumigatus* are commonly associated with the composting of various types of solid wastes. On-site observations showed that *A. fumigatus* could be consistently isolated from composting material at Johnson City at all stages of the process. In the insertion studies it survived for 28 days in capped test tubes. Inserted samples of *Geotrichum candidum* survived for 24 days.

All samples of *Endolimax nana* and *Endamoeba histolytica* were destroyed after 8 days' exposure. All samples of *Leptospira philadelphia*, withdrawn at from 2 to 9 days of exposure were deactivated.

Ova of hookworm (*Necatur americanus* or *Ancylostoma duodenale*) disintegrated after 7 days' exposure in the compost.

As with the occurrence studies, the insertion studies show that some morphologically intact parasite forms (*Ascaris*, *Trichuris*, *Necatur*, *Ancylostoma*, and *Hymenolopis* species) persisted to the end of the composting process. Facilities were not available at ETSU and the Tennessee State Department of Health for a determination of the viability of these parasite forms.

Of the 66 samples of an enterovirus (Polio II) assayed for active virus particles after remaining for various lengths of time in the composting mass, one 3-day and one 14-day sample were found positive. The number of active virus particles recovered from each of the two positive samples amounted to 1 percent of the original concentration inserted. No virus sample was positive after exposure for more than 14 days. The windrow temperatures recorded for the two positive samples at the time they were withdrawn were 133 F (56 C) and 147 F (64 C).

Concurrently with the studies carried on by the Public Health Service and the research done under contract by Gaby of East Tennessee State University, Morgan conducted a study of the survival of *Mycobacterium tuberculosis* in windrows at the Johnson City Plant.[5] The organism used was an avirulant *M. tuberculosis* var *hominis*, obtained from Trudeau Institute, Inc. The insertion technique was used and the samples were planted in the compost during fall, winter, spring, and summer months. Results revealed that *M. tuberculosis* was normally destroyed by the 14th day of composting where the average temperature was 149 F (65 C). In all cases the organisms were destroyed by the 21st day. In the study with one windrow, all *M. tuberculosis* organisms were killed by a temperature of 140 F (60 C) or less.

The negative results obtained in the search for pathogenic bacteria (such as *Salmonella, Shigella,* and *Staphylococcus*) in compost would indicate that windrow conditions at Johnson City will destroy such pathogens. The results obtained in the pathogen insertion studies, which were supported by the in-house work with *Mycobacterium phlei*, confirm this conclusion.

Of the fungi, *Blastomyces dermatitidis* samples withdrawn up to the 28th day were rendered nonviable. Although one of the inserted *Histoplasma capsulatum* samples was found to survive 26 days of composting, the search for this fungus in the compost was not successful. *Aspergillus fumigatus*, occasionally pathogenic to humans, could be isolated in the compost itself throughout the process. *Histoplasma capsulatum* has been isolated in garden soils and *Aspergillus fumigatus* is ubiquitous. The literature does not cite any references to fungal infection among sanitation workers in association with the disposal of solid wastes. Present data do not permit any estimate of the possible hazard of pathogenic fungi in this connection and the results at Johnson City do not warrant any restrictions on the use of compost due to these fungi.

Although morphologically intact parasite forms persisted through the process, the data shown by the Belding[6] show that the ova of *Ascaris lumbrocoides, Trichuris trichuria, Necator americanus, Ancylostoma duodenale,* and *Hymenolopsis diminuta* are killed at time-temperature conditions which are less severe than those which obtain in composting. The work of Scott[7] in composting bears this out for *Ascaris* ova. It was concluded that the forms found were nonviable although they were not tested with live animals.

Only two of 66 samples of enterovirus (Polio II) were found positive after 14 days in the compost. It is believed that these may have been recontaminated during assay as only very low counts were found and these organisms may be inactivated in 30 min at 122-130 F. No positive samples were found on withdrawal before 14 days.

Evidence from the ETSU studies, the in-house studies at Johnson City, and the work of others in the United States and Europe, indicates that properly processed compost of municipal waste and sewage sludge as used in gardening or agriculture does not constitute a public health hazard. For proper processing, it is imperative that all material in a given windrow be exposed to temperatures in the range of 122-130 F for a period of at least 7 days. To accomplish this the material in the toe area must be picked up and piled on top or at the end of the windrow before turnings. At Johnson City the temperature of each windrow is taken weekly to be sure that the necessary temperatures are reached and held for 7 days. Actually, windrows which have not reached 140 F or over and remained for 7 days, are condemned at Johnson City in order to have a factor of safety.

Cellulolytic Activity in Composting. Cellulases were extracted by homogenizing 200-gram samples of compost in 2 liters of cold phosphate buffer (pH 7.0). The homogenates were clarified by centrifugation, and cellulase activity in the supernatant fluid was determined by measuring the liberation of reducing sugars (as cellobiose) from acetate-buffered solutions of carboxymethylcellulose. The pH, temperature, ionic strength, and substrate concentration optima were determined for this reaction. The total free cellulase content of compost was measured in relation to the age of the compost to determine the time of maximal production of cellulolytic enzymes. The cellulolytic flora which produce these cellulases in compost were isolated on microcrystalline cellulose-mineral salts agar and identification of these organisms was initiated.

Detectable cellulase activity (as measured by its ability to liberate reducing sugars from carboxymethylcellulose) increased tenfold at a logarithmic rate during the 49-day composting cycle. Concurrently, the cellulose content of the compost decreased from 50 to 30 percent. The pH and temperature optima for the cellulolytic reaction were consistently 6.0 and 149 F (65 C), respectively. Variation of ionic strength between 0.1 and 1.0 had little effect on the velocity of the cellulase reaction. Maximal reaction velocity was achieved with a carboxymethylcellulose concentration of 2.5 percent, a concentration which is near the limit of solubility.

Three species of cellulolytic flora (designated as C-1, C-2, and C-3) were isolated from compost homogenates. C-1 resembled *Aspergillus fumigatus*, grew rapidly at 95-113 F (35-45 C), and caused intense clearing of the cellulose agar within 5 days. C-2, a Gram-variable sporeforming rod, grew rapidly at 95 F (35 C), slowly at 113 F (45 C), and produced diffuse zones of clearing on cellulose agar. C-3 appeared to be a thermophilic actinomycete (rapid growth at 125-131 F); it produced wide zones of cellulose clearing around colonies within 72 hr.

During the 49-day composting process, total cellulolytic activity increased tenfold while the cellulose content of the compost decreased from 50 to 30 percent. Consideration of temperatures which exist in the windrows would indicate that the greatest portion of cellulolytic activity is produced by the thermophilic actinomycete (C-3). This organism, which grows rapidly at 131 F (and has an upper growth limit of 140 F) is the only species isolated which seems compatible with windrow temperatures. This actinomycete might be profitably exploited in various cellulose decomposition or transformation processes. At the present time, studies are being performed to determine production of cellulase in pure culture and the factors which affect this production.

Fly Population Counts. As mentioned in the section on operations, an extensive fly problem developed in the plant area in the summer of 1967. Flies in all stages of their life cycle came to the plant with the refuse being delivered in compaction trailers. Adult flies were widespread over the plant area and were particularly concentrated on windrows just being formed. Table 12 shows the adult fly counts obtained with the Scudder grill from August 31 to September 15, 1967. It will be noted that fresh windrows were the most attractive to the flies. Although many flies came in with the refuse, there was some breeding in the plant at the foot of windrows.

Fly counts were taken in October 1968 to determine the comparative attractiveness of the storage area and several other areas. The storage area contained compost from 42 days old to more than 1 yr old. Table 13 shows findings which indicate that the stored compost had no attractiveness under the conditions which obtained. As would be expected, the greatest number was

TABLE 12

ADULT FLY COUNTS WITH SCUDDER GRILL - 1967

Windrow	8/31	9/1	9/6	9/7	9/8	9/11	9/12	9/13	9/14	9/15
11-13	0	0	-	-	-	-	-	-	-	-
12	1	0	-	-	-	-	-	-	-	-
14-15	0	0	0	-	-	-	-	-	-	-
16-17	0	1	4	-	-	-	-	-	-	-
18-19	10	2	0	1	0	0	2	0	-	-
20-21	3	1	2	2	1	0	3	0	0	-
22-23	3	0	1	1	2	0	0	0	1	1
24-25	3	1	9	3	0	0	5	0	0	0
26-28	2	1	2	1	8	3	5	1	0	0
27	6	11	0	7	3	6	0	2	3	3
29	1	4	5	4	6	3	2	10	4	2
30	2	6	3	3	1	1	3	7	3	2
31	3	-	3	2	-	-	-	-	-	-
32	2	6	4	6	5	1	0	6	1	5
33	5	-	3	1	-	-	-	-	-	-
31-33	-	-	-	-	4	2	3	0	1	1
34	5	6	5	1	2	5	3	3	1	0
35	3	2	5	3	1	0	9	5	4	2
36	6	9	3	1	1	2	1	-	1*	2
37	9	6	0	3	4	3	4	2	8*	10
38	3	1	2	1	4	4	4	1	0	5
39	1	3	5	6	5	4	3	0	2	3
40	1	9	3	4	2	3	2	6	1	0
41	7	2	2	9	11	4	2	5	5	10
42	4	2	15	10	5	6	4	4	8	8
43	0	5	7	9	5	3	1	1	5	7*
44	3	2	8	9	3	2	2	1	4	4
1A	2	3	3	1	3	1	1	4	5	3
2A	6	6	3	2	6	2	5	3	3	7*
3A	-	8	5	4	2	4	1	3	6*	3
4A		7	0	4	1	3	3	2	7	2
5A			2	2	1	5	0	1	0	1
6A			12	2	2	4	3	3	3	5*
7A			120**	3	5	10	4	3	0	2
8A				72**	5	4	0	2	2	0
9A					13**	5	5	4	0	7*
10A						28**	0	5	5	8
11A							25**	6	10	0
12A								15**	4	2
13A									21**	2
14A										10**
	Sunny	Cloudy and Windy	Sunny and Windy	Partly Cloudy	Partly Cloudy	Partly Cloudy	Clear	Clear	Clear	Clear

* Immediately after turning.
** Windrow formed on this day.

Note: Observations above the upper line within table were made in the drying and curing shed.

TABLE 13

FLY POPULATION DATA

	Fly Count							
Date	Receiving Building	0-day Windrow	35-day Windrow	Storage Area	Time	Wind	Cloud Conditions	Temp.
10/ 3/68	No reading	26 - 27	7 - 11	0 - 0	2:30 pm	Light	Cloudy	Cool
10/ 4/68	No reading	5 - 7	3 - 1	0 - 0	1:30 pm	Light	Clear	Cold
10/ 7/68	10 - 5	30 - 22	3 - 4	0 - 0	2:45 pm	Light	Partly	Warm
10/ 8/68	4 - 3	7 - 22	2 - 0	0 - 0	1:30 pm	None	Partly	Warm
10/ 9/68	7 - 3	20 - 9	0 - 5	0 - 0	3:30 pm	Light	Partly	Cool
10/10/68	No reading	24 - 17	0 - 3	0 - 0	4:15 pm	None	Cloudy	Cool
10/14/68	11 - 3	26 - 13	3 - 7	0 - 0	3:15 pm	None	Partly	Warm
10/15/68	7 - 20	5 - 30	3 - 3	0 - 0	3:00 pm	Strong	Partly	Warm

Count of flies resting on a Scudder grill in one minute. Two counts made at each observation point. No distinction made for species.

found where raw, unground refuse was being handled. The observations were made at the end of the fly season and may not be valid for a period of higher populations. At no time in 1968 or 1969 did the fly population reach a nuisance level at the plant.

Chemical and Physical Characteristics

Sampling Techniques. The chemist completed a series of studies designed to discover a reliable sampling procedure for determination of physical and chemical characteristics of compost.

Forty samples, each of 50 grams, wet weight, were collected from windrow 6H immediately after turning on the 25th day of composting. The windrow was of average cross-section and 120 ft in length. Samples were taken at 6-ft intervals, 20 per side. These were all dried and then ground in a Wiley mill (large pieces of glass, metal, and rock were removed to prevent damage to the mill). The windrow was sampled two additional times on the same day and each set composited. These composited samples were ground wet in a W-W grinder, each was well mixed, quartered, and dried. Randomly selected samples were taken from each quarter of the two samples and ground in the Wiley mill. The 40 individual samples and the four quarters of the two composite samples were then analyzed for nitrogen and ash. Results are summarized in the table below.

	Ash			Nitrogen		
	Avg. %	Std. Dev.	% Dev.	Avg. %	Std. Dev.	% Dev.
40 Individual Samples	19.11	3.46	18.1	.865	.083	9.6
Composite Sample I (8 samples)	26.04	1.61	6.2	.924	.017	1.8
Composite Sample II (8 samples)	25.94	0.66	2.5	1.033	.021	2.0

The lower percentage ash for the 40 individual samples is due to the fact that rocks, glass, etc., were removed prior to analysis.

Windrow 17D was sampled on the 2nd day of composting by taking two large (5,500 grams) composite samples and preparing them in the manner described above (W-W grinder, mixing, drying, Wiley mill). The windrow had not been turned prior to sampling and was at its maximum heterogeneity. Both composites were analyzed for nitrogen, lipids, ash, and pH.

	% Nitrogen	% Lipids	% Ash	pH
Composite I	0.757	5.69	22.7	5.14
Composite II	0.739	5.75	23.5	5.01

From another windrow, 15E, 28 individual samples (about 120 grams apiece) were taken at day 3 before turning. The moisture content of each was determined. The windrow was turned, 30 more samples were taken, and their moisture content determined. Results were:

	% Moisture	Variance	Std. Deviation
Before Turning	57.11	18.98	4.36
After Turning	56.8	5.18	2.28

The two large composite samples taken from 17D before turning were dried and their moisture content determined. Composite I contained 47.3 percent moisture and Composite II 47.1 percent, indicating a satisfactory accuracy of the sampling method. As a consequence, all moisture determinations are now made with a 2,000-4,000 gram composite sample taken after turning, the whole amount of which is dried for investigative work. For routine work, about 400 grams is taken from this well-mixed sample.

