

A STUDY ON WINDROW COMPOSTING
WITH A SOIL SHREDDER

Thesis for the Degree of M. S.
MICHIGAN STATE COLLEGE
Shi-who, Kao
1954

This is to certify that the

thesis entitled

A Study On Windrow Composting By A Soil Shredder

presented by

Shi Who Kao

has been accepted towards fulfillment
of the requirements for

MS degree in Civil Engineering

Frank R. Theron
Major professor

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A STUDY ON WINDROW COMPOSTING
WITH A SOIL SHREDDER

By
Shi-who, Kao

A Thesis
Submitted to School of Graduate Studies of Michigan
State College of Agriculture and Applied Science
in Partial Fulfillment of the Requirements
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ABSTRACT

This thesis is a study on windrow composting with a soil shredder. The study was conducted for the purpose of evaluating the major factors involved in the windrow composting of solid organic wastes. An equally important consideration was that of establishing the optimum value and practical range of each major factor.

Experiments were made with unturned windrows and with windrows turned every third day, every second day and every day. The materials used for study were garbage from the city of East Lansing and dewatered sewage sludge from the Saginaw, Michigan sewage treatment plant.

Unturned windrow piles showed a long composting period and were accompanied with odor and fly nuisance; the piles turned every third day, every second day and every day required 18, 14 and 9 days respectively for completion and were without odor or fly nuisance.

The tests used for judging the composts were temperature, pH, moisture content and percentage of color transmittance. Of these tests, color transmittance seemed to be most applicable as a yardstick of windrow composting.

This thesis is a preliminary study of windrow composting in warm seasons and results here showed that continued research is well warranted.

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Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099
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SECTION I

Introduction

In China, both on the mainland and on Formosa, difficult problems in public health sanitation and soil conservation exist. These problems are due to low health standards and poor farming practices. For centuries, China has faced the problem of the disposal of human excreta in the heavily populated cities. The problem of maintaining the soil fertility in order to grow the crops needed for China's huge population is also very serious.

The loss of the mainland, due to the Red invasion, resulted in loss of trained personnel in all fields, including sanitation. During the past ten years, the Free China government on Formosa has enrolled several persons for advanced training in Public Health and Sanitary Engineering. This writer was sent to the United States under this program to study composting.

Composting is of great importance to Formosa. Organic wastes from Formosa's cities are a major vehicle in the spread of intestinal diseases. The composting of garbage and human excreta offers an answer to the problem of sanitation and to the problem of restoring organic matter to the soil.

The windrow composting process promises Formosa a feasible disposal method for wastes and human excreta. The process is not highly mechanized; only a grinder and soil shredder are needed. Windrow composting is especially suitable for such places as Formosa where labor is cheap and the climate is warm.

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SECTION II

Review of Literature

Composting is "the production from organic wastes, through the agency of microorganisms, of a relatively stable humus which may beneficially be used on agricultural soils."¹ It is a natural biological process which proceeds most rapidly under optimum environmental conditions. Important considerations are temperature, moisture, particle size, and the composition of raw materials.

For centuries, man has been taking organic wastes and converting them into a useful fertilizer by the natural process. This procedure requires a long time, usually more than a year or two, although a good product can be produced. Due to a lack of scientific knowledge, the composting process had always been practiced as an art rather than a science.

The first important advance in the practice of composting was made about thirty years ago in India by Lord Howard who systematized the traditional practices and developed the Indore Process. The time required for the process to go to completion was still quite long, usually in excess of six to eight months. Since that time, various processes have been designed and patented to shorten the detention period of composting, as listed in Table I.

Over the past five years considerable work on a highly scientific level has been done in the development of important data to reduce the detention period of composting. The research carried on at Michigan State

College and other institutions throughout the world should result in the design of a modern, efficient, high-rate composting process which will provide an economical method for disposing of organic wastes and for reclaiming a valuable soil conditioner and fertilizer.²

TABLE I

A Comparison of Composting Processes

No.	Name of Process	Description of Methods	Detention Period of Composting	Date Since Developed	Place or Country where Practiced	Remarks
1.	Indore	Alternate layers of night soil and straw, open pile on ground. Drainage recirculated.	6 to 8 months, sometimes more than a year.	30 years ago.	India	Pile in open air about 5 ft. high. Systematized from traditional old method by Lord Howard. No machine used; good in place where fertilizer is scarce and labor is cheap. No protection from flies, rodents, odors, and freezing weather.
2.	Beccari	Involves initial anaerobic fermentation and final aerobic stage with air vents.	-	1920-1930	Italy	It is successfully used in Italy and France and it is also the early patented process.
3.	Verdier	A modified Beccari process with gas and drainage recirculated.	35-22 days	1920-1930	France	It takes only 18-24 days for the complete treatment in Miami compost plant using this process.
4.	Bordas	A batch composter in the form of silo with air introduced.	-	1931	France	Silo is a unit, its rotation aerates the materials and breaks up the larger particles.
5.	V.A.M.	Ground wastes	3-6 weeks in summer, 4-6 months in winter.	1932	Holland	It is good in any season and any place.
6.	Dano	A preparatory grinding and rasing operation followed by ground composting.	3-6 weeks	-	Denmark	It is employed by 12 communities in Denmark and Sweden. It is really not a composting process.

TABLE I (Cont'd)

A Comparison of Composting Processes

No.	Name of Process	Description of Methods	Detention Period of Composting	Date Since Developed	Place or Country where Practiced	Remarks
7.	Earp Thomas	Employs grinding, agitation, aeration and bact. seeding. It is a continuous flow type.	2.5 - 4 days with several curing days.	1939	Hampton, N.J. U.S.A.	It is probably the best process commercially announced today. M.S.C. built a large pilot scale plant to study municipal composting.
8.	Frazer	A silo with 4-5 decks, continuous flow type, highly mechanized.	5-7 weeks	1949	U. S. A.	Plant with 3,000 cu. ft. capacity can compost 50 tons a day.
9.	Australian	A modified Earp-Thomas process but highly mechanized.	2 days.	-	Sydney, Australia	It is stated the end products were not rotted down.
10.	New Zealand	Outdoor composting of windrow type	8 months	1947	New Zealand	Much importance is assigned to the blending of raw materials to adjust the initial average nitrogen composition of 1.7% N. A C/N ratio around 10-20 for the end products of composting is desired. Temperature is also considered important.
11.	California	Windrowing type.	2-3 weeks.	1953	U. of California, Berkeley, U.S.A.	Besides C/N ratio suggested by New Zealand method, turning the pile on time is considered to be another important factor for composting.
12.	Windrowing	Tin cans, bottles and excess paper were removed. The ground garbage mixed with secret inoculum, animal manure and placed on the ground in windrows and aer-	5-6 weeks	1952	Oakland, Cal. and San Salvador	Has been used in the City of Oakland by Compost Corp. of America.

SECTION III

Composting at Michigan State College

Research work at Michigan State College is being done in connection with (a) a large plant size digester, (b) twenty-two completely controlled one-pound laboratory units, (c) a prototype Crane digester, and (d) windrow composting.

The large plant size digester used in Michigan State College is a modified Earp-Thomas type. It stands twenty-three feet high, is ten feet in diameter, and is separated into eight decks. The digester is insulated with two inches of foamglass brick covered with tar paper. Raw garbage from East Lansing (Specific constituents are listed as Table II.) is delivered to the plant in trucks and dumped indoors on a concrete floor. Tin cans and bottles are removed. The garbage is then ground and conveyed by a bucket-type conveyor to a storage and dewatering tank where the moisture content is reduced from about 75-80 per cent to about 55-65 per cent.³ The material remains in this tank for one to six days for dewatering by gravity and then is conveyed to the top deck of the digester. A slowly rotating vertical shaft passes through each deck. A cross arm is mounted on the shaft in each deck and plows are attached to the cross arm. These plows aerate and mix the material and drop it from deck to deck gradually. The material takes two to three days to pass through the digester. This procedure produces a stable organic compost.

The one-pound laboratory units are lucite plastic digesters mounted in temperature controlled water baths. The material in these gas-tight digesters is mechanically aerated by slowly revolving arms which are mounted on a central driving shaft. Oxygen uptake, carbon dioxide production, and various other chemical yardsticks are measured.

The prototype Crane digester is a horizontal digester unit, one-sixteenth of the designed four deck size. The material is aerated and moved by a series of paddle type screw conveyors. Designed as a continuous flow operation the material is charged in the top deck and gradually moved and aerated. Material drops from deck to deck. Discharge at the bottom is of a composted material. The detention time may be adjusted by changing either the pitch of the aerating paddles or by changing the gear ratio of the driving mechanism.

The windrow composting work reported here has been carried on during the last six months. Ground and unground garbage as well as sewage sludge cakes have been shredded on the ground in windrows by a soil shredder. Piles have been turned every day, every other day, or every third day. Different readings have been tested. A series of variables, such as temperature, moisture, ash, pH, O.R.P., color transmittance and bacterial population have been measured.

TABLE II

Composition (wet weight) of Garbage During
the Period of January - April, 1954*

Garbage Constituent	Per Cent
Paper	18.5
Meat, Fat, Fish, Peanuts, Eggs, Cheese, Milk, and Cream	6.8
Citrus Fruits	18.5
Other Fruits, Bananas, Grapes, Tomatoes, Apples, etc.	7.4
Green Vegetables, Celery, Corn husks, Melons, Cabbages, Lettuce, etc.	11.6
Coffee Grounds and Tea Leaves	5.1
Bread, Cake, Macaroni, Cereal, etc.	9.2
Potatoes, Beans, Corn, Onions, Beets, etc.	14.4
Miscellaneous, Egg Shells, Nuts, Bottle caps, Bones, Rags, Rubber, etc.	8.5
	100.0

*This table taken from a thesis by Williams
G. Turney on "A Study Concerning the Estab-
lishment of a Yardstick for Garbage Digestion
by Composting."

SECTION IV

Windrow Composting

The windrow composting process is an old method with a new name. As has been previously stated, composting in its most primitive form has been practiced by farmers and gardeners for many centuries. Their procedure has been to pile vegetable matter and animal manure in some available open space and to allow it to ferment naturally until ready for application to the soil. This type of composting is without control and introduces flies, rodents, odors, and sometimes communicable diseases. A long detention period is necessary.

Because of research done during the last few years, windrow composting today is no longer an art but a science. The pile is turned periodically to eliminate the offensive odors through aeration. The temperature which results is sufficient to kill all disease-producing organisms. Humus can be produced within a few days or weeks.

The study reported in this thesis was made by composting organic material on sandy soil. The ground or unground materials were shredded by a movable soil shredder and placed in windrows. To form the piles a metal plate was set up a short distance from the shredder to act as a shield. This kept the lighter particles from flying past the end of the pile.

Temperature measurements and other tests were made at each turning with the shredder or fork for the purpose of determining and evaluating the major factors involved in successful composting of solid organic wastes and to establish the optimum practical range of variation of each major factor.

SECTION V

Theoretical Consideration

Because composting is a biological process, environmental factors influencing the activities of microorganisms determine the speed and course of the composting cycle. Such factors include seeding, moisture content, aeration, hydrogen ion concentration, temperature, particle size, color transmittance, and initial carbon-nitrogen ratio of food material.

Seeding

Although the decomposition of organic material depends upon bacterial activities the process appears to proceed most rapidly under thermophilic aerobic conditions. Seeding does not seem to be an essential part of a practical process for composting. Mesophilic and thermophilic organisms indigenous to garbage and sewage sludge are probably sufficient to carry on the composting process when environmental conditions of moisture and aeration are suitable.

Moisture Content and Particle Size

The moisture content of a raw material for composting is a relative thing. Two materials with the same initial moisture content but with different particle size may show different degrees of decomposition if other conditions remain the same. The coarse material has less surface area but has more voids in contact with air than the fine material, and rapid decomposition is carried out by facultative aerobic organisms without odor. Particle size of material is controlled by grinding. Ideally, the more minute the particle, the more susceptible it is to the bacterial

or fungi attack because of the greater surface exposed. Therefore, especially for windrow composting, coarser particles seem indicated at the beginning of the composting process with finer particles being desirable at the middle stage when the moisture has dropped to some extent.

Aeration and Moisture

Aeration supplies the oxygen required by aerobic bacteria in carrying out their activities. An aerobic process is more efficient than an anaerobic one in the decomposition of organic materials. For these reasons, compost piles should be turned frequently. Too low a moisture content deprives microorganisms of the water needed in their metabolism and consequently inhibits bacterial activity. Hence, consideration should be given to the per cent moisture at which the turning of the pile should be stopped unless additional moisture is added.