Two conclusions are evident from these data: (1) samples for chemical analysis should derive from a large composite that has been ground and mixed, and (2) sampling should be done, whenever possible, after turning.

Fifty temperature readings were taken on three different windrows at 18 in. Their ages were 8, 22, and 32 days. Results were:

Age of Windrow	Avg. Temperature	Std. Deviation	Variance
8 days	134 F	6.75	45.40
22 days	160 F	5.48	30.00
32 days	161 F	3.94	15.27

These data indicate increasing homogeneous composition as the age of the windrow increases. This can be ascribed to (1) decomposition by the microorganisms, (2) periodic mixing by the windrow turner, and (3) particle size reduction.

It can be seen that for consistent precision more measurements must be taken when working with windrows in the beginning of the composting cycle.

Moisture Content of Raw Refuse. With improved methods of sampling for moisture determinations, the dry weights of a number of windrows (11) were determined in the course of the work on the weight and volume losses. Knowing the weights of the same material as received from the city, the moisture content of raw refuse was determined. The moisture content by wet weight as received ranged from 22 percent to 61 percent over the period August 8 to December 6, 1968, with an average of 39 percent. This is in the neighborhood of the 35 percent which has been quoted on occasion.

Weight and Volume Losses in Composting. As previously mentioned, from 20 to 30 percent (by wet weight) of the incoming refuse is not compostable and is removed for burial in a landfill. Grinding then reduces the volume of the refuse retained for processing. As digestion proceeds, a weight loss in the form of the two principal products of decomposition, carbon dioxide and water, occurs. This amounts to between 20 and 30 percent of dry weight.

A study of seven batches (windrows) of refuse through the 42-day composting process at Johnson City showed the following relationship of incoming weights and volumes to those of the compost. In this study the amount of noncompostables was somewhat higher than the average of 26 percent observed at this plant.

	Refuse, as Received in Compaction Trailer	Noncompostables, Uncompacted	Picked, Ground Refuse, with Water Added	Compost in Windrow at End of Process
Wet weight, tons	100	28.8	111.7	50.4
Volume, cu yd	433	168.4	236.5	172.6
Moisture, percent by wet weight	39	39	60	30
Density, lb per cu yd at given moisture content	463	342	945	584
Density, expressed as the dry weight in lb per cu yd	282	209	378	409

This study shows a compost yield of 50.4 percent by wet weight and 40 percent by volume. It is assumed that the compost will go down on the field at the desired 60 percent moisture and that the finished compost will be dried to 30 percent moisture.

Elemental Composition of Compost. Analyses for certain elements were performed on samples of compost 42 days old or older. Wilson's methods for the gravimetric determination of carbon and hydrogen in solid wastes are given in Reference 8. Additional methods are available in Appendix I. Table 14 shows the average values found, on a dry weight basis. Table 15 gives the results for individual analyses made for six important elements.

Nitrogen in fresh ground refuse ranged from 0.58 to 1.01 percent by dry weight, averaging 0.85 percent. Carbon ranged from 34.4 to 43.6 percent of dry weight, averaging 39.8. For compost 42 days old or older, the nitrogen content was found to be between 0.85 and 1.07 percent of dry weight, averaging 0.93 percent. Table 16 shows the nitrogen content of some organic materials and soil for comparison with that of finished compost.

Analyses for Carbon/Nitrogen Ratios. A total of 37 windrows of different ages (0-130 days) was sampled and analyzed for carbon and nitrogen. The carbon analyses were made in the Research Services Laboratory of the Division of Research and Development, Bureau of Solid Waste Management, in Cincinnati. The nitrogen determinations were performed in the project laboratory.

Figure 54 shows the average carbon to nitrogen (C/N) ratios of composting refuse containing 3 to 5 percent sludge by dry weight for

TABLE 14

ELEMENTS IN FINISHED COMPOST

Johnson City
1968

Percent Dry Weight

Element	Average	Range
Carbon	33.01	26.23 - 37.53
Nitrogen	0.93	0.85 - 1.07
Potassium	0.30	0.25 - 0.40
Sodium	0.42	0.36 - 0.51
Calcium	1.55	0.75 - 3.11
Phosphorous	0.26	0.20 - 0.34
Magnesium	1.61	0.83 - 2.52
Iron	1.18	0.55 - 1.68
Aluminum	0.94	0.32 - 2.67
Copper	less than 0.05	--
Manganese	less than 0.05	--
Nickel	less than 0.01	--
Zinc	less than 0.005	--
Boron	less than 0.0005	--
Mercury	not detected *	--
Lead	not detected *	--

* Lower limits of detection: Mercury, 0.005 percent; lead, 0.05 percent. Neither was found above these levels in any samples tested.

TABLE 15

CONCENTRATION OF CERTAIN TRACE ELEMENTS IN SCREENED COMPOST
(Values expressed as percentage of dry weight unless otherwise noted)

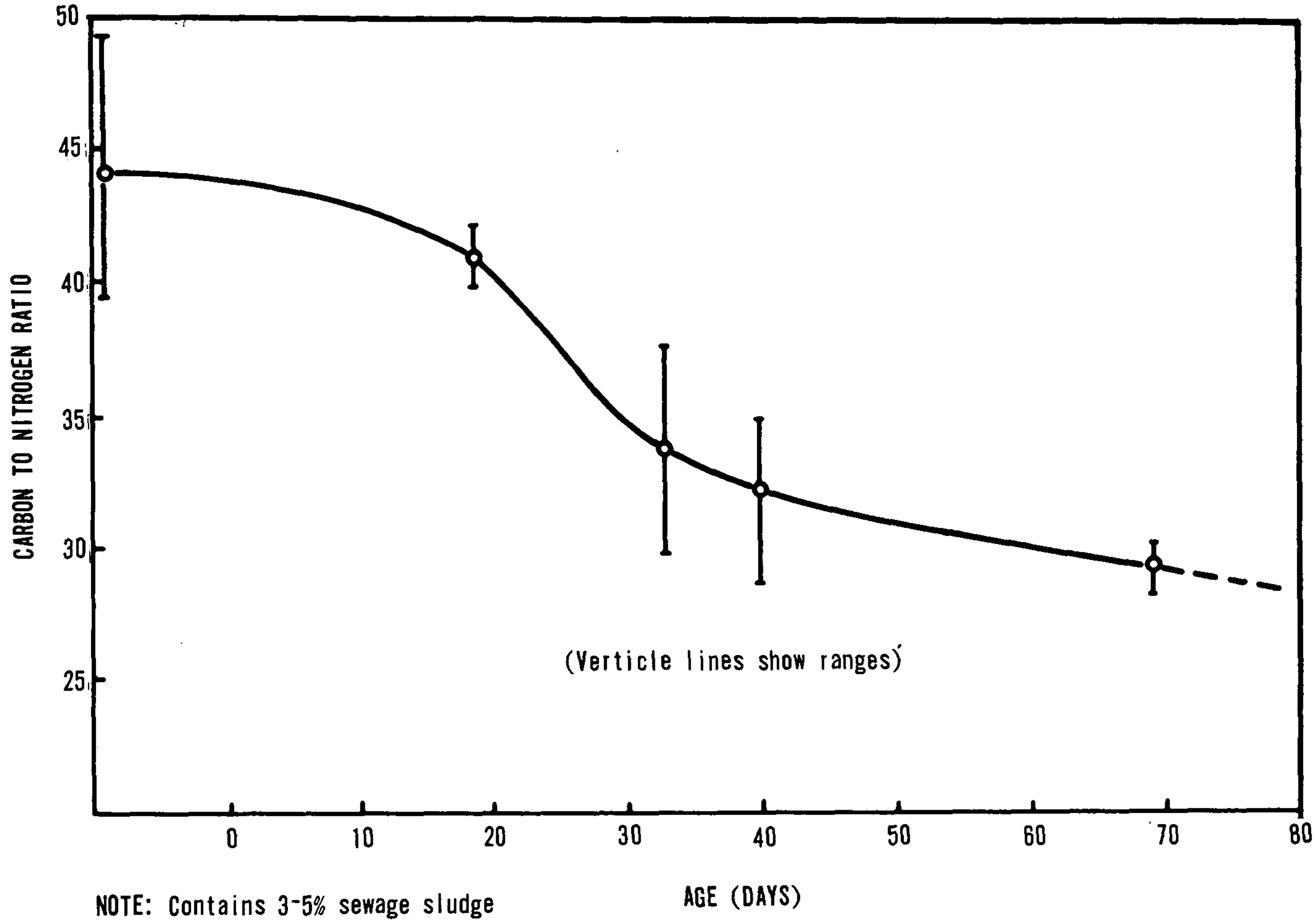
Windrow and age	Iron	Boron	Sodium	Potassium	Phosphorous	Calcium
17D - 42 day*		<2ppm	0.50	0.30		0.75
17D - 49 day*	1.38		0.40	0.29	0.22	1.12
5E - 42 day†	1.19		0.42	0.28		0.92
2E - 42 day‡	0.89	<2ppm	0.36	0.25	0.20	2.46
5E - 42 day§	1.07	<1ppm	0.43	0.25		1.89
Stockpile 1						
- 56 day¶	0.97		0.51	0.33	0.29	1.85
22-23E - 77 day‡	1.24	<2ppm	0.43	0.29	0.25	1.40
22-23E - 130 day‡					0.34	
Stockpile 2						
8G - 36 day¶	1.35	<1ppm			0.27	2.39
with NH_4NO_3 added					0.23	
5E - 154 day†	1.68	<1ppm	0.39	0.29	0.29	3.11
24-25E - 130 day§	1.47	<1ppm	0.43	0.32	0.24	2.29
8G - 42 day§	0.55		0.36	0.40	0.28	1.13

* Contained sewage sludge in an undetermined amount.
† Contained 12 percent sewage sludge solids.
‡ Contained 2 to 5 percent sewage sludge solids.
§ This portion of 5E contained 2 to 5 percent sewage sludge solids.
¶ Contained sewage sludge solids.

TABLE 16

NITROGEN CONTENT OF SOME ORGANIC MATERIALS AND SOIL

		% Nitrogen (dry weight basis)
(1)	Finished Compost	0.93
(2)	Sewage Sludge (raw)	2.58
(3)	Chicken manure	2.61, 2.40
(4)	Cow manure	3.42
(5)	Peat moss	1.91
(6)	Leaves (hardwood)	1.34
(7)	Pepper canning wastes	2.82
(8)	Tobacco stalks	1.41
(9)	Soil	0.1 - 0.3 (approximately)



NOTE: Contains 3-5% sewage sludge solids. 24 windrows sampled.

Figure 54. Average carbon to nitrogen ratio of 24 windrows containing 3-5 percent sewage sludge.

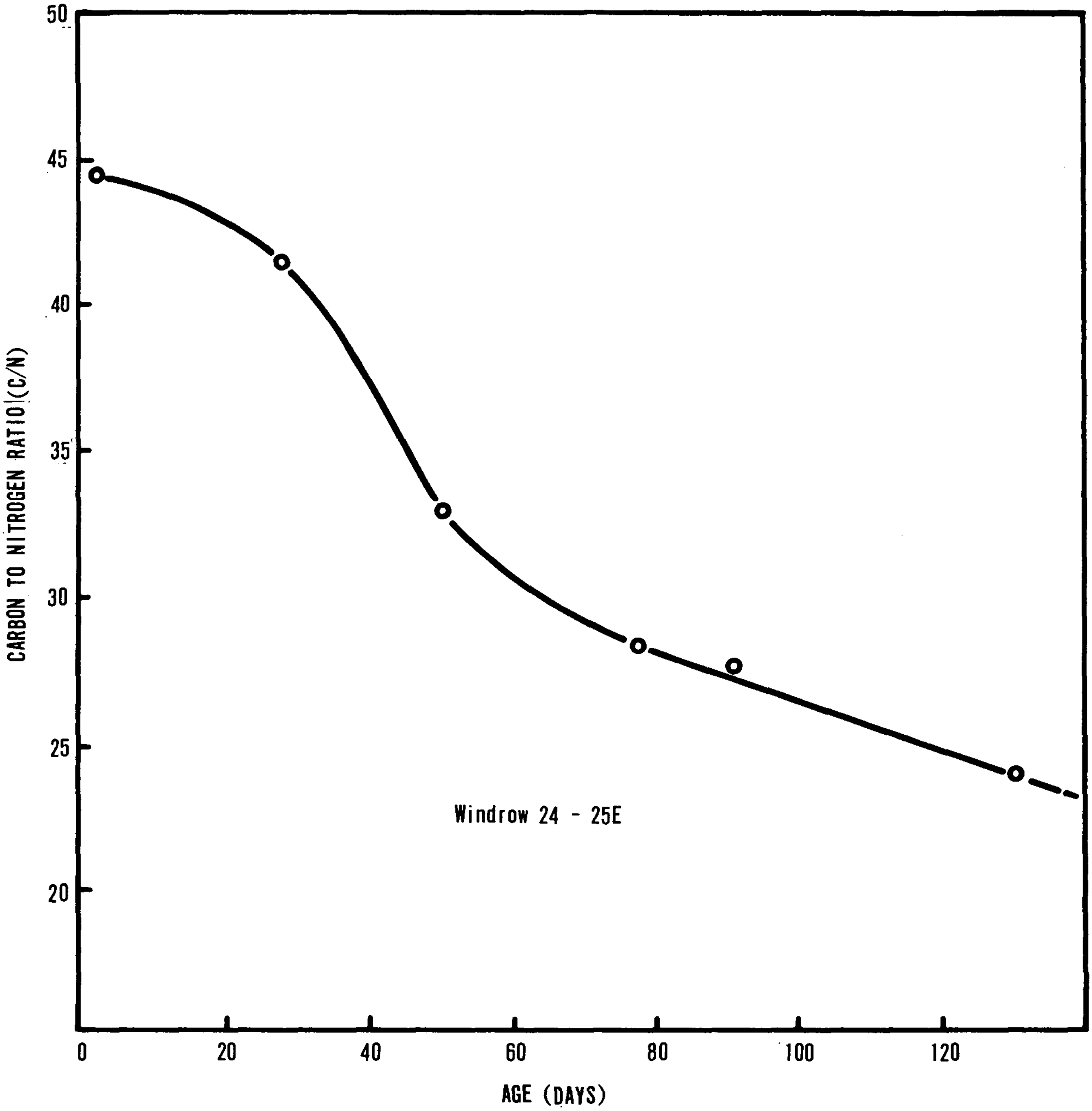
various ages. Ranges are shown but the data, taken from 24 windrows, does not represent a follow-through of all these windrows from 0 to 80 days. The initial C/N ratios of a group of seven windrows showed an average of 44.4. At 42 days of composting a similar group of five windrows showed an average C/N of 33.9 and at 49 days two of these showed an average of 31.9.