Hydrogen Ion Concentration

Most bacteria thrive at neutral and moderately high pH values, and fungi at low to neutral values. In composting, the acid producing bacteria are the first to appear and a significant drop in pH is always noted. An increase in pH then occurs, probably due to the breakdown of acids and the release of ammonia by protein decomposition. In the final stages, when the temperature begins to decline, actinomycetes become predominant with other mixed populations, and a high pH is observed. The pH value is very useful for indicating the change of composting of garbage during the initial stage but is not so helpful near the final stages. Color transmittance may prove to be a useful indicator for composting in the final stages.

Temperature

The composting temperature results from bacterial activity. Bacteria most readily obtain energy through the breakdown of sugars, ultimately in the form of glucose. Excess energy above the requirements of the bacteria is released and accumulated as the heat of the composting.

Bacteria are divided into two major types: Mesophilic and Thermophilic. The Mesophilic type of bacteria exist at temperatures from 8° to 45°C . and Thermophilic bacteria grow and thrive in temperatures from 45° to 65°C . or even higher.⁴ Therefore, the temperature reached largely determines which of these two types of bacteria will predominate. Consequently, temperature becomes an important control and an aid in judging the course of a compost pile.⁵

Color Transmittance

Glasstone⁶ (Textbook of Physical Chemistry) has explained color phenomenon. His remarks may be summarized as follows: "The absorption spectrum of a substance is related to its color, but when absorption is in the ultraviolet only, the substance will be colorless. Unsaturated electrons are less firmly bound than those forming linkages, so structural changes in a molecule cause the band to shift to regions of longer wave length. Two or more unsaturated groupings often enhance one another so that visible color is produced. For instance, stilbene itself, $\text{C}_6\text{H}_5(\text{CH}=\text{CH})\text{C}_6\text{H}_5$, is colorless, but as the number of $-\text{CH}=\text{CH}-$ group is increased, the color passes through yellow to green and orange. On the other hand, the introduction of a $-\text{CH}_2$ group in the unsaturated chain destroys the conjugation, and is accompanied by a shift of the absorption band to shorter wave lengths to render a substance colorless. This phenomenon may be illustrated by reference to $\text{C}_6\text{H}_5(\text{CH}=\text{CH})_4\text{C}_6\text{H}_5$, which is greenish yellow, while $\text{C}_6\text{H}_5\text{CH}_2(\text{CH}=\text{CH})\text{C}_6\text{H}_5$ is colorless."

The color of garbage-compost changes in solution from light gray to dark brown. This may be due to the increasing number of -CH=CH- groups in its electronic structure during the period of composting. On the other hand the color change from dark gray to light gray observed when composting sludge may be caused by introduction of a -CH_2 group in the unsaturated chain, thus causing some shift of the absorption band.

Carbon-Nitrogen Ratio

Carbon-nitrogen ratio is expressed by dividing the percentage of carbon in the sample by percentage of nitrogen. If this ratio is large (say 100) the C/N is spoken of as wide, whereas if the ratio is 10 it is described as narrow. It has been suggested that a narrow figure indicates that the nitrogen is immediately usable and composting may not be called for. If the ratio is wide, composting is necessary until the ratio is narrowed.⁵

SECTION VI

Instrumentation and Equipment

A series of tests were run on each compost sample. Each of these tests involved the use of a different instrument. Some of the laboratory instruments that were used were the Klett-Summerson photoelectric colorimeter, Beckman Model H-2 pH meter, commercial balances and drying ovens.

A special type calomel cell and platinum electrode were constructed and used with the pH meter for measuring oxidation-reduction potential.

Choice of Instruments

The Klett-Summerson photoelectric colorimeter^{7,8,9} was chosen for use in measuring color change observed during composting. The use of pH, C/N ratio, etc., also have been suggested as good compost yardsticks. However, pH is not so helpful near the final composting stage and C/N ratio is time consuming.

The photoelectric colorimeter is one of the newest improvements in the design of colorimeters. Errors due to the personal characteristics of each observer have been largely eliminated. It is convenient to carry and easy to run even though the observer is a beginner.

Klett-Summerson Colorimeter (Shown in Figure 1).

A schematic diagram of Klett-Summerson photoelectric colorimeter is shown in Figure 2. The light source, in the lamp housing, is a 100-watt tungsten projector lamp. The incident light passes through a lens and a suitable color filter F which is used to transmit light of the proper wave

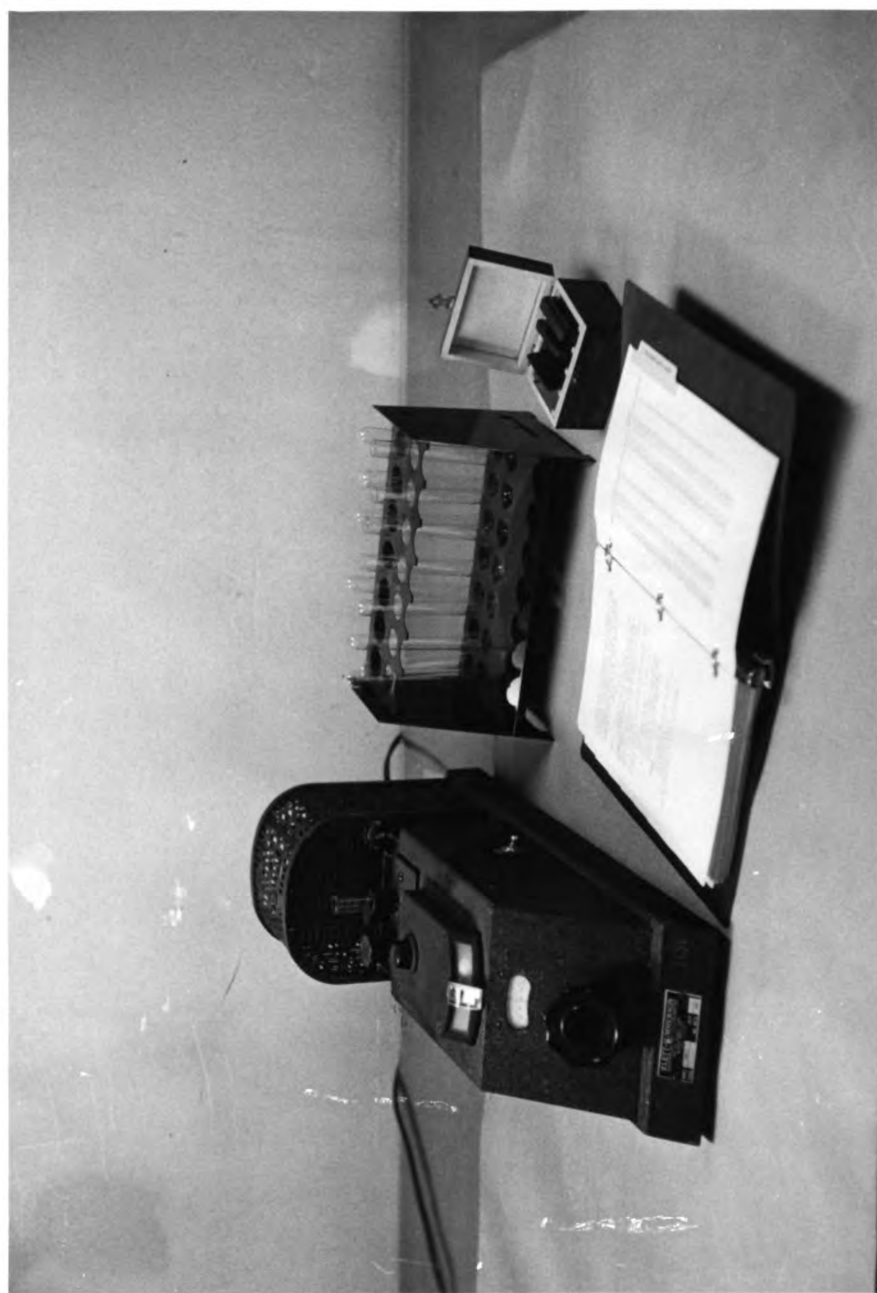


FIGURE 1 Klett-Summerson Photoelectric Colorimeter

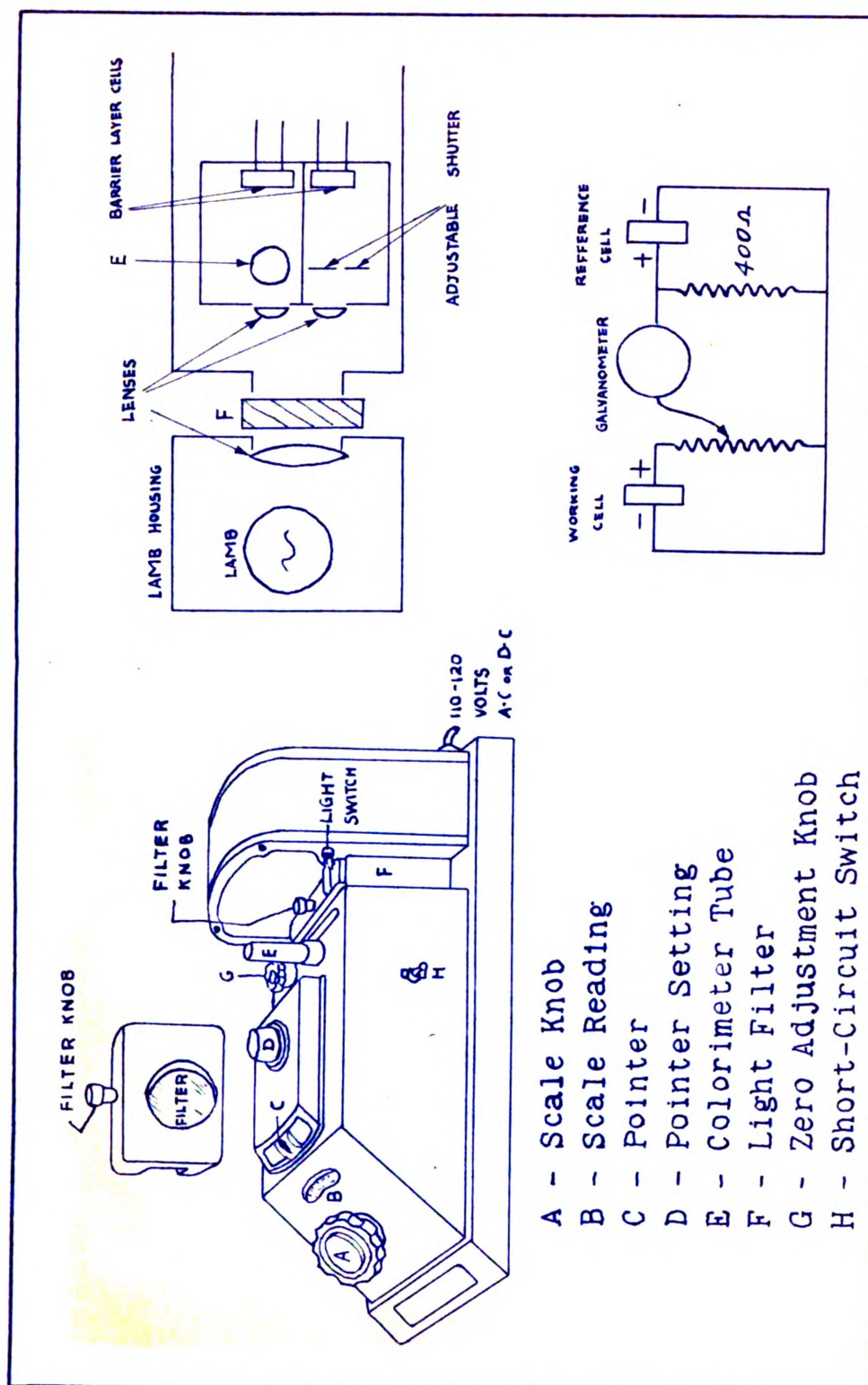


FIGURE 2. A SCHEMATIC DIAGRAM OF KLETT-SUMMERSON PHOTOELECTRIC COLORIMETER .

length range. The light falls upon the solution contained in a colorimeter tube E and the light transmitted through the solution reaches the Barrier layer cells. The generated current is measured on the scale reading B, which is graduated from 0 to 1,000.

The scale B is a most important part of the colorimeter. It has been designed so that the scale reading is directly proportional to the concentration of the substance being determined. The scale reading is a measure of and is proportional to the optical density of the colored solution as determined by the photoelectric cell. Since the optical density is theoretically proportional to the concentration of colored substance (Lambert-Beer's Law) the scale readings are likewise proportional to the concentration under the same conditions.

Other Equipment

1. Kemp Soil Shredder - Figures 3 and 4, shows the installation used in the field composting studies. It includes roughage cutter, industrial type gasoline engine with multiple U-belt drive, and with a mesh basket so constructed that the chopped material can be scattered in a windrow of approximately 20 feet apart from the shredder and distribute it uniformly.

2. Mitts and Merrill Type A Hog Grinder - Figure 5, shows the M. & M. grinder used in the High-rate composting plant at Michigan State College. It includes several knife edges in a running steel cylinder as a roughage cutter, and an electric motor with a common belt drive. The material through the M. & M. grinder is much coarser than that from Ray-Mo grinder.

3. The Ray-Mo Grinder - Figure 6, shows another type of grinder (Ray-Mo) which was much used in windrow composting studies. It consists

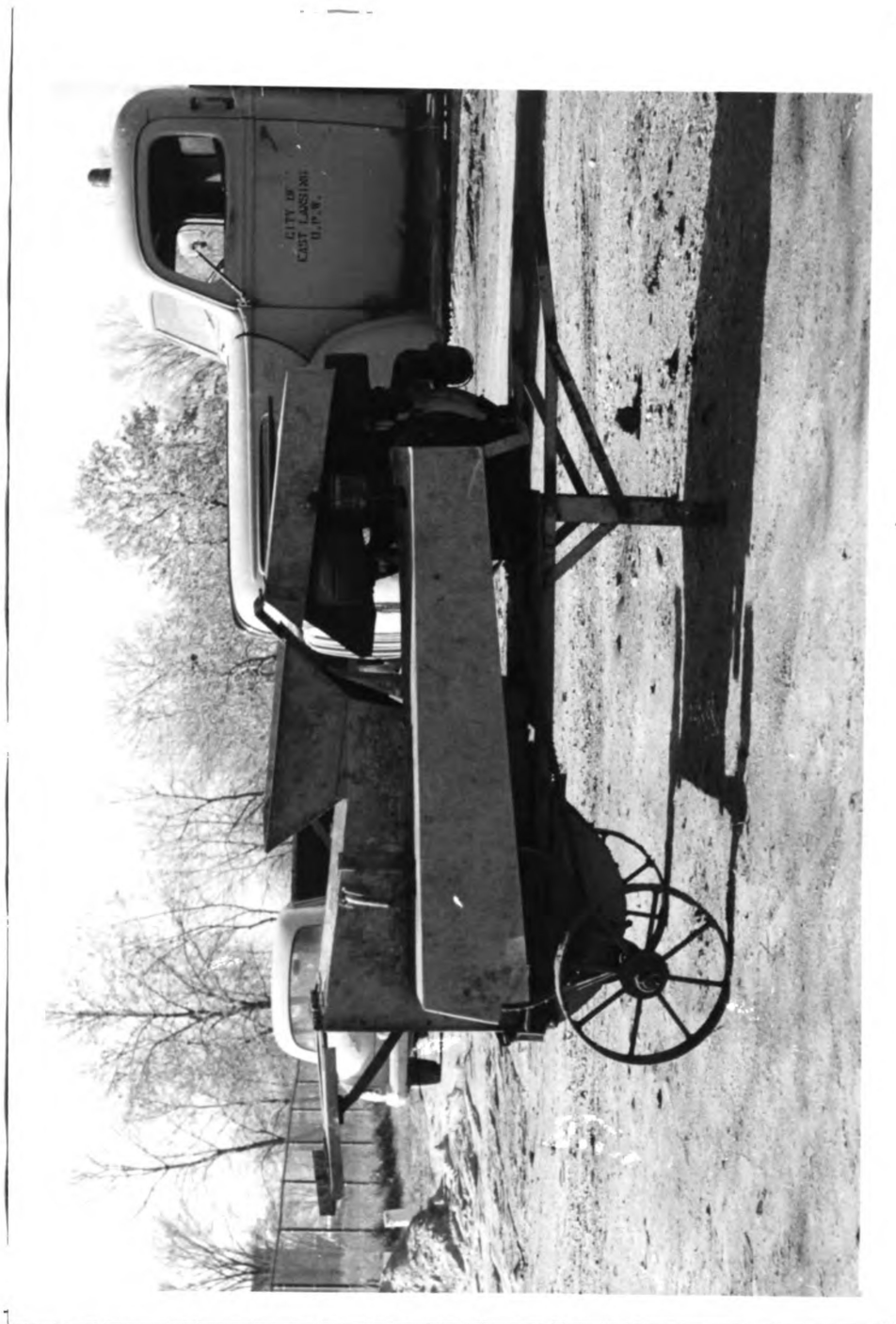


FIGURE 3 Kemp Soil Shredder Used in Windrow Composting Studies

of two screw conveyors, which are used to transmit the raw material to the cutter and the ground material to a truck from the cutter, and the high speed blade cutters which are driven directly by an electric motor. The ground material from the Ray-Mo grinder is much finer than that from the M. & M. grinder and is usually smaller than one-inch size.

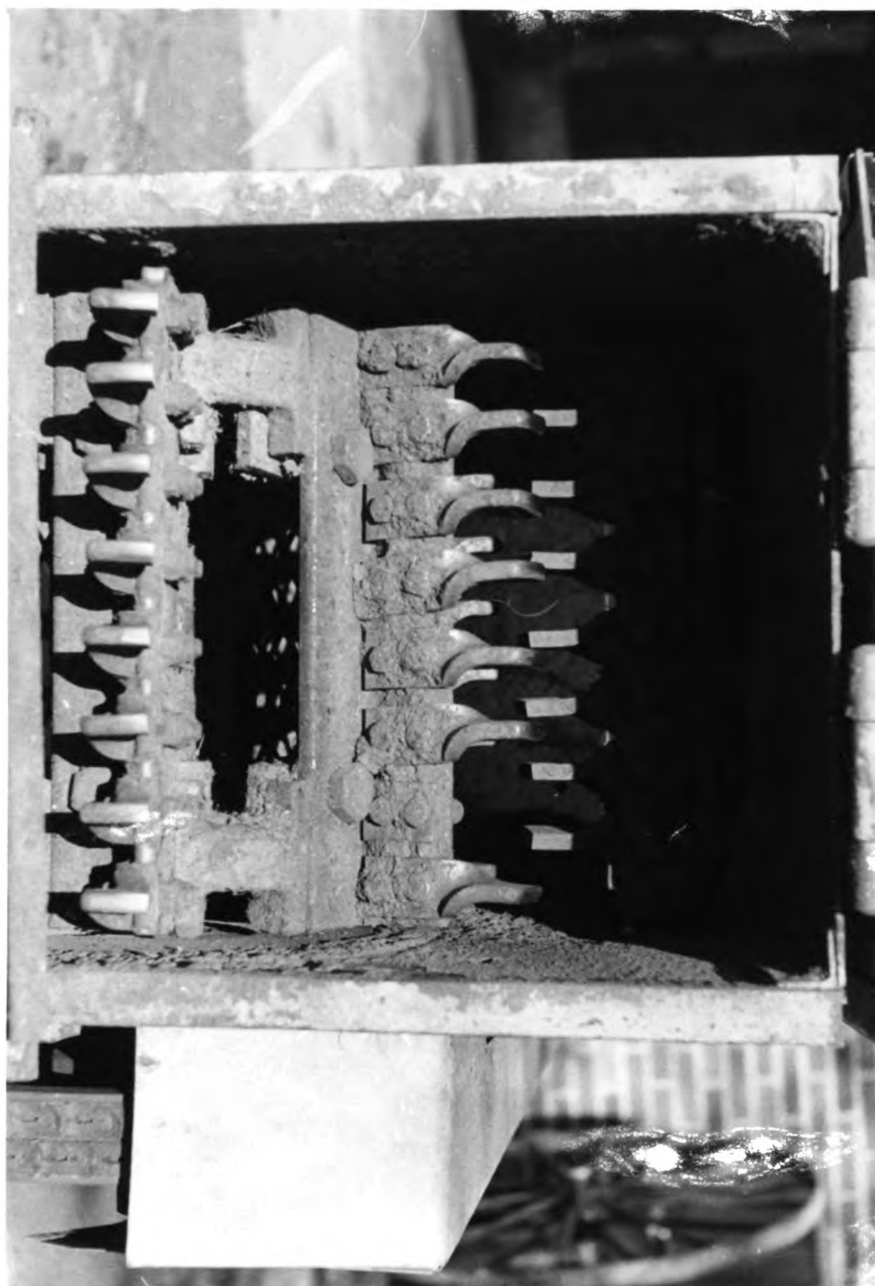


FIGURE 4 Details of Roughage Cutter in Kamp Soil Shredder



FIGURE 5 Mitts and Merrill Type A Hog Grinder Used for Grinding Coarse Material.



FIGURE 6 Ray-Mo Grinder Used for Grinding Fine Material

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SECTION VII

Experimental Procedures and Results

Experiment 1

The first series of tests was preliminary in nature and intended to give information on the effects of temperature changes and to study fly nuisance with composting piles having no treatment other than grinding. Three piles were built during mid-June. The first pile was built with 8,060 pounds of Ray-Mo ground raw garbage shredded together with 700 pounds of end products from the High-rate composting plant. Moisture content of the composted seed material was about 30 per cent. The second pile contained 7,835 pounds of Ray-Mo ground garbage and the third pile 5,625 pounds of unground garbage with high paper content. Each of these piles was shredded once with a Kemp soil shredder at the start and received no further turning. The shape of these piles was trapezoidal in section, 3 feet at top and 5 feet at bottom. The heights were 2 to 3 feet and lengths 12 to 20 feet (as shown in Figure 7). Weather was hot and dry.

The experiment was continued for 25 days until a layer of crust was formed on the surface of each pile. The effect of various environmental conditions on the rate of bacterial population and activity are illustrated by the temperature reached during the first 24 hours, as shown in Table III.

The similar temperature rise (as shown in Figure 8) observed in piles No. 1 and 3, shows that the bacterial population indigenous to garbage was just about as effective as that of the end products from the High-rate plant.