Figure 55 shows the decrease of the C/N ratios with age in a windrow especially sampled for this purpose. This windrow did not contain sludge solids. The initial C/N was 44.4 and at 49 days the ratio was 33.0. The similarity of Figures 54 and 55 will be noted.

The C/N ratios at the beginning and end of the composting on the field were determined for several windrows containing additives (Table 17). Windrows to which were added paunch manure and poultry manure showed lower initial C/N ratios. The decreases in the ratios while composting, however, were not as great as in normal windrows. The 42-day ratios were 28.8 for the material containing paunch manure and 24 for the chicken manure-refuse mixture.

The C/N ratios for two windrows to which urea-ammonium nitrate was added showed an increase rather than a decrease after composting. The rise was due to the loss of nitrogen as ammonia as a result of mass action from (1) the increase of pH in the system caused by the addition of Urea-NH_4NO_3, and (2) shifting of the equilibrium $NH_4^+ + OH^- \rightleftarrows H_2O + NH_3\uparrow$ to the right due to an increase of NH_4^+ and OH^- ions.

<u>Analyses for Chemical Oxygen Demand.</u> A total of 22 samples of compost of different ages (0-168 days) was analyzed for chemical oxygen demand (COD). The results showed a steady reduction with age



NOTE: Contains no sewage sludge.

Figure 55. Carbon to nitrogen ratio of a windrow without sewage sludge.

TABLE 17

CARBON/NITROGEN RATIOS OF COMPOST CONTAINING ADDITIVES

Windrow and Age	Additive	C/N Ratio
13G - 1 day	Paunch manure	31.2
42 days		28.5
19G - 1 day	Chicken manure	25.8
42 days		24.0
8G - 1 day	Urea-ammonium nitrate	9.8
42 days		12.9
17G - 1 day	Urea-ammonium nitrate	17.7
42 days		22.4
1H - 43 days	Urea-ammonium nitrate	29.6
56 days		22.8
30G - 54 days	Animal blood	22.5
33G - 51 days	Pepper canning waste	26.5

from about 900 milligrams per gram for fresh refuse to about 750 milligrams per gram at 56 days of age. A sample taken from compost 168 days old showed a COD of about 300 milligrams per gram. The COD can be used as a gauge of the degree of decomposition of refuse (Figure 56).

Cellulose, Starch, and Sugar Content. The average cellulose content of refuse at Johnson City was found to be 49 percent on a dry weight basis. After composting for 28 days, it was 43 percent and at 49 days the content was 31 percent.

The average initial starch content was 4.0 percent and dropped to less than 1.0 percent after 28 days of composting.

The average sugar content at the start of composting was 0.8 percent and dropped to less than 0.1 percent within 14 days.

Figure 57 illustrates the diminishing content of these constituents of refuse and compost with age.

Calorific Value of Refuse and Compost. At Johnson City, the calorific values for composite samples of composting refuse containing 3 to 5 percent sludge solids were found to be initially 4,077 calories per gram, diminishing to 3,669 on the 49th day of composting and to 2,947 calories per gram for compost 1 year old.

Cost Studies

A system of cost accounting for plant operations and maintenance was developed to provide accurate cost data for each phase of plant operation for appraisal of windrow composting as a method of solid waste management. Plant operations and activities were divided into various categories or

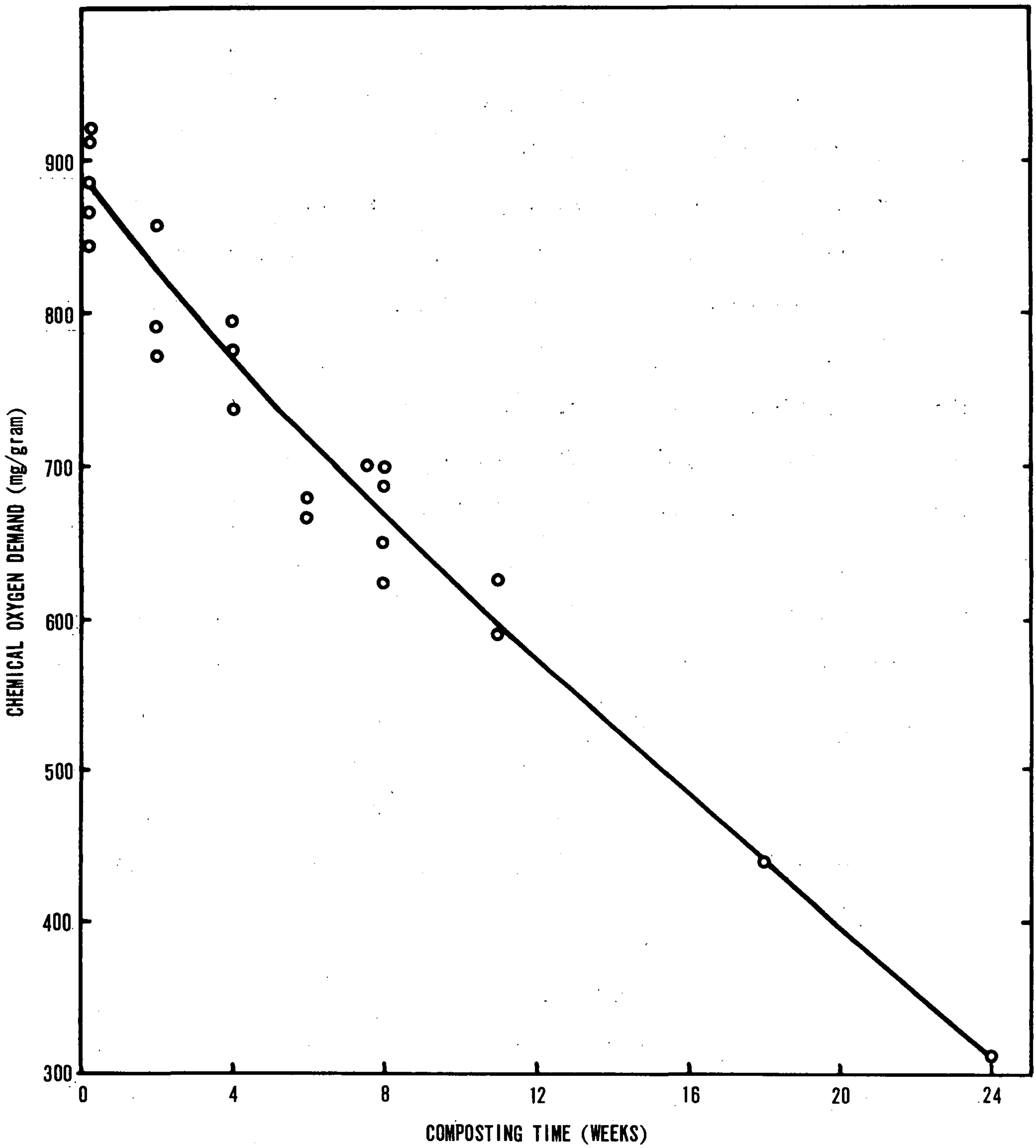
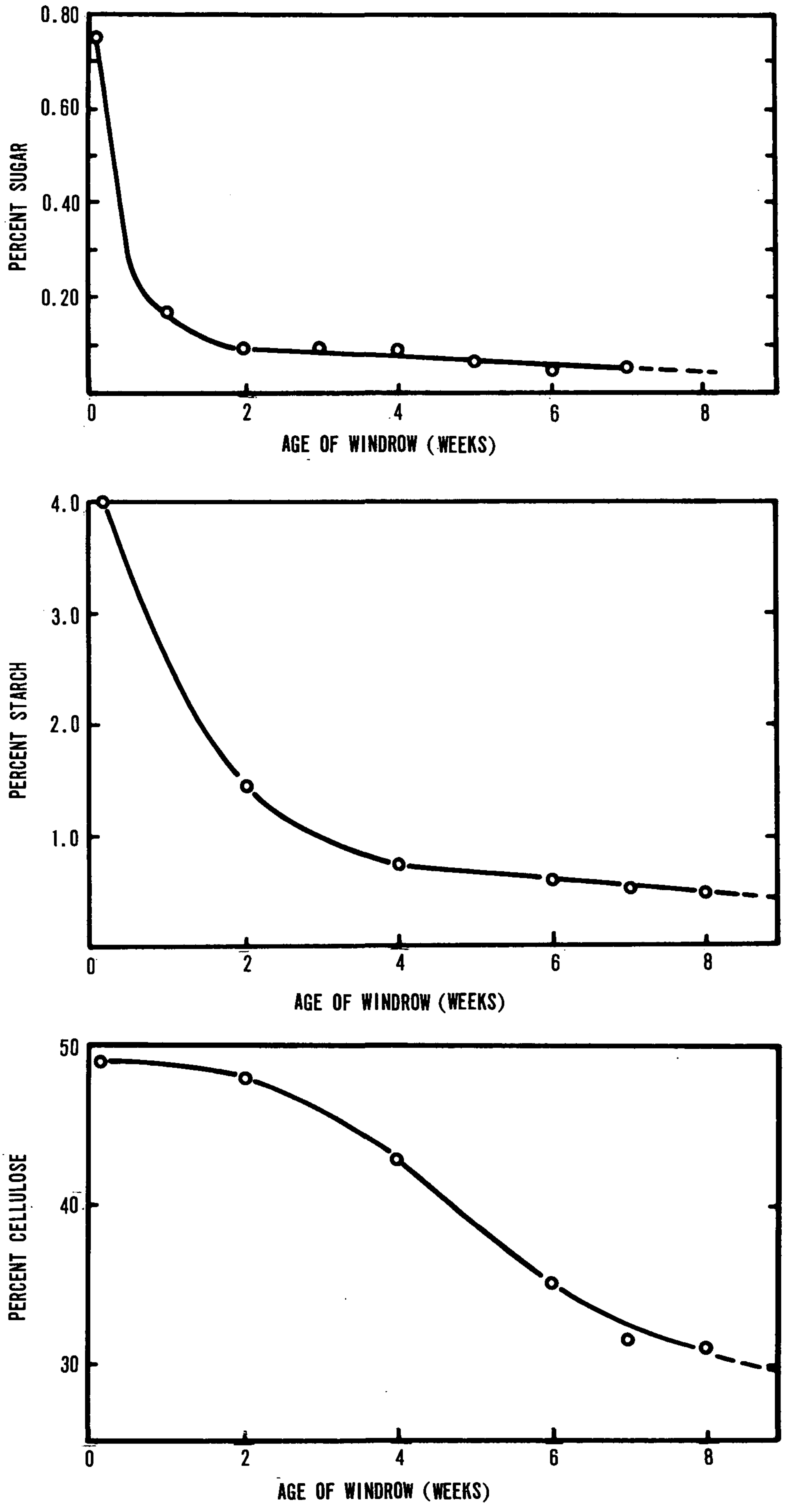


Figure 56. Chemical oxygen demand of composting refuse.

Figure 57. Sugar, starch, and cellulose content of composting refuse.



units with an account number each. Cost data used to report the project costs and provide the basis for projections to other windrow plants were obtained from these monthly, quarterly, and year-end financial statements of operations (Appendix II).

Capital Cost. The total construction cost for the plant, including the modifications made since startup, is $958,375. Table 18 itemizes these costs. On the basis of per ton daily capacity the actual capital investment costs* were $18,580. On a per-ton-refuse processed basis, the capital investment cost is $12.98 (at 34 tons per day in 1968) (Table 19).

The average rate at which the refuse has been received at the plant would permit the processing of 52 tons in a normal processing day (6-1/2 hr for processing and 1-1/2 hr for cleaning operations). Projecting the actual costs to the 52 tons per day basis, the capital investment cost would be $6.88 per-ton-refuse processed (Table 19).

Operating Cost. Actual costs for operating the composting plant in 1968 were $18.45 per-ton-refuse processed (Table 20). The nature of the operations (research and development) and the inability of the Johnson City municipality to deliver enough refuse for operation at full capacity are some reasons for this high unit cost. A cost of $13.40 per-ton-refuse processed was projected for operating this plant at 52 tons per day (Table 21). Some modifications were made for the research work being conducted.

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*Capital cost calculations assumed straight line depreciation over 20 years of buildings and equipment (excluding land) and bank financing at 7-1/2 percent over 20 years.