FIGURE 7 A Windrow Pile With 2-3 Feet High and 12-20 Feet Long

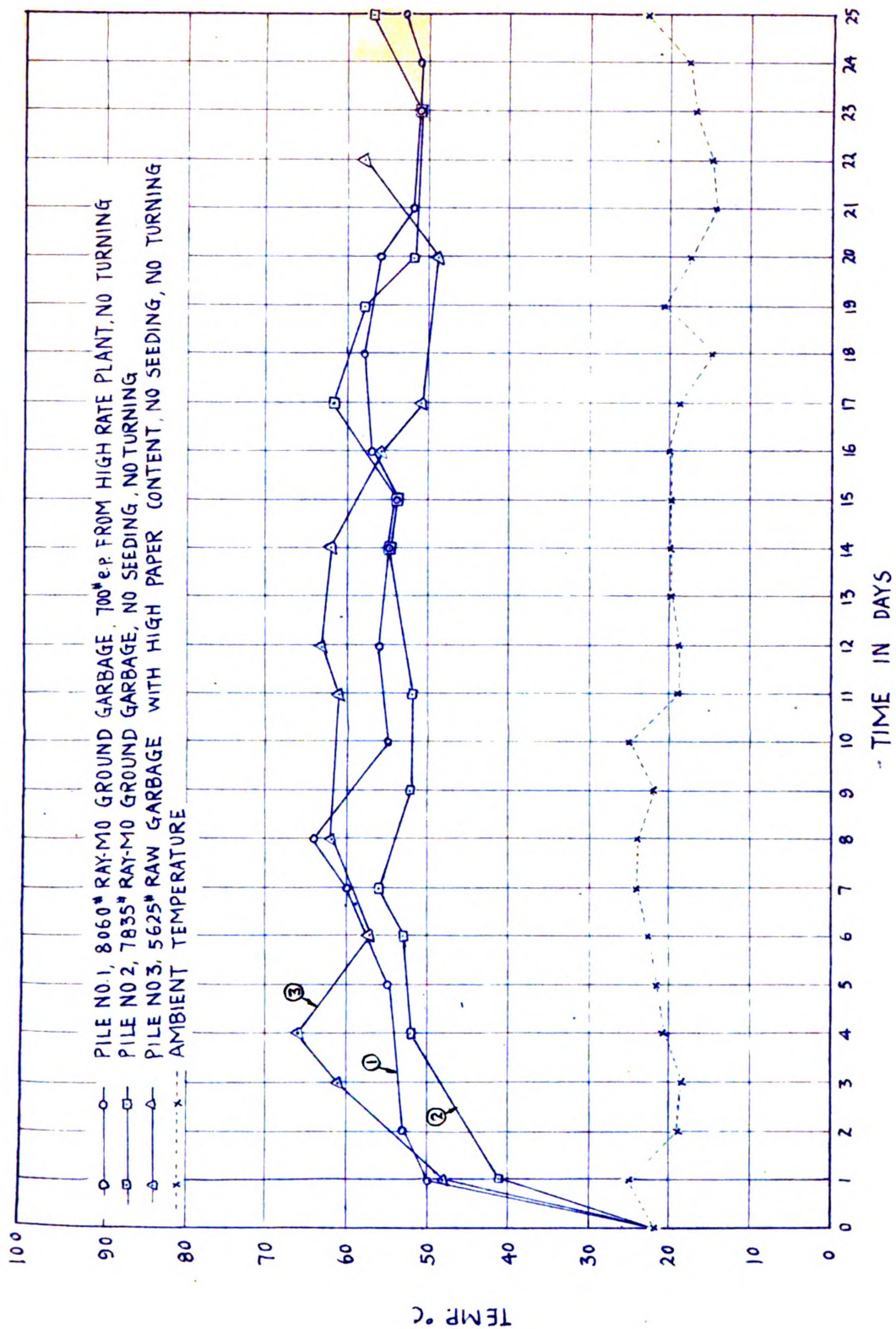


FIGURE 8. THE TEMPERATURE CURVES OF COMPOSTING MATERIAL IN EXPERIMENT 1.

TABLE III

The Rate of Bacterial Activity During the
First 24 Hours. As Shown by Temperature.

Pile No.	Material	Treatment	Ambient Air Temperature, °C	Temperature of Compost, °C
1.	8,060# Ray-Mo ground raw garbage; 700# e.p.* with 30% moisture.	Shredded with Kemp shredder at start; no turning.	26	50
2.	7,835# Ray-Mo ground raw garbage.	" "	26	41
3.	5,625# raw garbage with high paper content.	" "	26	48

*e.p. = end product

The material in pile No. 2 showed a somewhat smaller rise in temperature, probably because the voids were largely sealed by the moisture which was much higher than Piles No. 1 and 3.

During the first three days, Pile No. 3 proved attractive to birds because of its undecomposed food materials. After three days, a foul odor together with considerable larvae was observed in all these three piles. On the fifth day, about half of the larvae were dead in Pile No. 3, and the balance were still active near the pile or immediately below the surface of the pile. The same conditions existed on the sixth day in Pile No. 2 and the seventh day in Pile No. 1. Several fly traps were constructed for trapping flies emerging from pile or ground, using 4-inch tin cans, with top and bottom cut away, and 20-mesh screen welded to one end. These were placed around each pile on the fifth day. From the tenth day on, flies were trapped continuously until the twentieth day.

At the close of the experiment on the twenty-sixth day, no satisfactory degree of decomposition was apparent. In the top four inches of each pile

a pleasant earthy odor was apparent, while an unpleasant putrefaction odor existed in the center.

Three and a half months later, the piles were examined after a heavy rain. Piles No. 1 and 2 recovered with temperature readings of approximately 42°C; in contrast, Pile No. 3 showed no recovery of temperature and appeared to be a good compost. This indicated decomposition of Pile No. 3 far advanced to that observed in Pile No. 1 and No. 2. The increased decomposition was probably due to the high paper content and the type of grinding giving more porosity to the pile and allowing good aeration through its structure.

The experiment demonstrated that:

1. Without turning, a better decomposition can be obtained by composting coarser material due to the increased porosity of the pile.
2. A windrow composting pile without further treatment may cause odor and fly nuisance during the composting period.
3. Unturned piles require a longer time for decomposition.
4. Seeding of such piles is of little value.
5. Larvae are killed at temperatures around 60°C.*
6. The highest temperatures are reached in the top 4-inch layer of these unturned piles.

Experiment 2

The second experiment was designed to study the effect of aeration by turning the pile every third day. One pile was prepared by shredding 6,600 pounds of Ray-Mo ground garbage into a windrow. This was turned four times during the composting period. The pile was a 3-foot by 5-foot trapezoid, 12 feet long and 3 feet high. A maximum temperature of 67°C in the top

*52°C was reported by "New Zealand Engineering", Vol. 6, Nos. 11-12.

four inches was reached on the sixth day. After the sixth day temperatures dropped gradually to 25°C until, on the eighteenth day, a finished compost was produced. The temperature curve is shown in Figure 9.

No larvae appeared during the experiment and no flies emerged from ground into the traps placed around the pile.

Figure 9 also contains a plot of pH versus time. The pH drop in the two-inch layer on the ninth day was probably due to some relatively undecomposed materials which were moved to the top layer by shredding.

The moisture content on top and bottom layers of the pile had a difference of 32 per cent as shown in Figure 10. The effect of turning every third day had little influence on the moisture drop to the bottom layer of the pile.

Experiment 2 showed that:

1. Turning the pile every third day eliminates foul odors and fly nuisance.
2. Eighteen days is required for composting when turning every third day under suitable environmental conditions.
3. High temperatures at 8-inch depth indicate that good aeration can be obtained by turning every third day.
4. A declining temperature below 40°C, a pH higher than 7.0, a moisture content less than 55 per cent, and a well composted material with a good earthy odor may be expected after eighteen days.

Experiment 3

In order to determine the relative importance of seeding and turning in producing a shorter composting period than in Experiment 2, another pile in windrow shape was prepared for study. 4,100 pounds of Ray-Mo ground raw

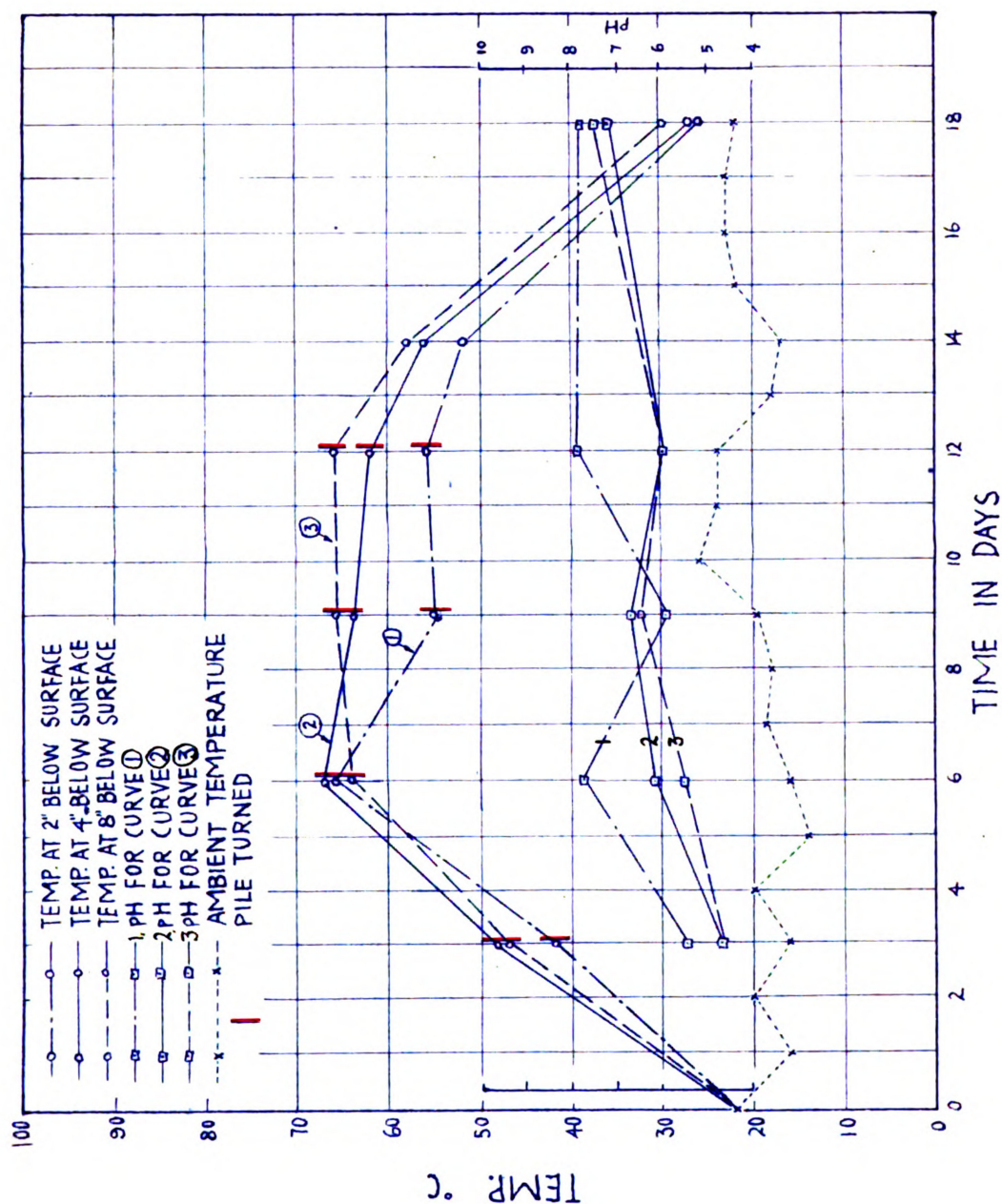


FIGURE 9. THE EFFECT OF TURNING EVERY THIRD DAY ON THE TEMPERATURE OF COMPOSTING MATERIAL.

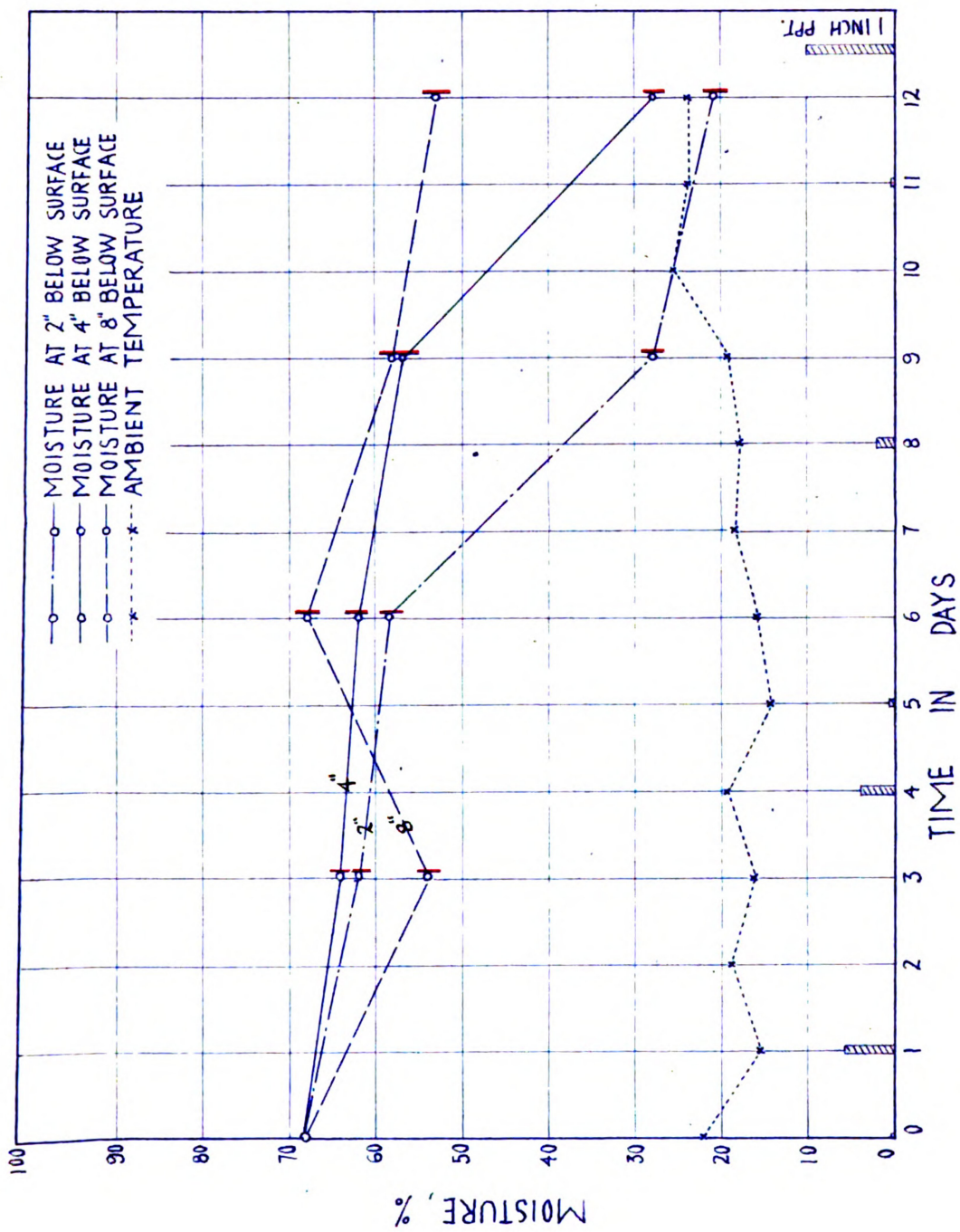


FIGURE 10. THE EFFECT OF TURNING EVERY THIRD DAY ON THE MOISTURE OF COMPOSTING MATERIAL.

garbage and 2,000 pounds of end products from Experiment 2 were shredded together. The pile was aerated with the Kemp shredder every day.

The per cent moisture of raw garbage dropped from 72.6 to 61 when mixed with the end product. pH dropped from 4.9 to 4.8 with a per cent ash rise from 10.8 to 18.1.

The initial moisture of the pile was relatively low and dropped rapidly by daily turning. This moisture drop reduced the level below that required for good composting. Turning of the pile was discontinued after the tenth day to prevent further moisture loss. Composting period of the pile was fourteen days.

More extensive tests were made with Experiment 3 than previously; new tests were percentage of ash, Oxidation-Reduction Potential, and percentage of color transmittance. Procedures for these tests are listed in Appendix.

The temperature curve (as shown in Figure 11) for the 4-inch depth rose gradually from 35°C to 64°C on the eighth day, and then declined to 38°C on the fourteenth day. On the basis of temperature, the compost was considered to be finished with a declining temperature around 40°C.

Figure 12 represents a plotting of per cent moisture versus time. This curve shows why it was necessary to stop turning the pile on the tenth day. The per cent moisture on the ninth day had dropped to 32. This value was considered a lower limit for bacterial metabolism. A one-quarter inch moisture penetration was observed after a rain of 0.44 on the eighth day. This indicates that rainfall had little influence on the moisture content of the pile.

The ash curve as shown in Figure 13 is almost meaningless. It was found difficult to collect a representative sample free of sand or grass

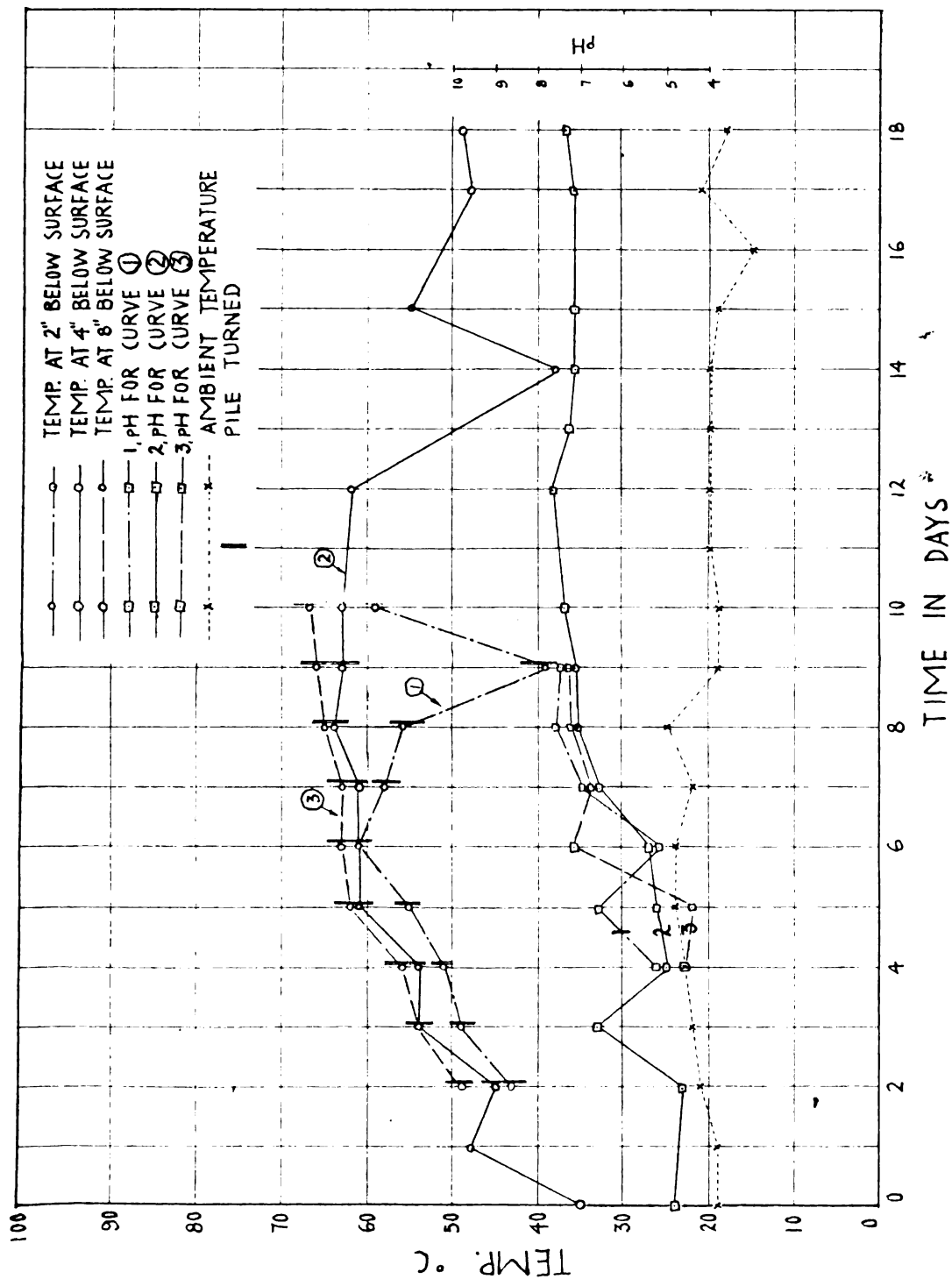


FIGURE 11. THE EFFECT OF TURNING EVERYDAY ON THE TEMPERATURE OF COMPOSTING MATERIAL IN EXPERIMENT 3.

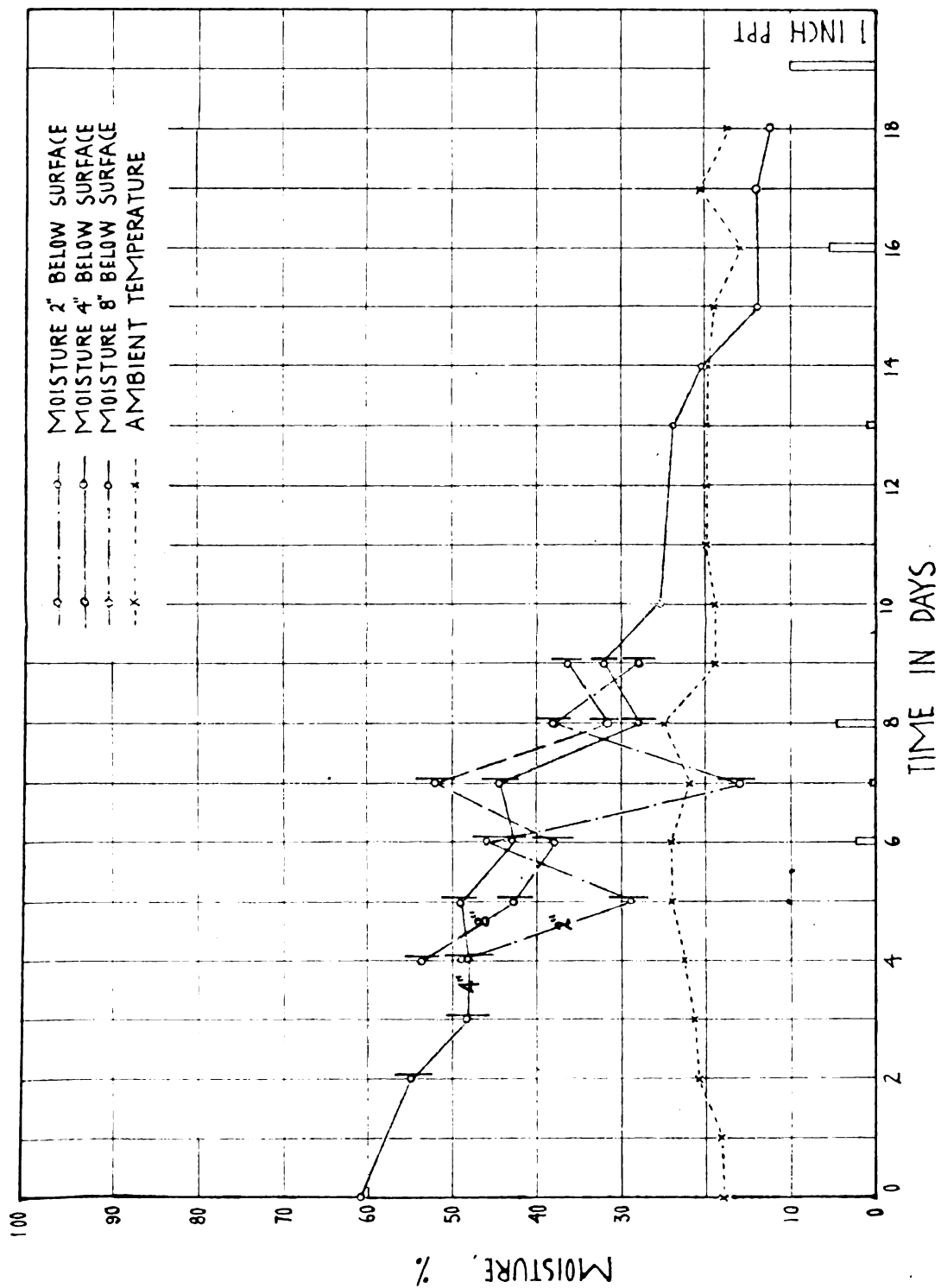


FIGURE 12. THE MOISTURE CURVE OF COMPOSTING MATERIAL IN EXPERIMENT 3.