TABLE 18

CONSTRUCTION COSTS FOR THE USPHS-TVA

WINDROW COMPOSTING PLANT (52-Ton Per Day) 1/

	Construction or Installation	Equipment and/or Materials	Engineering Design	Total
Site improvements	$ 78,059.88 2/		$ 10,032.00	$ 88,091.88
Buildings				
Receiving building	90,381.82 2/		13,982.00	104,363.82
Process building	142,742.36 2/		21,800.00	164,542.36
Office and laboratory	40,245.28 2/		7,883.00	48,128.28
Curing and drying shed	44,192.55 2/		7,111.00	51,303.55
Receiving machinery and equipment				
Hopper conveyor and leveling gate	12,643.94	$ 24,865.72	5,800.00	43,309.66
Scale	8,058.67	4,266.00	1,112.00	13,436.67
Processing				
Elevating conveyor (sorting belt), w/magnetic separator	23,608.17 2/	11,667.00	6,828.00	42,103.17
Reject hopper	7,118.70 2/		965.00	8,083.70
Rasping machine (grinder)	7,477.38	51,160.00	9,380.00	68,017.38
Hammermill (grinder) 3/	2,086.63	9,262.00	1,880.00	13,228.63
Chuting	8,152.52	1,838.19	1,570.00	11,560.71
Conveyors	7,851.69	5,801.00	2,418.00	16,070.69
Sludge filter and appurtenances, including sludge holding tank	2,299.67 2/	23,273.10	4,320.00	29,892.77
Ground refuse-sludge mixer	3,029.34	6,527.77	1,490.00	11,047.11
Sludge piping	13,760.08	2,698.65	2,700.00	19,158.73
Power and control system	36,181.73 2/		5,820.00	42,001.73
Bucket elevator	1,408.77	6,000.00	1,282.00	8,690.77
Loading bin and chute	11,602.99 2/		1,324.00	12,926.99
Composting field, site preparation and waterlines	28,792.61 2/		9,901.00	38,693.61
Regrinding and screening	47,500.00 4/	13,689.65		61,189.65
Gasoline dispensing installation	1,754.62	788.00	253.00	2,795.62
Mobile equipment, including front end loaders and turner		48,789.48		48,789.48
Tools, small equipment, etc.		6,738.74		6,738.74
Office and laboratory equipment 5/		4,210.00		4,210.00
	$618,949.40	$221,575.30	$117,851.00	$958,375.70
Estimated cost of site (9.5 acres)				7,600.00
				$965,975.70

1. Based on one shift per day, 6½ hours of processing and 1½ hours for cleanup.
2. Contains all or part of required materials.
3. This mill is being replaced.
4. Includes installation, construction materials, and design costs.
5. Laboratory costs include only that for simple process control equipment.

TABLE 19

YEARLY INVESTMENT COSTS FOR THE USPHS-TVA WINDROW COMPOSTING PLANT

Item of Cost	Cost ($)*
Construction	958,375
Land costs	7,600
Total	965,975
Depreciation/year†	47,920
Interest/year ‡	45,080
Cost per ton daily capacity	18,580
Cost per ton refuse processed	12.98 (6.88)§

* 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.

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

‡ Bank financing at 7 1/2 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.

TABLE 20

ACTUAL COST OF OPERATIONS FOR THE USPHS-TVA COMPOSTING PLANT (1968) 1/
(7,164 tons processed in 210 days)

	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 1/	$ 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 2/	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
	$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

1. At plant site.
2. Includes cost of haulage to landfill (no landfilling costs).

TABLE 21

ACTUAL ANNUAL COSTS OF OPERATING THE USPHS-TVA PLANT PROJECTED TO FULL CAPACITY (1968) [1]

	OPERATIONS						MAINTENANCE				
	Salaries & Benefits	Electric Power	Truck Use	Supplies & Materials	Miscel-laneous	Total	Salaries & Benefits	Supplies & Materials	Repairs	Total	Total
Receiving [2]	$ 11,400	$ 145	$	$ 50	$	$ 11,595	$ 1,550	$ 500	$ 500	$ 2,550	$ 14,145
Picking & Sorting	17,200	40		500		17,740	900	100		1,000	18,740
Disposal of Rejects [3]	9,650		2,768	70		12,488	750	75		825	13,313
Grinding (rasper)	4,550	1,530		100		6,180	4,750	5,000		9,750	15,930
Composting	18,150	55	5,000	1,090	75	24,370	8,200	1,600	950	10,750	35,120
Curing	1,750		536	50		2,336			25	25	2,361
Storage	5,200		1,384	50	50	6,684					6,684
Operation & Maintenance of Grounds, Buildings, & Utilities		1,430			200	1,630	6,000	650		6,650	8,280
Cleanup of Process & Receiving Buildings	11,550			150		11,700					11,700
Office & Laboratory [4]	7,250	465		800	800	9,315					9,315
Other				5,000	1,000	6,000					6,000
Regrinding & Screening	8,150	870	1,384	500		10,904	2,900	300	200	3,400	14,304
Sewage Sludge Processing	7,200	140		2,935		10,275	2,350	1,250	250	3,850	14,125
	102,050	4,675	11,072	11,295	2,125	131,217	27,400	9,475	1,925	38,800	170,017
Administrative & Overhead	8,600					8,600	2,400			2,400	11,000
	$110,650	$4,675	$11,072	$11,295	$2,125	$139,817	$29,800	$9,475	$1,925	$41,200	$181,017

1. Production of 13,520 tons, based on 260 working days in year.
2. At plant site.
3. Includes cost of haulage to landfill but no landfilling costs.
4. Operations only. Does not include maintenance of building, etc.

Table 22 summarizes the actual capital and 1968 operating costs for the plant.

The construction cost of $958,375 for the 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 equipment independently of the structure, would have permitted less expensive construction. A case in point is the 150-ton-per-day plant at Gainesville, Florida, where the cost of the buildings, estimated at $150,000, is approximately 11 percent of the total plant investment.

Labor Cost. With respect to the plant operating costs in 1968, labor constituted about 75 percent of this cost. Based on 50 tons of refuse processed per day, 1969 labor costs amounted to 78 percent of operating expenses. Table 23 provides salary information of the TVA working complement as of January 1, 1969.

Cost Data Projected to Other Plants. Estimates of the capital, investment, and operating costs for various capacity windrow composting plants were developed based on the actual costs recorded during the report period at the USPHS-TVA plant (Tables 24, 25, and 26). The projections indicate that the total yearly costs for various size windrow composting plants will range from $19.77 per-ton-refuse processed for a 50-ton-per-day plant to $10.71 per-ton-refuse processed for a 200-ton-per-day plant on two shifts (Table 27).

TABLE 22

SUMMARY OF ACTUAL COSTS FOR THE 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	$18.45	$31.43
52 (13,520 tons/year) ***	18,580	6.88	13.40	20.28

* Based on actual costs of Johnson City composting plant with 7½ 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.

** Actual processing for 1968 operations.

*** Operations projected to full capacity.

TABLE 23

SALARIES OF TVA PERSONNEL

PHS-TVA Composting Project

January 1, 1969

	ANNUAL SALARY
Foreman	$9300
Asst. Foreman	7740
Equipment Operator (2)	7050
Truck Driver (3)	6885
Maintenance Mechanic (2)	8490
Laborer (4)	6100

The salaries shown are for an 8-hour day, with 8 paid holidays, and 20 paid vacation days. Added benefits amount to 16.75 percent of the salaries, not including leave benefits. Overtime is paid at the rate of time and one-half on regular workdays and double time on holidays.

TABLE 24

ESTIMATED CAPITAL COSTS FOR WINDROW COMPOSTING PLANTS

Item of cost	52 T/D (Johnson City Plant - 1 shift) 1/	50 T/D (1 shift) 2/	100 T/D (50 T/D 2 shifts) 3/	100 T/D (1 shift) 3/	200 T/D (100 T/D 2 shifts) 3/
	Daily plant capacity in tons per day (T/D)				
Buildings	$368,335	$210,000	$231,000	$ 231,000	$ 251,000
Equipment	463,250	482,700	482,700	607,100	607,100
Site improvement 4/	126,790	126,800	126,800	152,000	152,000
Land cost 5/	7,600	8,400	12,400	12,400	21,200
Total cost	$965,975	$827,900	$852,900	$1,002,500	$1,031,300
Total cost per ton daily capacity	$ 18,580	$ 16,560	$ 8,530	$ 10,020	$ 5,460

1. Actual cost of the research and development PHS-TVA Composting Plant at Johnson City, Tennessee.
2. Based on Johnson City cost data adjusted for building and equipment modifications.
3. Estimates based on actual Johnson City cost data projected to the larger daily capacity plants. (See Tables 28 through 33).
4. Includes preparation of composting field with crushed stone and needed utility lines.
5. Land costs are estimated based on approximate land values near Johnson City, Tennessee, of $800 per acre.

TABLE 25

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) 1/	50 T/D (1 shift, 13,000 T/year) 2/	100 T/D (2 shifts, 26,000 T/year) 2/	100 T/D (1 shift, 26,000 T/year) 2/	200 T/D (2 shifts, 52,000 T/year) 2/
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 3/	$47,920	$41,000	$42,000	$49,500	$53,550
Interest/year 4/	$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) 5/	$ 6.12 (5.38) 6/	$ 3.15 (2.76) 6/	$ 3.68 (3.28) 6/	$ 2.01 (1.73) 6/

1. 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.
2. Based on Johnson City plant cost data adjusted for less elaborate equipment, buildings, and modifications.
3. Straight line depreciation over 20 years of buildings and equipment, excluding land.
4. Bank financing at 7½ percent over 20 years. Yearly figure is average of 20-year total interest charge. Land cost included.
5. Cost of Johnson City plant adjusted to design capacity of 13,520 tons refuse processed per year.
6. Estimated cost without sludge processing equipment.

TABLE 26

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 PHS-TVA composting plant at design capacity of 52 tons per day (13,520 T/year) in 1969.
*** Estimated costs based on PHS-TVA composting project operating cost data.

TABLE 27

SUMMARY OF ESTIMATED CAPITAL, OPERATING AND TOTAL COSTS
FOR VARIOUS SIZE WINDROW COMPOSTING PLANTS [1/]

Plant Capacity tons/day (tons/year)	Number of Shifts	Capital cost [2/] (per ton/day)	Yearly cost per ton refuse processed		
			Capital & Investment	Operating [3/]	Total
52 [4/] (13,520)	1	$18,580	$6.88	$13.40	$20.28
50 (13,000)	1	$16,560	$6.12	$13.65	$19.77
100 (26,000)	2	$ 8,530	$3.15	$10.50	$13.65
100 (26,000)	1	$10,020	$3.68	$ 9.90	$13.67
200 (52,000)	2	$ 5,460	$2.01	$ 8.70	$10.71

1. Based on actual costs of Johnson City composting plant with modifications with 7½ percent bank financing over 20 years. Straight line depreciation of buildings and equipment over 20 years.

2. Includes land costs estimated at $800/acre (Johnson City, Tenn.).

3. Does not include costs for landfilling rejects. For an estimate of these costs, add $0.88, $0.72, and $0.52 to the 50-, 100-, and 200-tons-per-day plants respectively. Costs for landfilling refuse generated in a municipality the size of Johnson City range from $2.00 to $5.00 per ton of refuse deposited.[9,10] Using the average of $3.50, the 12.5 tons of compost plant rejects deposited each day would cost $43.75 or $0.88 per ton of refuse processed. Corresponding landfill costs for cities operating 100- and 200-ton-per-day composting plants are about $2.75 and $2.00 respectively per ton of refuse deposited.[9,10] Costs for landfilling the rejects from these plants would be $0.72 and $0.52 per ton respectively.

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

The cost estimates include equipment for processing sewage sludge. Also included are costs for land, depreciation, and debt service. Because use of compost is normally seasonal, the estimates include land area for storage of 6 month's production of compost in rectangular piles 15 ft high. Land costs were assumed at $800 per acre--consistent with land values near Johnson City. If land costs were assumed at $1,500 per acre, the capital cost for the 100- and 200-ton plants on two shifts would increase by no more than one cent per ton of refuse processed. For the 100-ton plant on one shift, the increase would be about 3 cents per ton of refuse processed.

Details of the construction and operating costs projections to these plants are provided in Tables 28, 29, 30, 31, 32, and 33.

Plant Income. None of the compost produced has been sold. Also, salvaging of potentially salable materials has not been practiced. Therefore, the project has not obtained cost data with respect to potential plant income from such sources. The potential income of composting plants, other economic considerations and the potential of windrow composting in solid waste resource management systems, will be discussed in a report entitled "Composting of Municipal Solid Waste in the United States."[11]

Demonstration and Utilization

None of the compost produced at the Johnson City plant has been sold. Prior to March 1969, the Bureau of Solid Waste Management had asked TVA to restrict the uses to which it was put pending the outcome

TABLE 28

USPHS-TVA PLANT CONSTRUCTION COSTS

PROJECTED TO A 50-TON PER DAY PLANT *

Site improvements	$ 88,100
Buildings	
Receiving building	75,000
Processing building	90,000
Open shed (6,000 square feet)	25,000
Office and laboratory	20,000
Receiving machinery and equipment	
Hopper conveyor and leveling gate	43,300
Scale (automatic talley)	18,500
Processing	
Elevating conveyor (sorting belt), with magnetic separator	28,500
Reject hopper	8,100
Rasping machine (grinder)	68,000
Chuting	9,000
Conveyors	10,400
Sludge dewatering apparatus, degritter, thickening tank and sludge pump	68,000
Ground refuse-sludge mixer	11,000
Sludge piping	19,100
Power and control system	42,000
Loading bin with bucket elevator	16,000
Ballistic separator	20,000
Composting field, surface preparation (crushed stone) and water lines	38,700
Regrinding and screening	50,000
Gasoline dispensing installation	2,800
Mobile equipment, including front end loaders and turner	56,000
Tools, small equipment, etc.	7,000
Office and laboratory equipment	5,000
Construction Total	$819,500
Land costs (10.5 acres at $800/acre)	8,400
Total	$827,900

* Based on costs of Johnson City plant (1966-67), revised for lower building costs and some changes in machinery and equipment. Plant would operate one shift of 8 hours each day. To operate this plant on two shifts for 100 tons of raw refuse per day the receiving building apron would require enlargement and cover and the site would require expansion to 15.5 acres. The added cost would be $21,000 for receiving area and $4,000 for land, bringing total to $852,900.