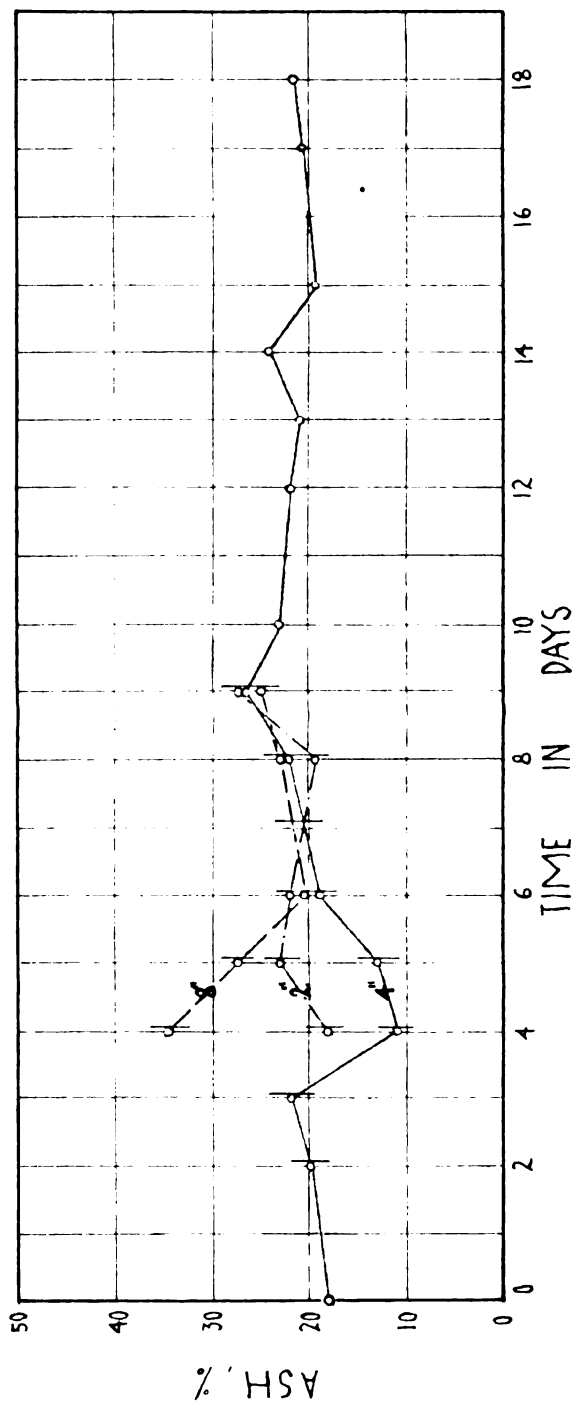
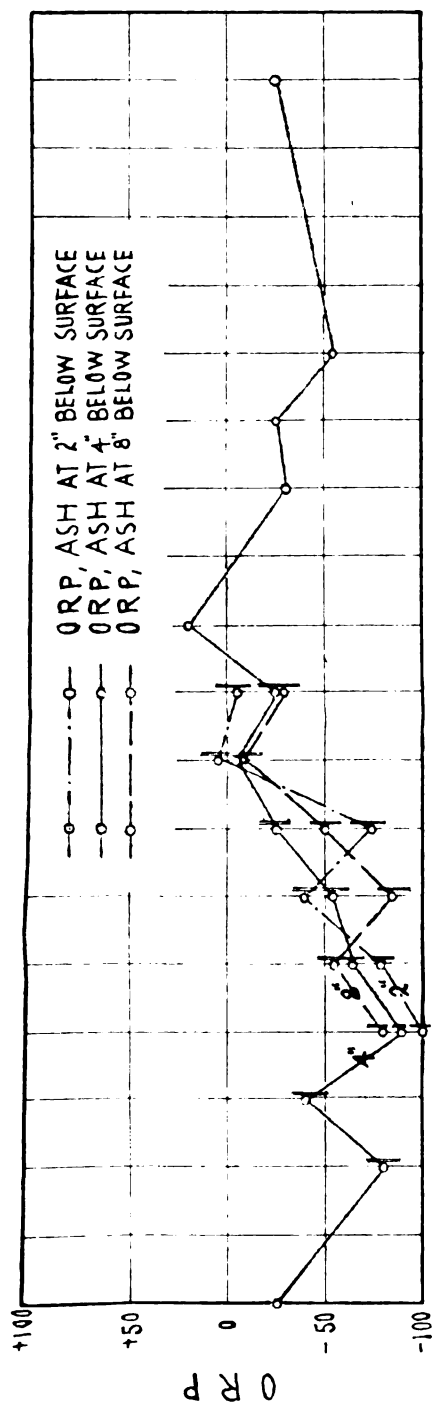


FIGURE 13. THE ASH CURVE OF COMPOSTING MATERIAL IN EXPERIMENT 3.

FIGURE 14. THE ORP CURVE OF COMPOSTING MATERIAL IN EXPERIMENT 3.

picked up from the sandy soil during turning. The ash test was therefore omitted in the latter experiments.

Figure 11 also shows the pH curve for this experiment. The initial pH of 4.8, dropped slightly on the second day, and then rose gradually to a figure between 7.0 and 8.0 when composting was finished. This appears to be a typical composting pH curve. Molds and actinomycetes were found in the pile during the final stage when pH was high.

The Oxidation-Reduction Potential (abbreviated as ORP) curve shown in Figure 14 appeared to be a good indicator for pile turning. During this period of turning from the first to tenth day the curve rose gradually to a value of -225 millivolts. When turning was stopped on the tenth day, the curve dropped to -300 millivolts on the fourteenth day. Although another rising value -270 millivolts were observed at the seventeenth day, it is probably due to the influence of moisture loss and consequently the pile got more aerated.

The initial and final percentages of color transmittance of 4-inch samples are shown in Table IV.

TABLE IV

Initial and Final Percentage of Transmittance
with Different Filters in Experiment 3

Filter Used	Initial	Final
Without Filter	94	52
Red Filter	79	48
Green Filter	65	17
Blue Filter	31	1

For best results with the photoelectric colorimeter it was found important that the proper light filter be used. Results indicate that the green filter is most suitable for garbage compost. This filter covers

not only the colored solution of red, yellow, purple, orange and blue⁷, but the transmittance curve changes distinctly according to each composting period. This change in transmittance is also noted with the blue filter during early stages of composting but little change is noted in later stages. For this reason the green filter is preferred.

From the curve obtained with the green filter (as shown in Figure 15), it appears that the percentage of transmittance changes from an initial reading of 65-90 to a final reading of around 20.

It was concluded from Experiment 3 that:

1. When moisture content is satisfactory aeration by daily turning appears to produce good compost within a shorter period than when turned every third day.
2. Ash is not a good indicator of windrow compost on sandy soil bround.
3. ORP may be a good yardstick for composting and should be investigated in the future research.
4. A declining temperature below 50°C and a percentage transmittance drop to about 20, with a green filter, may be a good yardstick for judging the condition of a garbage composting pile.
5. Heavy seeding dropped the initial moisture content to 60 per cent. This moisture content was found too low to be suitable for continuous every day turning. The experiment required eighteen days because of low moisture content.

Experiment 4

Experiment 4 was set up to test the effect of seeding and re-seeding, with or without turning. A series of three piles were prepared as outlined in Table V.

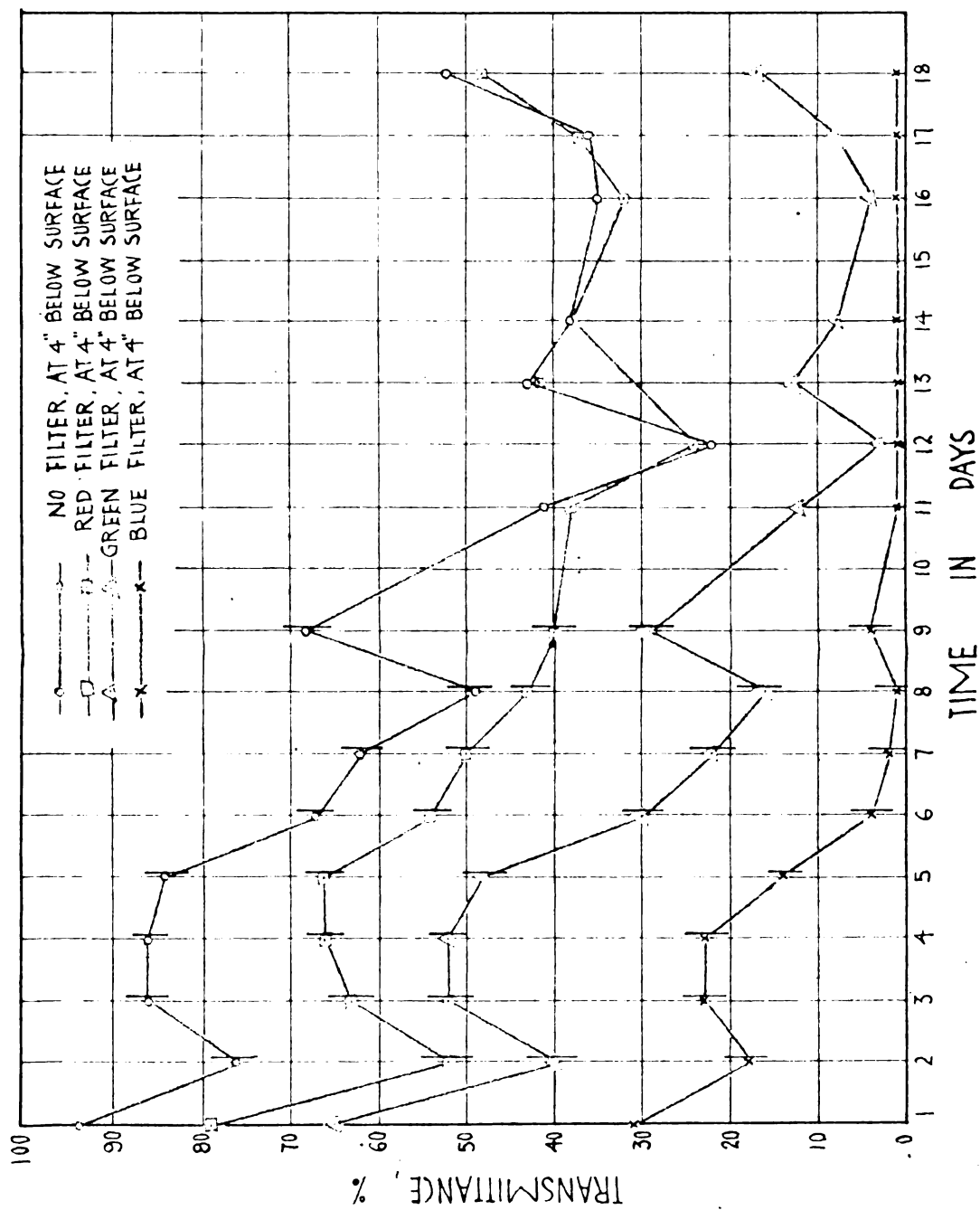


FIGURE 15. THE COLOR TRANSMITTANCE CURVE OF COMPOSTING MATERIAL IN EXPERIMENT 3.

TABLE V

Summary of Methods of Treatment
and Material Used in Experiment 4

Pile No.	Material	Treatment
1.	1933# Ray-Mo Ground Raw Garbage	25% Seeding with e.p. from Experiment 3, turned every day with shredder.
2.	" " "	25% Seeding with e.p. from Experiment 3, 25% re-seeding on the 4th day with the same e.p., turned every day with shredder.
3.	" " "	25% Seeding with e.p. from Experiment 3, turned 4 times in 4 days, turning stopped on 5th day.

The experiment was continued for nine days, although at the end of this period the piles were still warm.

The similar temperature rise and fall and similar color transmittance in Pile No. 1 and 2 showed that seeding and re-seeding had very little, if any, effect on the time necessary to obtain a good end product when the piles were turned daily. Pile No. 3, with the discontinuance of turning after the fifth day, was not as well decomposed as the other two during the same composting period. The initial and final analysis of material composted in Experiment 4 was shown in Table VI.

TABLE VI

Initial and Final Analysis of Material Composted in Experiment 4

File No.	Initial						Final					
	Temp. °C.		% Moisture*		pH		% Transmittance		Temp. °C.		% Moisture	
	4in.	8in.	4in.	8in.	4in.	8in.	4in.	8in.	4in.	8in.	4in.	8in.
1.	28	28	62	62	4.7	4.7	70	70	59	65	32	35
2.	28	28	62	62	4.7	4.7	70	70	59	65	31	29
3.	28	28	62	62	4.7	4.7	70	70	59	65	43	57
											7.7	5.2
											29	52

*The moistures were 68% immediately before 25% seeding.

The pH of the 8-inch sample of Pile No. 3 was 5.2 after nine days, indicating that the bottom layer still remained partly composted. The other two piles, which were turned daily, had the same final pH values and the material appeared to be well composted even though the temperatures were still high. The pH curve is shown in Figure 16.

Figure 17 shows the moisture change of these three piles. Re-seeding caused a one per cent moisture drop at four inches and a six per cent drop at six inches for Pile No. 2 as compared with Pile No. 1. The discontinuance of turning of Pile No. 3 resulted in a higher moisture content than for the other two piles.

Curves shown in Figure 18 represent the change in color transmittance when using a green filter for 2-, 4- and 8-inch depths in Piles 1, 2 and 3. These curves showed a drop from a value of 70 per cent transmittance to around 10 per cent near the point of completed product. A reversal of this trend and rise to about 20 per cent transmittance is noted during the final drop of composting. The per cent transmittance of 8-inch final sample in Pile No. 3 was 52, a figure still far from composted.

Experiment 4 indicated that:

1. Seeding and re-seeding may not be an essential part of a practical process for composting garbage.
2. Discontinuance of turning the pile delayed the composting period on the bottom layer which was not properly aerated.
3. Color transmittance curves further indicated that this test is a good indicator of degree of composting.
4. Turning the pile every day reduced the composting time of those piles to nine days.

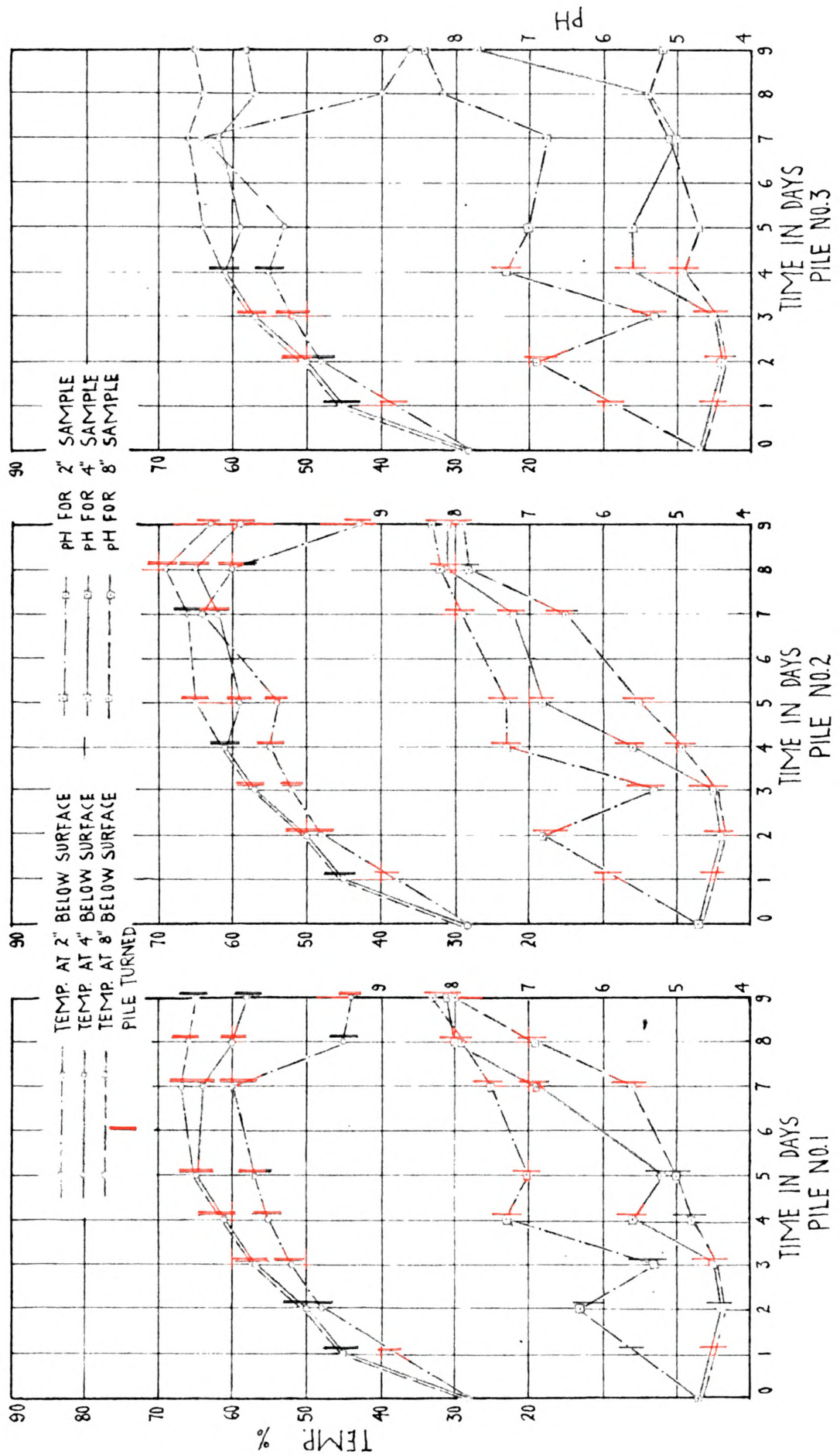


FIGURE 16. pH AND TEMPERATURE CURVES OF COMPOSTING MATERIAL IN EXPERIMENT 4.

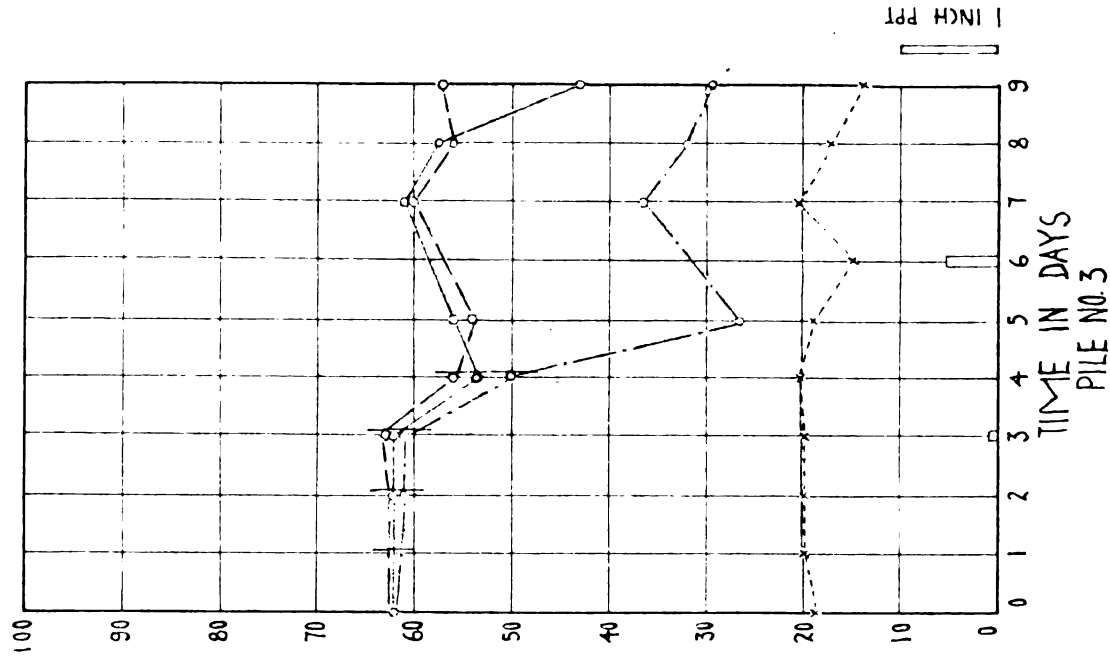
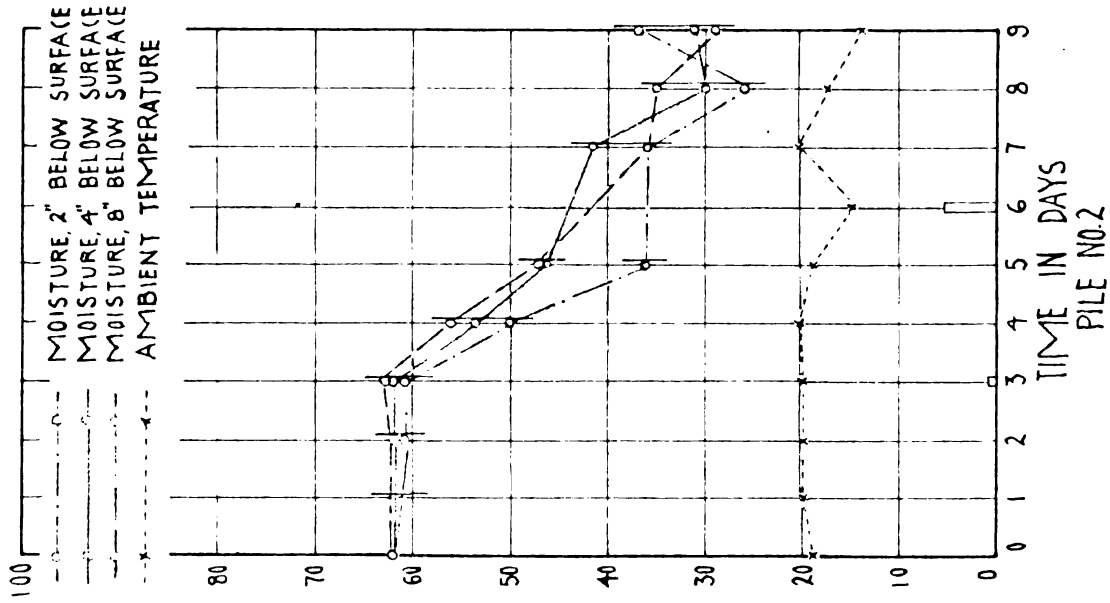
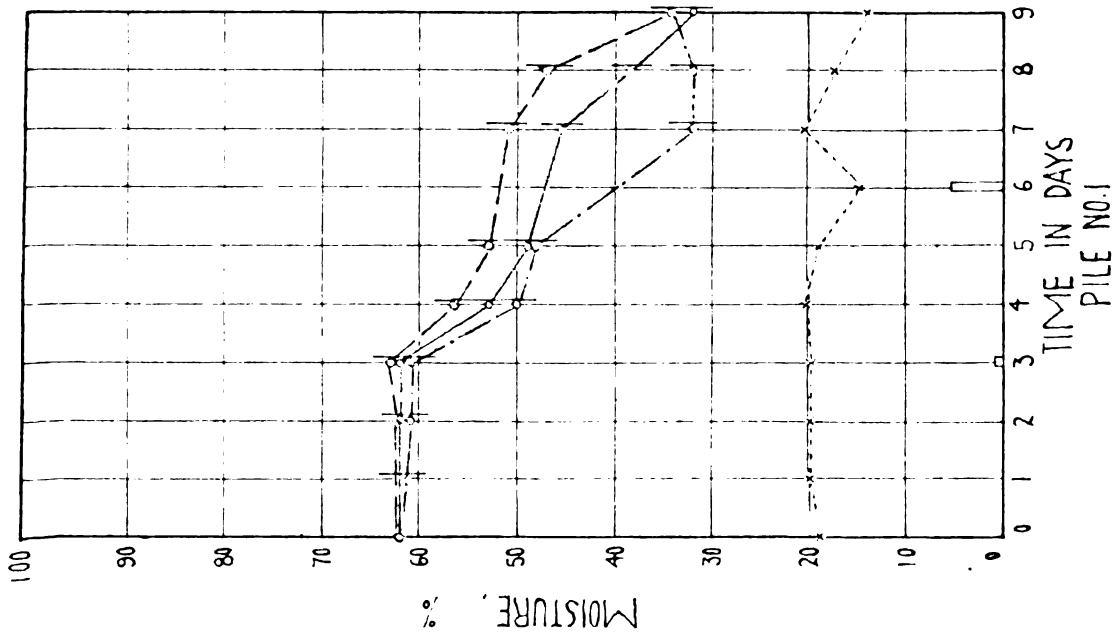


FIGURE 17.

MOISTURE CURVES OF COMPOSTING MATERIAL IN EXPERIMENT 4.