TABLE 29

USPHS-TVA PLANT CONSTRUCTION COSTS
PROJECTED TO A 100-TON PER DAY PLANT *

Site improvements	$ 90,000
Buildings	
Receiving building	96,000
Processing building	90,000
Open shed (6,000 square feet)	25,000
Office and laboratory	20,000
Receiving machinery and equipment	
Hopper conveyor and leveling gate	43,300
Scale (automatic talley)	18,500
Processing	
Elevating conveyor (sorting belt), with magnetic separator	28,500
Reject hopper	10,000
Rasping machine (grinder)	136,000
Chuting	12,000
Conveyors	12,500
Sludge dewatering apparatus, degritter, thickening tank and sludge pump	92,000
Ground refuse-sludge mixer	16,500
Sludge piping	20,000
Power and control system	45,000
Loading bin	20,000
Ballistic separator	20,000
Composting field, surface preparation (with crushed stone) and water lines	62,000
Regrinding and screening	50,000
Gasoline dispensing installation	2,800
Mobile equipment, including front end loaders and turner	67,000
Tools, small equipment, etc.	7,000
Office and laboratory equipment	5,000
Construction Total	$ 989,100
Land costs (15.5 acres at $800/acre)	12,400
Total	$1,001,500

* Based on unit costs (1966-67) at Johnson City, revised for less expensive buildings and some changes in machinery and equipment. Plant would operate one shift of 8 hours each day. To operate this plant on two shifts for a capacity of 200 tons of raw refuse per day would require enlargement of the receiving building, enlargement of the sludge thickening tank, expansion of the site to 26.5 acres, and the addition of one front end loader and one windrow turner. Added costs would be $20,000 for receiving, $15,000 for sludge handling, $8,800 for land, and $47,100 for mobile equipment, bringing the total to $1,092,400.

TABLE 30

USPHS-TVA PLANT ANNUAL OPERATING COSTS PROJECTED TO A 50-TON PER DAY PLANT (one shift) 1/

	OPERATIONS						MAINTENANCE				
	Salaries & Benefits	Electric Power	Truck Use	Supplies & Materials	Miscel-laneous	Total	Salaries & Benefits	Supplies & Materials	Repairs	Total	Total
Receiving 2/	$ 11,400	$ 130	$	$ 50	$	$ 11,580	$ 1,650	$ 500	$ 500	$ 2,650	$ 14,230
Picking & Sorting	17,200	40		300		17,540	1,000	100	100	1,200	18,740
Disposal of Rejects 3/	9,650		2,700	70		12,420	850	100		950	13,370
Grinding (rasper)	4,550	1,330		100		5,980	4,750	5,000	200	9,950	15,930
Composting	18,950	20	1,740	1,000	100	21,810	8,200	2,000	1,000	11,200	33,010
Curing	1,750		1,220	50		3,020			100	100	3,120
Storage	5,200		1,220	50		6,470			100	100	6,570
Operation & Maintenance of Grounds, Buildings, & Utilities		1,580			200	1,780	6,450	800	500	7,750	9,530
Cleanup of Process & Receiving Buildings	11,600			150	300	12,050					12,050
Office & Laboratory 4/	7,250			800	500	8,550					8,550
Regrinding & Screening	8,200	1,360	1,220	500		11,280	3,000	500	500	4,000	15,280
Sewage Sludge Processing	5,300	1,070		500		6,870	1,900	500	1,000	3,400	10,270
	101,050	5,530	8,100	3,570	1,100	119,350	27,800	9,500	4,000	41,300	160,650
Other (including Administrative & Overhead	8,600			5,000	1,000	14,600	2,400			2,400	17,000
	$109,650	$5,530	$8,100	$8,570	$2,100	$133,950	$30,200	$9,500	$4,000	$43,700	$177,650

1. Plant capacity of 50 tons of raw refuse per day in one 8-hour shift. Costs are for 260 days of operation for a total of 13,000 tons per year.
2. At plant site.
3. Includes haulage to a landfill site but no landfilling costs.
4. For laboratory and office functions only. Does not include cost of building maintenance.

TABLE 31

USPHS-TVA PLANT ANNUAL OPERATING COSTS PROJECTED TO A 100-TON PER DAY PLANT (two shifts) 1/

	-OPERATIONS-						-MAINTENANCE-				
	Salaries & Benefits	Electric Power	Truck Use	Supplies & Materials	Miscel-laneous	Total	Salaries & Benefits	Supplies & Materials	Repairs	Total	Total
Receiving 2/	$ 18,700	$ 195	$	$ 100	$	$ 18,995	$ 1,750	$ 1,000	$1,000	$ 3,750	$ 22,745
Picking & Sorting	38,450	55		600		39,105	1,000	200	500	1,700	40,805
Disposal of Rejects 3/	18,050		4,590	150		22,790	850	200		1,050	23,840
Grinding (rasper)	7,800	1,935		200		9,935	5,150	9,550	400	15,100	25,035
Composting	31,900	30	2,345	2,000	200	36,475	9,500	4,000	2,000	15,500	51,975
Curing	3,350		1,645	100		5,095			200	200	5,295
Storage	10,050		1,645	100		11,795			200	200	11,995
Operation & Maintenance of Grounds, Buildings, & Utilities		1,435			200	1,635	6,450	1,000	500	7,950	9,585
Cleanup of Process & Receiving Buildings	12,100			200	400	12,700					12,700
Office & Laboratory 4/	7,250			1,000	600	8,850					8,850
Regrinding & Screening	15,600	1,635	1,645	1,000		19,880	4,000	1,000	1,000	6,000	25,880
Sewage Sludge Processing	9,550	1,390		1,000		11,940	2,300	1,000	2,000	5,300	17,240
	172,800	6,675	11,870	6,450	1,400	199,195	31,000	17,950	7,800	56,750	255,945
Other (including Administrative & Overhead	13,600				1,000	14,600	2,400			2,400	17,000
	$186,400	$6,675	$11,870	$6,450	$2,400	$213,795	$33,400	$17,950	$7,800	$59,150	$272,945

1. Plant of 50 tons of raw refuse capacity in one 8-hour shift working two 8-hour shifts. Costs are for 260 days of operation for a total of 26,000 tons per year.
2. At plant site.
3. Includes haulage to a landfill site but no landfilling costs.
4. For laboratory and office functions only. Does not include cost of building maintenance.

TABLE 32

USPHS-TVA PLANT ANNUAL OPERATING COSTS PROJECTED TO A 100-TON PER DAY PLANT (one shift) 1/

	OPERATIONS						MAINTENANCE				
	Salaries & Benefits	Electric Power	Truck Use	Supplies & Materials	Miscel-laneous	Total	Salaries & Benefits	Supplies & Materials	Repairs	Total	Total
Receiving 2/	$ 16,150	$ 130	$	$ 100	$	$ 16,380	$ 1,750	$ 1,500	$1,000	$ 4,250	$ 20,630
Picking & Sorting	29,250	75		600		29,925	1,000	200	500	1,700	31,625
Disposal of Rejects 3/	18,050		5,385	150		23,585	850	200		1,050	24,635
Grinding (rasper)	7,300	2,715		200		10,215	5,350	9,550	400	15,300	25,515
Composting	29,550	25	2,600	2,000	200	34,375	9,500	4,000	2,000	15,500	49,875
Curing	3,350		1,825	100		5,275			200	200	5,475
Storage	9,750		1,825	100		11,675			200	200	11,875
Operation & Maintenance of Grounds, Buildings, & Utilities		1,485			200	1,685	6,450	1,000	500	7,950	9,635
Cleanup of Process & Receiving Buildings	11,600			200	400	12,200					12,200
Office & Laboratory 4/	7,250			1,000	600	8,850					8,850
Regrinding & Screening	15,600	1,710	1,825	1,000		20,135	4,000	1,000	1,000	6,000	26,135
Sewage Sludge Processing	6,550	1,400		1,000		8,950	2,300	1,500	1,500	5,300	14,250
	154,400	7,540	13,460	6,450	1,400	183,250	31,200	18,950	7,300	57,450	240,700
Other (including Administrative & Overhead	13,600				1,000	14,600	2,400			2,400	17,000
	$168,000	$7,540	$13,460	$6,450	$2,400	$197,850	$33,600	$18,950	$7,300	$59,850	$257,700

1. Plant capacity of 100 tons of raw refuse per day in one 8-hour shift. Costs are for 260 days of operation for a total of 26,000 tons per year.
2. At plant site.
3. Includes haulage to a landfill site but no landfilling costs.
4. For laboratory and office functions only. Does not include cost of building maintenance.

TABLE 33

USPHS-TVA PLANT ANNUAL OPERATING COSTS PROJECTED TO A 200-TON PER DAY PLANT (two shifts) [1/]

	OPERATIONS						MAINTENANCE				
	Salaries & Benefits	Electric Power	Truck Use	Supplies & Materials	Miscel-laneous	Total	Salaries & Benefits	Supplies & Materials	Repairs	Total	Total
Receiving [2/]	$ 29,550	$ 190	$	$ 200	$	$ 29,940	$ 2,450	$ 3,000	$ 2,000	$ 7,450	$ 37,390
Picking & Sorting	62,700	105		1,200		64,005	1,400	400	1,000	2,800	66,805
Disposal of Rejects [3/]	35,700		9,185	300		45,185	1,150	300		1,450	46,635
Grinding (rasper)	13,100	3,730		400		17,230	6,000	19,100	800	25,900	43,130
Composting	52,200	30	4,950	4,000	400	61,580	13,750	8,000	4,000	25,750	87,330
Curing	6,500		3,470	200		10,170			400	400	10,570
Storage	19,600		3,470	200		23,270			400	400	23,670
Operation & Maintenance of Grounds, Buildings, & Utilities		1,400			400	1,800	6,650	1,200	500	8,350	10,150
Cleanup of Process & Receiving Buildings	12,000			300	500	12,800					12,800
Office & Laboratory [4/]	14,700			1,200	1,000	16,900					16,900
Regrinding & Screening	29,000	2,220	3,470	2,000		36,690	6,000	2,000	2,000	10,000	46,690
Sewage Sludge Processing	9,950	1,795		2,000		13,745	3,600	3,000	3,000	9,600	23,345
	285,000	9,470	24,545	12,000	2,300	333,315	41,000	37,000	14,100	92,100	425,415
Other (including Administrative & Overhead	22,700				1,000	23,700	3,300			3,300	27,000
	$307,700	$9,470	$24,545	$12,000	$3,300	$357,015	$44,300	$37,000	$14,100	$95,400	$452,415

1. Plant capacity of 100 tons of raw refuse in one 8-hour shift working for two 8-hour shifts. Costs are for 260 days of operation for a total of 52,000 tons per year.
2. At plant site.
3. Includes haulage to a landfill site but no landfilling costs.
4. For laboratory and office functions only. Does not include cost of building maintenance.

of pathogen survival studies. These restrictions and the lack of a finished product has limited the activity of the Division of Agricultural Development, TVA, in its utilization studies.

The TVA agriculturist assigned to the project has, however, been active in setting up demonstrations where the unfinished material could be used and where owners of the sites agreed to abide by the restrictions. The demonstation areas are on public lands or the land of private owners who have agreed to allow the agriculturist to supervise the application and to follow the progress of the plantings.

Due to the troubles experienced with the final grinding and screening equipment which was not completed until February 1969, the bulk of the material used in Fiscal Year 1969 was unfinished (unreground or screened). It represents 80 percent of the compost produced in the year.

The demonstration sites include tobacco, corn, gardens, grass or sod establishment, erosion control and reclamation, orchards, shrubs and flowers, golf courses, soybeans, and miscellaneous. TVA experimental test plots are in corn and grain sorghum, each involving 52 test plots, 12 x 30 ft each, in which various application rates are being examined, some with fertilizers and some without. Another concerns an evaluation of compost on Bermuda grass. Appendix III provides preliminary results of the experiments.[12]

The rates of application on the demonstration plantings range from 10 to 100 tons per acre for corn and 5 to 30 tons per acre for tobacco. The agriculturist hopes to evaluate the merits of application rates of 4 to 200 tons per acre and various rates of fertilization in several seasons over the next 3-1/2 years.

Three other demonstrations deserve special mention. Two of these involve erosion control and reclamation of strip mine spoil bank areas, one project in cooperation with the TVA Strip Mine Reclamation Section, and one project in cooperation with the Southern Soil Conservation Committee in Mercer County, West Virginia. Approximately 100 tons were shipped to the Oak Ridge National Laboratory for use as a soil amendment in a radioactive burial ground area being used for special ecological studies.

In addition to demonstration and research with compost in the vicinity of Johnson City, the Division of Agricultural Development undertook research into the effect of compost on a planting of pine tree seedlings at Holder, Citrus County, Florida. Because of the distance and cost for shipment from Johnson City, arrangements were made to obtain compost from the Gainesville Municipal Waste Conversion Authority plant at Gainesville, Florida. Through cooperation from the Soils Department, University of Florida, compost was obtained at no cost and advice and consultation were obtained from the staff. The physical appearance of this compost compared well with the Johnson City compost, but the moisture content was about twice and the nitrogen content 50 to 80 percent that of the compost as used in demonstrations at Johnson City.

REFERENCES

1. Mason, H. G. Extending life of disposal areas. Compost Science, 10(1-2):26-31, Spring-Summer 1969.

2. Reclamation of municipal refuse by composting. Technical Bulletin No. 9. Berkeley, Sanitary Engineering Research Laboratory, University of California, June 1953. 89 p.

3. Wiley, J. S., and O. W. Kochtitzky. Composting developments in the United States. Compost Science, 6(2):5-9, Summer 1965.

4. Gotaas, H. B. Composting-sanitary disposal and reclamation of organic wastes. World Health Organization Monograph Series No. 31. Geneva, World Health Organization, 1956. 44 p.

5. Morgan, M. T., and F. W. Macdonald. Tests show MB tuberculosis doesn't survive composting. Journal of Environmental Health, 32(1):101-108, July-Aug. 1969.

6. Belding, D. L. Basic clinical parasitology. New York, Appelton-Century-Crofts, Inc., 1958. 469 p.

7. Scott, J. S. Health aspects of composting with night soil. World Health Organization Expert Committee on Environmental Sanitation, 3rd session, Geneva, July 27-31, 1953. 8 p.

8. Wilson, D. L. Laboratory procedure for the gravimetric determination of carbon and hydrogen in solid wastes (for methods manual); a Division of Research and Development open-file report (RS-03-68-17). [Cincinnati], U.S. Department of Health, Education, and Welfare, 1970. 35 p. [Restricted distribution.]

9. Muhich, A. J. Sample representatives and community data. In Black, R. J., et al. The national solid wastes survey; an interim report. [Cincinnati], U.S. Department of Health, Education, and Welfare, [1968]. p. 7-25.

10. Sorg, T. J., and H. L. Hickman, Jr. Sanitary landfill facts. 2d ed. Public Health Service Publication No. 1792. Washington, U.S. Government Printing Office, 1970. 30 p.

11. Breidenbach, A. W., et al. Composting of municipal solid wastes in the United States. Washington, U.S. Government Printing Office, 1971. 103 p.

12. Mays, D. A., E. M. Evans, R. C. Dyram, and C. E. Worley. Excerpt Forage Research Report No. 6. Summary of 1969 forage investigations. Soils and Fertilizer Research Branch, Tennessee Valley Authority, Muscle Shoals, Alabama.

APPENDIX I

Methods Used for Chemical Analyses

Test for Moisture. Moisture contents were determined by oven drying at 100 C using 2,000 gram or larger samples. In most cases a drying period of 24 hr was used as the water content was rarely over 60 percent by wet weight. Moisture content was calculated by the relation:

$$\frac{100 \text{ (loss in weight)}}{\text{(net wet weight)}} = \% \text{ moisture (wet basis)}$$

Digestion of Compost Samples for Elemental Analyses. Digest from 2.0 to 3.0 grams of compost (dried, finely ground, and weighed to the nearest milligram) in a mixture of 20 milliliters of concentrated sulfuric acid and 50 milliliters of concentrated nitric acid in a Kjeldahl flask for 2 hr or until clear, adding additional nitric acid if necessary. Filter and dilute this to 500 milliliters in a volumetric flask and save for further analyses.

Test for Nitrogen (Organic and Ammoniacal). The test used in the project laboratory is a modification of the Kjeldahl-Wilfarth-Gunning method described in Appendix A, *Municipal Refuse Disposal*, American Public Works Association, 2 ed., 1966.

Equipment - Kjeldahl flasks for digestion and distillation, 800 milliliter; exhaust hood and special stack to outside for venting acid fumes during digestion;

Kjeldahl connecting bulbs (use bulbs 5 to 6 centimeters in diameter, fit lower end with rubber stopper, and connect upper end to a condenser with rubber tubing); Erlenmeyer flasks, 500 milliliter.

Reagents - Standard sulfuric acid, 0.1N; standardize by any official method.

Boric acid solution, 40 g/l.

Sulfuric acid, 93 to 96 percent H_2SO_4, free from nitrates and $(NH_4)_2SO_4$.

Mercuric oxide, reagent grade, free from nitrogen.

Sodium hydroxide-thiosulfate solution: dissolve 450 grams of NaOH, free from nitrates, in water and allow to cool; add 80 grams of $Na_2S_2O_3.5H_2O$, keeping solution cool, and make to 1 liter with water.

Methyl red indicator: dissolve 1 gram of methyl red in 200 milliters of 95 percent ethyl alcohol.

Potassium sulfate, K_2SO_4.

Granulated zinc.

Procedure - Weigh to fourth decimal place 0.7 to 2.5 grams of redried sample (indirectly from aluminum sample container) into a piece of Whatman No. 1 filter paper (9 centimeters). Fold paper and introduce into digestion flask. Add 15 to 18 grams of K_2SO_4, about 0.7 grams of mercuric oxide, and 25 milliliters of concentrated H_2SO_4. Heat gently until frothing ceases, then boil briskly, continuing digestion for about 2 hr after the mixture is colorless or nearly so. Cool, add 200 milliliters of water, and dissolve cake. Add 1 gram of granulated zinc to prevent bumping and 75 milliliters of alkali-thiosulfate solution, pouring down the side of the flask so that it does not mix at once with the acid solution. Connect flask immediately to the condenser by means of the Kjeldahl connecting bulk, taking care that the tip of the condenser extends below the surface of the standard acid in the 500-milliliter flask, which acts as a receiver. Mix the contents by shaking and distill into 50 milliliters of the boric acid solution until about 200 milliliters of distillate has been obtained. The first 150 milliliters of the distillate usually contains all of the NH_3. It is helpful to mark the receiving flasks at about 200 milliliters and distill to the mark. Titrate with the standard acid solution, using the methyl red indicator.

Calculations - $\frac{\text{ml } 0.10N \; H_2SO_4 \times 0.14}{\text{Weight of sample (grams)}} = \%$ Nitrogen

Determination of Carbon Content of Compost and Refuse. Determinations for carbon content was made by the Research Services Laboratory, Division of Research and Development, BSWM, in Cincinnati, where special procedures were developed. The gravimetric method for determination of carbon and hydrogen is described in an open file report.[8]

Test for Phosphorus. Dilute the previously digested sample to 500 milliliters in a volumetric flask and determine the phosphorous content as in *Standard Methods for the Examination of Water and Wastewater*, 12th ed., 1965, p. 234-236, with the following modifications:

1. Use only recently digested samples, no more than 1 week old. Old samples give erratic, inaccurate results.
2. Dilute 5 ml of digested material to 100 ml for the determinations.
3. Standard addition must be used with this method. Make two additional preparations of each sample and add 0.05 milligrams and 0.10 milligrams phosphorus to each, respectively. It was found that there is a color suppressant in the compost that will result in low values if the analyses are performed against a standard curve. This interference is readily overcome with the standard addition technique, giving accurate, reliable results.

Tests for Sodium, Potassium, Calcium, and Magnesium. Using previously digested samples of compost, these elements are determined by flame photometry using the methods as described in Dean, John A., *Flame Photometry*, McGraw-Hill, 1960, New York, p. 153-179.

Test for Boron. Using a digested compost sample, boron is determined by two methods as given in Snell and Snell, *Colorimetric Methods of Analysis*, Vol. 11A, D. Van Nostrand Company, 1959, Princeton, New Jersey. Page 594 of this text describes a method using quinalizarin, and page 596 describes a method using carminic acid (carmine red). Both of these methods were found to be satisfactory; however, both methods should be employed with each sample tested to assure accurate results.

Test for Copper. Add 4 milliliters of a digested sample (2 to 3 grams in 500 milliliters of water) to a separatory funnel, then add 5 milliliters of 10 percent hydroxylamine hydrochloride and 10 milliliters of 30 percent sodium citrate. Add concentrated NH_4OH by drops until the pH is between 4 and 6. Then add 10 milliliters of 10 percent neocuproine, mix and extract with 10 milliliters of $CHCl_3$. Let the layers separate, draw off the chloroform layer and read the absorbance in a spectrophotometer at 457 millicrons. Run standards with a range of from 10 to 50 ppm copper. The reference for this test is Snell and Snell, *Colorimetric Methods of Analysis*, page 75.

Test for Iron. Dilute the previously digested sample to 500 milliliters in a volumetric flask. Pipet 5.0 milliliters into a separatory funnel, add 10 milliliters 5 percent KCNS solution and extract the red complex with exactly 50.0 milliliters ether. Draw off the aqueous phase and read the absorbance of the ether phase in a spectrophotometer at 440 millimicrons. For standards use 20, 50, and 100 ppm iron (Fe^{+3}). Compute the concentration of the sample directly from the standard curve in ppm. The iron content of the sample is determined by the relation:

$$\frac{\text{Concentration of sample (ppm)}}{20 \times \text{initial sample wt.}} = \%\ \text{Iron}$$

Fairly reliable results can be obtained by simply boiling the sample in strong hydrochloric, nitric, or sulfuric acid (3N to 6N) to dissolve the iron, filtering and washing the resultant mass, and diluting the filtrate to 500 ml, then proceeding as above. This would eliminate the digestion step, thus giving a more rapid analysis with results accurate enough for routine analysis. The reference for the iron test is Snell and Snell, *Colorimetric Methods of Analysis*, Vol. IIA, p. 229-231.

Test for Aluminum. Remove iron from the sample as described in page 246 of Snell and Snell, *Colorimetric Methods of Analysis*, Vol. II, Van Nostrand, New York, 1949.

After removal of the iron is complete, determine the aluminum by following the directions given on pages 48-50 of the above reference.

Tests for Manganese, Nickel, Zinc, Mercury, and Lead. These elements are present in compost in trace amounts, and their upper limits of concentration were set using methods as described in Feigl, Fritz, *Qualitative Analysis by Spot Tests*, Elsevier Publishing Company, New York,

1946. These elements can be quantitatively determined by atomic absorption spectroscopy or by mass spectroscopy. Polarographic techniques may also be used, but difficulty will be encountered since the compost contains an abundance of elements with electrode half-potentials similar to these, and special solvent extraction or masking techniques would have to be used to achieve reliable results. Atomic absorption spectroscopy is probably the easiest, most rapid and accurate technique to employ for these elements.

<u>Determination of Chemical Oxygen Demand (C.O.D.)</u> The reference used for this determination is *Standard Methods for the Examination of Water and Waste-water*, 12th ed., 1965, p. 510-514, where the technique and standardization procedure can be found.

Reagents - Potassium dichromate solution, 1.00N.
Standardized ferrous ammonium sulfate.
Concentrated sulfuric acid.
Ferroin indicator.

Procedure - Weigh out 0.2 to 0.3 grams of finely ground, dry, compost (2 millimeter mesh) to the nearest milligram and place the sample in a 250 milliliter Erlenmeyer flask. Pipette in exactly 50.0 milliliters of 1.00N $K_2Cr_2O_7$, add 30 milliliters of water and 20 milliliters of concentrated H_2SO_4. Place on a hotplate and boil gently for 1 hr, adding water to compensate for evaporation. Dilute to 250 milliliters in a volumentric flask, mix well, pipette 10.0 milliliters into a 500 milliliter flask and add about 100 milliliters of water. Titrate with standardization ferrous ammonium sulfate (about 0.1 to 0.2N) using ferroin as an indicator.

Calculations - $$C.O.D. = \frac{(A - B) \times C \times 200}{\text{grams of sample}}$$ (in milligrams/gram

where:

A = milliliters of titrant used for blank

B = milliliters of titrant used for sample

C = normality of titrant

It is advisable to run a duplicate of the original sample and a duplicate of each dilution. Good precision was found in duplicate assays, indicating that the method is stable and reproducible for a given sample of compost. This observation is further substantiated by the results plotted in Figure 56, which show the COD in milligrams/gram of randomly selected windrows versus age. Johnson City compost, at 8 weeks, showed a COD of less than 700 mg/gram, as opposed to around 900 mg/gram for fresh refuse.

<u>Determination of Cellulose Content.</u> Two methods for the determination of cellulose content were used in the laboratory, the anthron colorimetric method and the gravimetric method.

(Anthrone Method)

Reagents - Diluted H_2SO_4 (760 ml conc. H_2SO_4 + 300 ml water)

Anthrone reagent: 1 gram anthrone in 500 ml cold 96% H_2SO_4. Let stand at room temperature 4 hr before use.

Benzene

Pure cellulose standard

Procedure - Weigh out a finely ground and redried compost sample to the nearest milligram, place in a Soxhlet extractor, and extract with benzene for 8 hr. Dry the composite sample and weight it in order to compute the percent material extracted with benzene. Extract this sample again with hot water for 8 hr. Dry the sample and weigh it in order to compute the percent material extracted with water. Take between 0.5 to 1.0 gram of the composite sample weighed to the nearest milligram and place it in a 250 milliliter beaker, wet it with a few drops of ethanol, methanol, or acetone. Pipet in 10.0 milliliters water, then 60.0 milliliters diluted sulfuric acid and stir to dissolve the cellulose solution into a 500 milliliter volumetric flask and dilute to 500 milliliters. Pipet 1 milliliter of this into a test tube, add 10.0 milliliters anthrone reagent, mix, seal the tube and heat in a 100 C bath for 15 min. Cool to room temperature and read the absorbance with a spectrophotometer at 630 millimicrons. Run cellulose standards to bracket the sample concentration and a blank with each series of samples. A blank and standards must be included with each group of samples heated in the 100 C bath.

Calculations - % cellulose $= \frac{W_c \times (100 - [\% E_b + \% E_w])}{\text{grams of extracted sample}}$

where:

W_c = weight of cellulose found in grams

E_b = benzene extract

E_w = water extract

Note: If all the sample can be recovered and used after the benzene and water extractions, then it is unnecessary to compute the percent of extracted material. Simply know the initial weight of the sample, the number of grams found (from the anthrone standard curve) and compute the percent cellulose from this. This is easily accomplished by placing 0.5 gram to 1.0 gram of compost in a porcelain thimble with an asbestos filter, capping with glass wool, extracting, and then washing all the sample into a beaker and proceeding with the determination as above.

(Gravimetric Method)

Reagents - Concentrated nitric acid

Glacial acetic acid

Benzene

Ether

Methanol

Acetone

Procedure - Weigh out about 1 gram of redried, finely ground compost to the nearest milligram, place in a 125 milliliter Erlenmeyer flask and add 6 milliliters water, 24 milliliters glacial acetic acid, and 2 milliliters concentrated nitric acid. Bring to a gentle boil on a hotplate for 20 min, cool to about 80 C, add 50 milliliters benzene and swirl vigorously to extract materials soluble in benzene. Set up a Gooch crucible with an asbestos filter on a suction flask, decant as much of the benzene layer as possible into the filter (with suction) taking care not to let the bottom layer spill over. Then add 50 milliliters of ether to the flask, swirl vigorously, let settle and decant all the liquid into the crucible. Wash all the solid material into the crucible with acetone, taking care not to leave any behind. Wash the filter cake thoroughly with successive portions of hot benzene, hot methanol, and ether. After washing, clean the outside of the crucible, place in an oven to dry, cool in a desiccator, weigh to the nearest milligram and ignite at 625 C for 1 hr. Cool, weigh, and report the loss on ignition.

Calculations - $\frac{\text{Loss on ignition x 100}}{\text{Initial sample weight}}$ = % Cellulose

Discussion - Duplicate samples should always be run to assure precision. Swirling the benzene with the hot reaction mixture is necessary to assure rapid filtering of the successive solvents used. Compost contains a tar-like material that plugs the filter, and most of this is soluble in benzene.

An alternate approach is provided by combining the two methods. Complete the solvent washings as in the gravimetric method, then dissolve the entire sample as in the anthrone method and determine the cellulose colorimetrically. This was done three times with a 0-day composite compost sample, and the results were 49.4 percent, 49.4 percent, and 49.6 percent. The gravimetric method on the same sample yielded 50.2 percent, 50.0 percent, and 50.3 percent. The higher results indicate that some substances were not removed by the extractions (0.7%) and were not cellulose, but were lost on ignition.

Analyses were performed on samples to which known amounts of cellulose had been added to further check the gravimetric method.

		% Cellulose				
0-day compost	found	50.3	55.1	60.6	65.4	
	theoretical		55.2	60.5	65.4	
56-day compost	found	24.3	37.6	29.4	60.9	
	theoretical		36.8	28.7	61.5	
1-year compost	found	19.1	28.0	38.3	48.1	60.8
	theoretical		28.2	39.1	49.2	61.1

The gravimetric method is recommended because it is more rapid and easier to perform than the colorimetric anthrone method.

Tests for Volatile Solids and Ash. This test was made in accordance with the procedure described in Appendix A, *Municipal Refuse Disposal*, American Public Works Association, 2d ed., 1966, p. 381.

Test for Lipids. Lipids content was determined by the ether extract method described in Appendix A, *Municipal Refuse Disposal*, American Public Works Association, 2d ed., 1966, p. 381.

Tests for Sugars and Starch. Extract a carefully weighed sample (about 3-5 grams) with ether in a Soxhlet extractor for 6 hr. Remove the ether, dry the sample, and extract with 95 percent ethanol for 8 hr. - Dry the sample and extract again with water for 15 hr. Determine the sugars in the ethanol extract and the starch in the water extract by the anthrone method as described in the Determination of Cellulose, page 77, or in Appendix A,, *Municipal Refuse Disposal*, American Public Works Association, 2d ed., 1966, p. 386.

Glucose alone may be determined by using a device known as a "glucostat" manufactured by the Worthington Biochemical Company, available from Matheson Scientific Company.

TVA 5133 (DRP-6-68)

APPENDIX II

STATEMENT OF OPERATIONS

DIVISION OF RESERVOIR PROPERTIES

Per Cent of F. Y. Expired 25%

EASTERN DISTRICT

MONTH OF SEPTEMBER 19 69

Account Title	HRS	YTD	Account Number	Expense: This Month	Expense: Fiscal Year To Date	Budget	Per Cent Expended
USPHS-TVA Composting Plant							
Delivery and Receiving							
Operation			012-01.11				
11 - Salaries, ST	161.5	502.0		618	1,886		
OT	9.0	13.0		38	58		
12 - Benefits				107	312		
Total salary expense				763	2,256		
26 - Supplies and materials				-	-		
Total				763	2,256		
Maintenance			012-01.12				
11 - Salaries, ST	124.0	200.0		573	917		
OT	25.5	26.5		152	158		
12 - Benefits				115	171		
Total salary expense				840	1,246		
25 - Tire repairs, loader repairs				-	15		
26 - Supplies and materials				163	264		
Total				1,003	1,525		
Total Delivery and Receiving				1,766	3,780		
Picking and Sorting							
Operation			012-02.11				
11 - Salaries, ST	184.5	575.5		650	2,029		
OT	3.0	5.0		13	22		
12 - Benefits				113	352		
Total salary expense				776	2,403		
26 - Supplies and materials				13	38		
Total				789	2,441		
Maintenance			012-02.12				
11 - Salaries, ST	-	1.0			4		
OT	-	-			-		
12 - Benefits					1		
Total salary expense				-	5		
26 - Supplies and materials					-		
Total				-	5		
Total Picking and Sorting				789	2,446		
Grinding							
Rasper Operation			012-03.11				
11 - Salaries, ST	125.0	340.5		506	1,393		
OT	.5	7.5		3	36		
12 - Benefits				88	241		
Total salary expense				597	1,670		
26 - Supplies and materials				-	-		
Total				597	1,670		

TVA 5133 (DRP-6-68)

STATEMENT OF OPERATIONS

DIVISION OF RESERVOIR PROPERTIES

Per Cent of F. Y. Expired 25%

EASTERN DISTRICT — MONTH OF SEPTEMBER 19 69

Account Title	HRS	YTD	Account Number	Expense: This Month	Expense: Fiscal Year To Date	Budget	Per Cent Expended
Grinding - Continued							
Rasper Maintenance			012-03.12				
11 - Salaries, ST	1.0	114.0		5	547		
OT	-	32.0		-	191		
12 - Benefits				1	79		
Total salary expense				6	817		
26 - Supplies and materials				8	792		
Total				14	1,609		
Hammermill Operation			012-03.21				
11 - Salaries, ST	-	34.0			141		
OT	-	-			-		
12 - Benefits					25		
Total salary expense				-	166		
26 - Supplies and materials					-		
Total				-	166		
Hammermill Maintenance			012-03.22				
11 - Salaries, ST	16.0	33.0		84	156		
OT	-	1.0		-	5		
12 - Benefits				4	17		
Total salary expense				88	178		
26 - Hammers, belts, miscellaneous				26	26		
Total				114	204		
Total Grinding				725	3,649		
Sludge Thickening and Mixing Operation			012-04.11				
11 - Salaries, ST	6.5	89.0		25	364		
OT	-	2.0		-	9		
12 - Benefits				4	62		
Total salary expense				29	435		
26 - Supplies and materials				-	-		
60 - Mileage				-	8		
Total				29	443		
Maintenance			012-04.12				
11 - Salaries, ST	17.5	77.5		80	343		
OT	1.0	1.0		6	6		
12 - Benefits				14	59		
Total salary expense				100	408		
26 - Supplies and materials				-	120		
Total				100	528		
Total Sludge Thickening and Mixing				129	971		

TVA 5133 (DRP-6-68)

STATEMENT OF OPERATIONS

DIVISION OF RESERVOIR PROPERTIES

Per Cent of
F. Y. Expired 25%

EASTERN DISTRICT MONTH OF SEPTEMBER 19 69

Account Title	HRS	YTD	Account Number	Expense This Month	Expense Fiscal Year To Date	Budget	Per Cent Expended
Composting							
Hauling Operation			012-05.11				
11 - Salaries, ST	141.0	453.0		564	1,806		
OT	2.0	4.0		10	19		
12 - Benefits				99	314		
Total salary expense				673	2,139		
26 - Supplies and materials				3	3		
60 - Truck use				365	948		
Total				1,041	3,090		
Hauling Maintenance			012-05.12				
11 - Salaries, ST	4.0	74.0		20	366		
OT	-	4.0		-	24		
12 - Benefits				3	47		
Total salary expense				23	437		
26 - Supplies and materials				33	67		
Total				56	504		
Turning and Wetting Operation			012-05.21				
11 - Salaries, ST	124.0	342.5		499	1,395		
OT	1.5	1.5		8	8		
12 - Benefits				85	240		
Total salary expense				592	1,643		
26 - Supplies and materials				12	79		
Total				604	1,722		
Turning and Wetting Maintenance			012-05.22				
11 - Salaries, ST	37.5	93.5		166	426		
OT	-	-		-	-		
12 - Benefits				29	70		
Total salary expense				195	496		
25 - Tire repairs				-	35		
26 - Supplies and materials				45	423		
Total				240	954		
Total Composting				1,940	6,270		
Curing							
Operation			012-06.11				
11 - Salaries, ST	1.0	25.0		4	101		
OT	-	-		-	-		
12 - Benefits				1	19		
Total salary expense				5	120		
26 - Supplies and materials				-	-		
60 - Truck use				-	8		
Total				5	128		

TVA 5133 (DRP-6-68)

STATEMENT OF OPERATIONS

DIVISION OF RESERVOIR PROPERTIES

Per Cent of F. Y. Expired 25

EASTERN DISTRICT MONTH OF SEPTEMBER 1969

Account Title	HRS	YTD	Account Number	Expense: This Month	Expense: Fiscal Year To Date	Budget	Per Cent Expended
Curing - Continued							
Maintenance			012-06.12				
11 - Salaries, ST	-	-			-		
OT	-	-			-		
12 - Benefits					-		
Total salary expense				-	-		
26 - Supplies and materials				-	-		
Total				-	-		
Total Curing				5	128		
Regrinding and Screening							
Operation			012-07.11				
11 - Salaries, ST	152.0	450.5		661	1,925		
OT	-	-		-	-		
12 - Benefits				97	319		
Total salary expense				758	2,244		
[illegible] - Supplies and materials				62	317		
60 - Truck use				325	640		
Total				1,145	3,201		
Maintenance			012-07.12				
11 - Salaries, ST	137.0	185.0		666	899		
OT	1.0	1.5		6	8		
12 - Benefits				89	125		
Total salary expense				761	1,032		
26 - Supplies and materials				34	81		
Total				795	1,113		
Total Regrinding and Screening				1,940	4,314		
Hauling Rejects							
Operation			012-08.11				
11 - Salaries, ST	151.5	481.5		603	1,918		
OT	4.5	9.5		22	46		
12 - Benefits				106	334		
Total salary expense				731	2,298		
26 - Supplies and materials				-	15		
60 - Truck use				341	907		
Total				1,072	3,220		
Maintenance			012-08.12				
11 - Salaries, ST	5.0	149.5		25	702		
OT	-	-		-	-		
12 - Benefits				4	82		
Total salary expense				29	784		
[illegible] - Supplies and materials				11	155		
Total				40	939		
Total Hauling Rejects				1,112	4,159		

TVA 5133 (DRP-6-68)

STATEMENT OF OPERATIONS

DIVISION OF RESERVOIR PROPERTIES

Per Cent of F. Y. Expired 25

EASTERN DISTRICT MONTH OF SEPTEMBER 19 69

Account Title	HRS	YTD	Account Number	Expense: This Month	Expense: Fiscal Year To Date	Budget	Per Cent Expended
Disposal of Nonmarketable Processed Mat'l			012-09				
11 - Salaries, ST	67.0	157.0		270	633		
OT	2.5	4.0		13	21		
12 - Benefits				48	111		
Total salary expense				331	765		
60 - Truck use				32	101		
Total				363	866		
Distributing Processed Material			012-10				
11 - Salaries, ST	67.0	175.5		286	723		
OT	.5	20.5		2	100		
12 - Benefits				48	122		
Total				336	945		
26 - Supplies and materials, services				16	24		
60 - Vehicle use				37	227		
Total				389	1,196		
General Expense							
Operation of Grounds			012-19.11				
11 - Salaries, ST	108.5	195.5		333	645		
OT	-	70.5		-	317		
12 - Benefits				21	75		
Total salary expense				354	1,037		
26 - Supplies and materials				2	2		
Total				356	1,039		
Maintenance of Grounds			012-19.12				
11 - Salaries, ST	-	6.0			25		
OT	-	.5			3		
12 - Benefits					4		
Total salary expense				-	32		
26 - Supplies and materials				18	30		
60 - Truck use				-	-		
Total				18	62		
Supervision			012-19.21				
11 - Salaries, ST	184.5	567.0		1,046	3,187		
OT	20.0	84.0		125	536		
12 - Benefits				179	543		
Total salary expense				1,350	4,266		
21 - Travel expense				65	86		
60 - Vehicle use				101	255		
Total				1,516	4,607		

TVA 5133 (DRP-6-68)

STATEMENT OF OPERATIONS

DIVISION OF RESERVOIR PROPERTIES

Per Cent of F. Y. Expired 25

EASTERN DISTRICT MONTH OF SEPTEMBER 1969

Account Title			Account Number	Expense This Month	Expense Fiscal Year To Date	Budget	Per Cent Expended
Processing Building Cleanup			012-19.31				
	HRS	YTD					
11 - Salaries, ST	176.5	507.5		635	1,857		
OT	2.5	36.0		12	171		
12 - Benefits				104	317		
Total salary expense				751	2,345		
26 - Supplies and materials				-	-		
Total				751	2,345		
Office and Lab Expense			012-19.41				
11 - Salaries, ST	13.5	46.5		44	163		
OT	-	19.0		-	85		
12 - Benefits				5	25		
Total salary expense				49	273		
25 - Contractual services				-	14		
26 - Supplies and materials				-	26		
60 - Trailer rental				68	184		
62 - Office equipment use				12	36		
Total				129	533		
Utilities			012-19.51				
11 - Salaries, ST	8.0	33.0		36	155		
OT	-	-		-	-		
12 - Benefits				6	27		
Total salary expense				42	182		
23 - Power				355	720		
- Water				12	40		
- Telephone				-	59		
26 - Supplies and materials				19	94		
Total				428	1,095		
Gasoline			012-19.61				
26 - Gasoline purchases				437	449		
Other			012-19.71				
11 - Salaries, ST	264.0	445.0		1,084	1,788		
OT	3.0	14.0		17	69		
12 - Benefits				191	311		
Total salary expense				1,292	2,168		
21 - Travel				17	50		
22 - Freight				53	53		
26 - Supplies and materials				514	898		
60 - Vehicle use				15	80		
70 - Power Stores issues				-	99		
Total				1,891	3,348		
Total General Expense				5,528	13,479		

TVA 5133 (DRP-6-68)

STATEMENT OF OPERATIONS

DIVISION OF RESERVOIR PROPERTIES

Per Cent of F. Y. Expired 25

EASTERN DISTRICT — MONTH OF SEPTEMBER 19 69

Account Title	HRS	YTD	Account Number	Expense: This Month	Expense: Fiscal Year To Date	Budget	Per Cent Expended
General Expense Distribution			012-20.61				
86 - Gas and oil issues to TVA				-153	-420		
Modification & Additions to Plant Equip.			012-50				
11 - Salaries, ST	90.0	324.5		448	1,604		
OT	3.0	19.0		18	116		
12 - Benefits				78	243		
Total salary expense				544	1,963		
22 - Freight				40	40		
23 - Equipment rental				180	180		
25 - Contractual services				-	-		
26 - Supplies and materials				118	345		
31 - Equipment				-	-		
60 - Truck use				-	-		
82 - Suborder costs				-	-		
Total				882	2,527		
Activity Totals - USPHS-TVA Compost Plant			012				
11 - Salaries, ST	2368.0	6678.5		9,929	28,095	104,770	27
OT	79.5	376.0		445	2,010	9,170	22
12 - Benefits				1,641	4,649	18,000	26
Total salary expense				12,015	34,754	131,940	26
21 - Travel				82	136	500	27
22 - Freight				93	93	1,000	09
23 - Telephone, util., equip. rental				548	999	6,000	17
25 - Other services				94	157	3,000	05
26 - Supplies and materials				1,426	4,139	15,000	28
31 - Equipment				-	-	20,000	-
60 - Transp. Branch equip. use				1,285	3,359	17,560	19
62 - Office equipment use				12	36	-	-
66 - Reproduction				13	13	-	-
70 - Warehouse issues				-	99	-	
82 - Transferred costs				-	-	5,000	-
Gross				15,567	43,785	200,000	22
86 - Distribution			012-20	-153	-420	-5,000	08
Expenditures				15,414	43,365	195,000	22
50 - Income			012-999	-15,414	-43,365	-195,000	22
Net				-	-	-	-

APPENDIX III

Preliminary Results of Agricultural Research on Compost

Corn Grain Research Project, Johnson City, Tennessee. This project involves the use of refuse-sludge compost in the growth of corn on agricultural soils. Application rates in fall or spring ranged from 0 to 200 tons per acre. The purpose of such a range in application rates was to determine the soil and crop improvement resulting from various amounts of compost and the maximum amount of compost that can be applied before the effect is adverse or deleterious. The fall applications of 4, 8, 50, 100, and 200 tons per acre of unscreened compost were made in November 1968, and plowed under shortly thereafter. Spring applications were made in April 1969, and disked into the soil. Nitrogen rates of 80 and 160 lb per acre were also compared alone and with 8 tons of spring-applied compost. There was a total of 52 test plots with each plot receiving phosphorus and potassium at rates adequate for maximum plant growth. The corn was planted on May 2, 1969.

There was a slight reduction in germination on the plots that received the three highest rates of compost (50, 100, and 200 tons per acre) with the lowest percentage germination coming on the 200-ton-per-acre rate. One factor that contributed to this reduction in germination was the inability because of the bulkiness of the compost to prepare a firm seedbed, especially on the plot receiving the 200-ton-per-acre rate. Other factors that affected the overall number of plants on all plots were (1) the crop was damaged somewhat by birds, (2) extremely cool temperatures occurred during the germination period, and (3) there was also some damage caused by hail.

Nitrogen deficiencies developed in all plots that did not receive supplemental inorganic nitrogen. Early growth was extremely poor on the plots that received the three heaviest compost applications; however, toward the middle of the growing season, the corn on these plots began to make some progress. The first noticeable growth response came on the 50-ton-per-acre treatment followed in sequence by the 100- and 200-ton-per-acre rates. The final results indicated that these three treatments gave favorable results when compared to the plots receiving the 80- and the 160-lb-per-acre nitrogen treatments with no compost. It was also noted that the corn on the 200-ton-per-acre plot remained green longer than any other treatment. These early results would seem to indicate that the heavy application of compost had a definite effect on the amount of nitrogen being released to the soil in a form readily available to the plant, the heavier the application of compost, the longer it took for the corn to respond. It was approximately 7 months from the time the compost was plowed under in the 200-ton-per-acre treatment before there was any visual growth response that could be considered a normal growth pattern.

Final yield results of this first year observation showed that grain yields increased from 55 bushels per acre without nitrogen or compost to 76 bushels with 80 lb of nitrogen or with 100 tons of compost and to 90 bushels per acre with 160 lb of nitrogen plus 8 tons of compost.

Four to 8 tons per acre of compost alone resulted in slight, if any, increase in corn yields.

The value of compost on corn in terms of increased yields ranged from a (minus) -$1.75 per ton on spring applied compost at a rate of 4 tons per acre with no supplemental nitrogen to a (plus) +$3.18 per ton on spring applied compost at a rate of 8 tons per acre with 160 lb of supplemental nitrogen per acre. The value of compost when applied at a 200-ton-per-acre rate with no supplemental nitrogen was $.08 (8 cents) per ton, however, this does show that large amounts of compost can be utilized on agricultural soils with positive results. Additional studies will determine the residual effect of high rates of application of compost over a period of years.

It was apparent during the first year of testing that a combination of compost plus inorganic fertilizer produced greater yield than either compost or fertilizer alone. The response from the corn on the plot that received compost plus 160 lb of nitrogen was evident throughout the growing season as the corn stalks appeared greener and stronger than stalks from other plots. When inorganic fertilizer was used without compost, the yield on the 80 lb per acre of nitrogen and the 160 lb per acre of nitrogen treatments was approximately the same which would indicate that the excess over 80 lb per acre of nitrogen was not efficiently utilized by plant uptake. This situation can be partly attributed to the relatively small number of plants per plot; however, when 8 tons per acre of compost was used in conjunction with 160 lb per acre nitrogen, there was an approximate 20 percent increase in yield over the 160 lb per acre of nitrogen alone or the 8 tons per acre compost with 80 lb per acre of nitrogen. It would appear that the compost had somewhat of a synergistic effect on the inorganic nitrogen since it is very doubtful that 8 tons of compost per acre would supply enough nitrogen or moisture to bring about such an increase in yield.

There are some preliminary conclusions drawn from 1 year of testing. More valid information can be gathered from results obtained from 4 or 5 years of continuous testing. Table 1 presents a summary of yield data obtained from corn research at Johnson City during 1969.

Use of Compost for Sorghum Production. (Experiment 56, National Fertilizer Development Center, Muscle Shoals, Alabama.)

Yields of dry sorghum forage increased from 5 tons/A without compost or N to 7.5 tons with 82 tons of compost and to 8 tons with 160 lb of applied N. Thus, the value of the compost in terms of the N it supplied was very low. Less wilting during dry periods on plots receiving large applications of compost indicated that it increased the moisture holding capacity of the soil. The results also indicate that agricultural land will accept large amounts of compost with small positive yield effects.

Procedure. Unground compost from Johnson City, Tennessee, was applied in fall, spring, or combination applications for Funk's 101F forage sorghum at total rates ranging from 6 to 82 tons per acre. Fall-applied compost was plowed under shortly after application, while spring applications were incorporated by disking. Compost rates were compared with 80 to 160 lb/A of N, with three treatments supplying both N and compost and a check treatment with no N or compost.

TABLE 1

Compost Experiment--Johnson City

Ear Corn Yields - Acre Basis

1969

Treatment	Stalks	Ear Corn Pounds	Ear Corn Bushels
1 - None	8230	3570	55
2 - 80 N	8470	4960	76
3 - 4T-Spring	8230	3235	49
4 - 160 N	8230	4750	73
5 - 8T-Spring	8710	4325	66
6 - 8T-Fall	8230	3810	58
7 - 4T-Fall	7745	3900	60
8 - 8T-Spring + 80 N	8710	4900	75
9 - 8T-Spring + 160 N	8470	5870	90
10 - 8T-Fall	8230	3780	58
11 - 50T-Fall	7745	4535	69
12 - 100T-Fall	7745	4990	76
13 - 200T-Fall	6775	4295	66
L.S.D., 5% Level	N.S.	855	13

Compost contained 40% moisture; application rates are on a dry basis. N was applied in spring as ammonium nitrate. Pounds of ear corn are as harvested (Av. of 14.5% moisture); bushels are on the basis of 15.5% moisture (70 pounds per bushel). The corn variety was Funk's G-5757.

Chemical components in the compost were as follows (%, dry weight basis):

Application Time	N	P	K	C	Ca	Na	Mg	S	Zn
Fall 1968	1.2	0.24	0.80	34.2	3.6	0.49	0.49	0.4	0.13
Spring 1969	1.3	0.40	0.96	26.8	6.4	0.82	0.87	0.4	0.15

P and K were applied at rates thought to be adequate for maximum plant growth. Forage sorghum was planted on April 23, and harvested on July 28 and October 15.

Results and Discussion. Forage yields, percentages, N content and N uptake are given in Table 2. Total yields of dry sorghum forage increased in a generally linear fashion with higher compost rates. Yields ranged from 10,814 lb/A on the check plot to 15,032 with 82 tons of compost/A. In contrast, 80 lb of N produced 13,850 lb of forage, while 160 lb produced 16,384 lb/A. The highest yield, 18,823 lb/A., was produced by 160 lb of N and 40 tons of compost. Forty tons of compost produced as much forage as 80 lb of N, but no compost rate was as good as 160 lb of N. In all cases, compost plus N produced more forage than either material alone.

At the first harvest, N contents of the forage were much higher with N alone than with compost alone, but differences were small at the second harvest. N uptake for similar yields was less from compost-treated than from N-fertilized plots. The N content and uptake data indicated that this was probably due largely to luxury uptake of N on fertilized

TABLE 2

Response of Forage Sorghum to Applications of Compost and N

Compost Rate Fall (Tons/A)	Compost Rate Spring (Tons/A)	N Rate (Pounds/A)	Dry Forage, Pounds/A Cut 1	Dry Forage, Pounds/A Cut 2	Dry Forage, Pounds/A Total	N Content, % Cut 1	N Content, % Cut 2	N Uptake, Pounds/A Cut 1	N Uptake, Pounds/A Cut 2	N Uptake, Pounds/A Total	N Uptake, Pounds/A Increase over no N or compost
0	0	0	8155f	2659e	10814g	.63	1.08	51.3	29.2	80.4g	-
0	0	80	10205c	3643de	13850de	1.08	.91	109.9	33.7	143.6d	63.2
0	6.2	0	8696ef	2943e	11640fg	.66	.95	57.3	27.9	85.1g	4.7
0	0	160	11306f	5076b	16384b	1.33	1.13	150.6	58.1	208.8ab	128.4
0	12.4	0	9214de	3434e	12649e	.71	1.03	65.5	36.0	101.5f	21.1
8	0	0	8736ef	3158e	11895fg	.65	1.00	55.9	31.5	87.3fg	6.9
4	6.2	0	9035def	3411e	12447f	.68	.90	61.6	30.7	92.3fg	11.9
0	12.4	80	11717b	4138cd	15856bc	1.10	.99	128.0	41.0	169.0c	88.6
0	12.4	160	12158ab	5729ab	17888a	1.15	1.06	139.1	61.0	200.1b	119.7
8	12.4	0	8871def	3531d	12403f	.72	1.06	63.7	37.3	101.0f	20.6
16	24.8	0	9483cde	4340c	13825de	.78	.97	73.2	42.0	115.3e	34.9
32	49.6	0	9773cd	5258b	15032cd	.88	1.11	86.4	55.1	141.4d	61.0
16	24.8	160	12670a	6151a	18823a	1.20	1.11	150.0	67.4	217.4a	137.0

Note: In all yield tables means with the same letter are not significantly different at the 5 percent level.

plots. Observation of the sorghum during dry periods indicated that compost contributed some moisture holding capacity to the soil. There was always less leaf curling on plots treated with the higher compost rates.

A slight stand reduction occurred on plots receiving 50 tons in the spring. It was not possible to incorporate this amount of compost well enough to provide the firm seedbed needed for good germination.

Value of compost per ton in terms of its contribution to yield increase was lower with increasing application rates. Dry matter yield increases per ton of compost ranged from 255 lb at the 6 ton rate to 52 lb at the 80 ton rate. The yield contributions were similar with and without N additions. Assuming that sorghum forage is worth $10 per ton on a green weight basis, compost was worth approximately $2.20 per ton at 8- to 12-tons-per-acre application rates and approximately $1.10 at rates of 20 tons per acre or more. If, on the other hand, the value is based on the amount of N needed to give equal yield, it was worth about $0.13 per ton.

As with the bermudagrass experiment (No. 57), this experiment showed that large amounts of compost can be disposed of by application on agricultural land without apparent yield reductions.

The compost used in these two experiments was unground and contained plastic, both film and dense type, fairly large pieces of glass and metallic waste. It would have been completely unsuitable for application to grazing or hay land and was objectionable from an aesthetic viewpoint for most surface application uses.

Evaluation of Compost on Common Bermudagrass. (Experiment 57, National Fertilizer Development Center, Muscle Shoals, Alabama.)

Yields of bermudagrass forage increased from 2.9 tons with no compost or N to 3.5 tons with 12 tons per acre of compost. The corresponding yield with 160 lb per acre of N/A were 5.0 tons without compost and 5.2 tons with 12 tons per acre of compost. The increases for compost were of insufficient value to pay for application costs.

Procedure. Compost was topdressed on common bermudagrass sod in November 1968, at rates of 0, 4, 8, and 12 tons per acre. In 1969, N rates of 0 and 160 lb per acre were superimposed on plots of each compost rate. Half the N was applied in April and half after the second harvest. The grass was cut four times. Results are presented in Table 3.

Results and Discussion. Without added N there was a slight but consistent increase in total yield with increasing compost rates ranging from 5,772 lb per acre with no compost to 7,045 lb with 12 tons per acre of compost. Where N was applied the 4-ton-per-acre compost application resulted in a slight reduction in yield, and 8 and 12 tons per acre in slightly increased yield. The increase was greater with 8 than with 12 tons per acre of compost.

Although there were inconsistencies in yield response to compost, the 8-ton-per-acre rate at both N levels resulted in approximately 900 lb additional forage per acre. At $25.00 per ton as the market value for bermudagrass hay, this compost would have been worth $1.25 per ton spread on the field. This would hardly pay spreading costs let alone production and transportation expense. However, this data does indicate that it might be possible to dispose of significant amounts of compost by spreading it on grasslands providing that it did not contain solid material harmful to livestock.

RD7-309

TABLE 3

Response of Common Bermudagrass

To Compost and Nitrogen, 1969

Treatments		Forage harvested, pounds				
Compost, T./A	N, Lbs/A	Cut 1	Cut 2	Cut 3	Cut 4	Total
4	160	2899	2177	1731	3290	10,098a
4	0	1663	1826	504	2644	6,639bc
8	160	3017	2533	2031	3590	11,172a
8	0	2025	1943	574	2211	6,755bc
12	160	2529	2696	1845	3444	10,515a
12	0	1628	1992	721	2702	7,045b
0	160	3156	2048	1961	3146	10,312a
0	0	1732	1436	535	2069	5,772c

Note: In all yield tables means with the same letter are not significantly different at the 5 percent level.

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