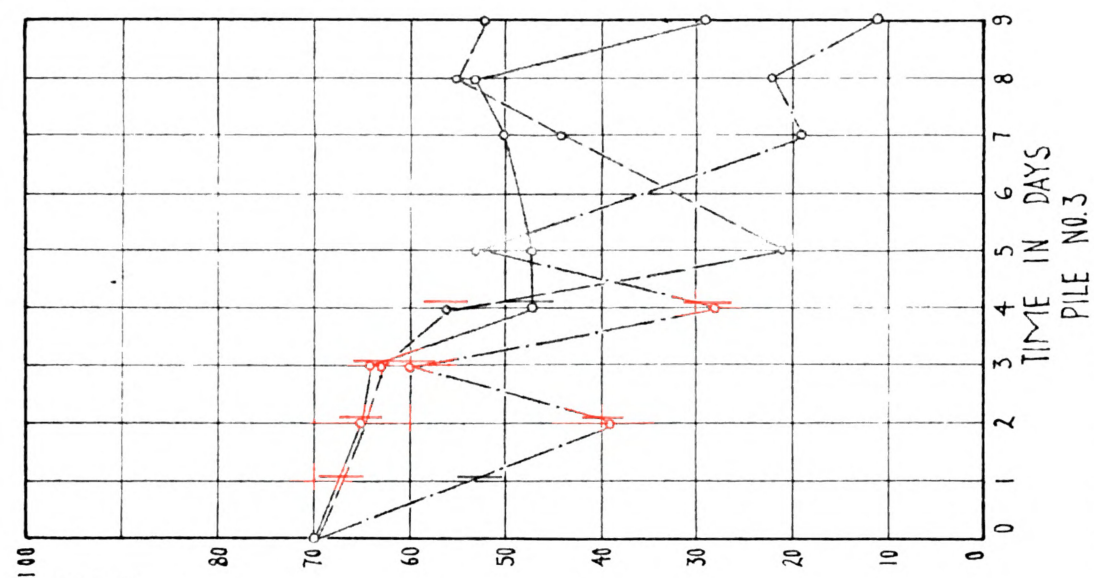
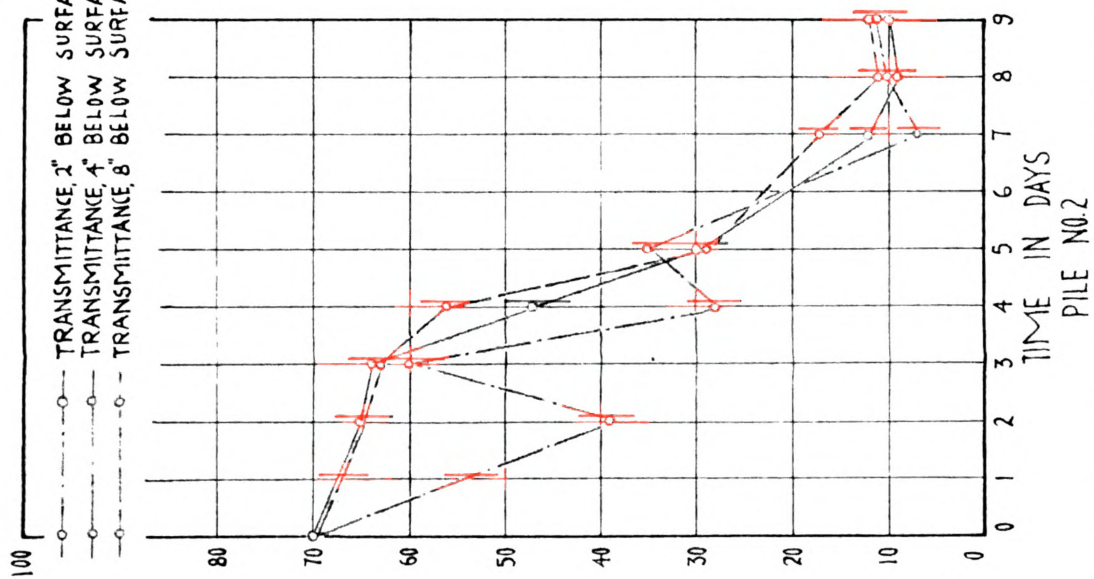
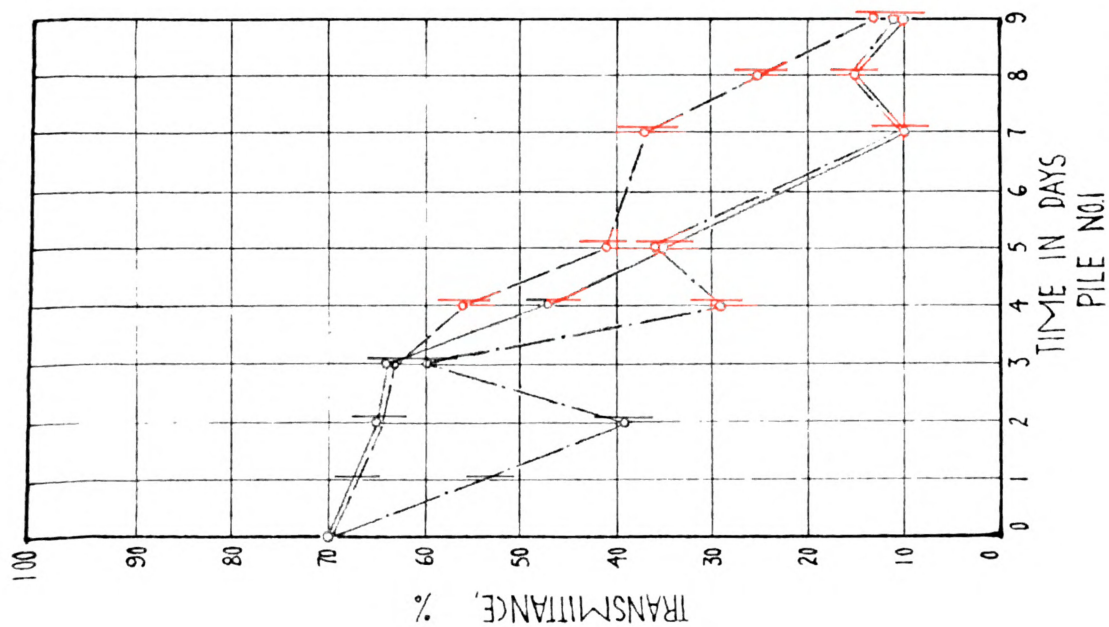


FIGURE 18. GREEN FILTER TRANSMITTANCE CURVES OF COMPOSTING MATERIAL IN EXPERIMENT 4.

Experiment 5

Experiment 5 was designed to determine the influence of particle size and to further study the effect of turning on garbage composting. During this experiment piles were turned every two days. Methods of treatment are listed in Table VII.

TABLE VII

Summary of Methods of Treatment
and Material Used in Experiment 5

File No.	Material	Treatment
1.	1,050# Ray-Mo fine ground raw garbage, 38# e.p. from High-rate plant.	10% seeding. Turned every 2 days with shredder.
2.	1,000# Ray-Mo fine ground raw garbage, 38# e.p. from Experiment 4.	10% seeding. Turned every 2 days with fork.
3.	900# M. & M. coarse ground raw garbage, 38# e.p. from High-rate plant.	10% seeding. Turned every 2 days with shredder.

Temperature rise and fall of these piles is shown in Table VIII and Figure 19.

TABLE VIII

A Comparison of Temperature Change in Experiment 5

File No.	Initial Temp.	High Temperature Reached and Date	Low Temperature Reached and Date	Physical Conditions
1.	32°C	4in. 69°C, 6th day	4in. 13°C, 31st day	Fine material turned with shredder. Heat built up slowly and lost slowly.
		8in. 71°C, 8th day	8in. 13°C, 31st day	
2.	20°C	4in. 72°C, 7th day	4in. 6°C, 14th day	Fine material turned with fork, with resulting $\frac{1}{2}$ inch balls. Heat built up slowly, lost quickly.
		8in. 72°C, 7th day	8in. 6°C, 14th day	
3.	36°C	4in. 70°C, 6th day	4in. 16°C, 29th day	Coarse material turned with shredder. Heat built up quickly and lost quickly.
		8in. 73°C, 6th day	8in. 20°C, 29th day	

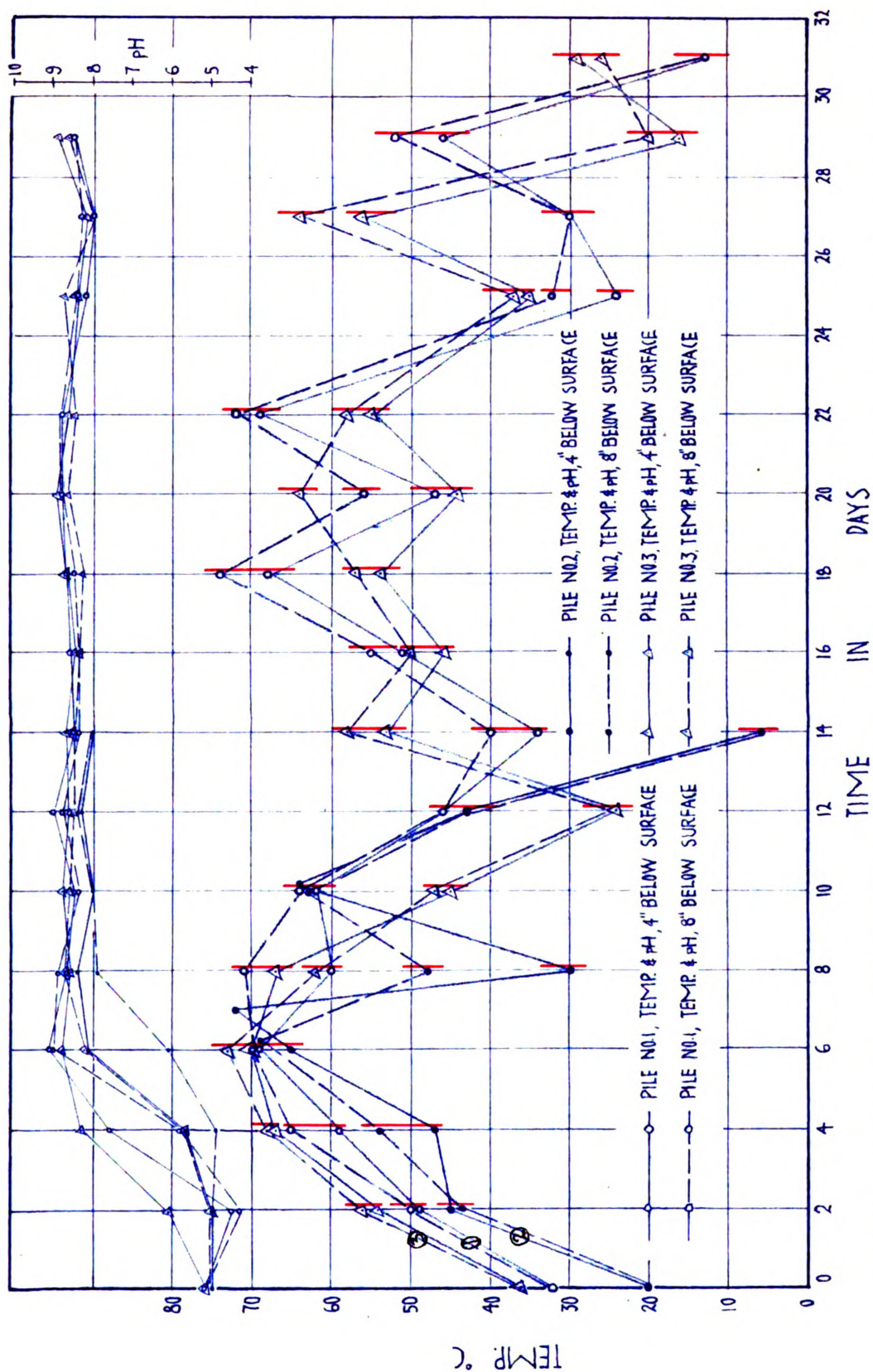


FIGURE 19. EFFECT OF TURNING EVERY SECOND DAY ON THE TEMPERATURE AND pH OF COMPOSTING MATERIAL IN EXPERIMENT 5.

The rapid drop of moisture influenced the temperature drop of Piles No. 1 and 3, as shown in Figure 20. The temperatures of these unfinished piles built up again when moisture content was restored by heavy rains. Such results account for the thirty-one days required to complete the composting process, a longer period than that required for 3-day turning.

Pile No. 3 was turned with a fork and not too thoroughly aerated, as evidenced by foul odors and a fresh color at the bottom of the pile before the third turning. Half-inch balls gradually formed as a result of the fork turning. A rapid temperature rise was first observed, but this rise was followed by a rapid loss in temperature because of a lack of insulation.

One advantage of this kind of pile, unshredded, was the capacity to absorb moisture from rainfall and in this way to maintain a higher moisture content during the composting period. The disadvantages are:

1. Quick loss of moisture content if no precipitation occurred during the composting period.
2. The centers of the half-inch balls not completely decomposed.
3. An anaerobic decomposition existed at the beginning, accompanied with foul odor and slow composting.

The initial 4-inch pH of Pile No. 1 was 5.2. This dropped to 4.5 and then rose to 9.1 just before the third turning. A similar condition was observed in Piles No. 2 and 3, which had little initial pH drop, if any. Piles 2 and 3 did not follow the typical pH curve as previously established. The pH curves of this experiment are also shown in Figure 19.

The percentage of green filter color transmittance is shown in Figure 21. This indicates that the raw material of Piles No. 1 and 3

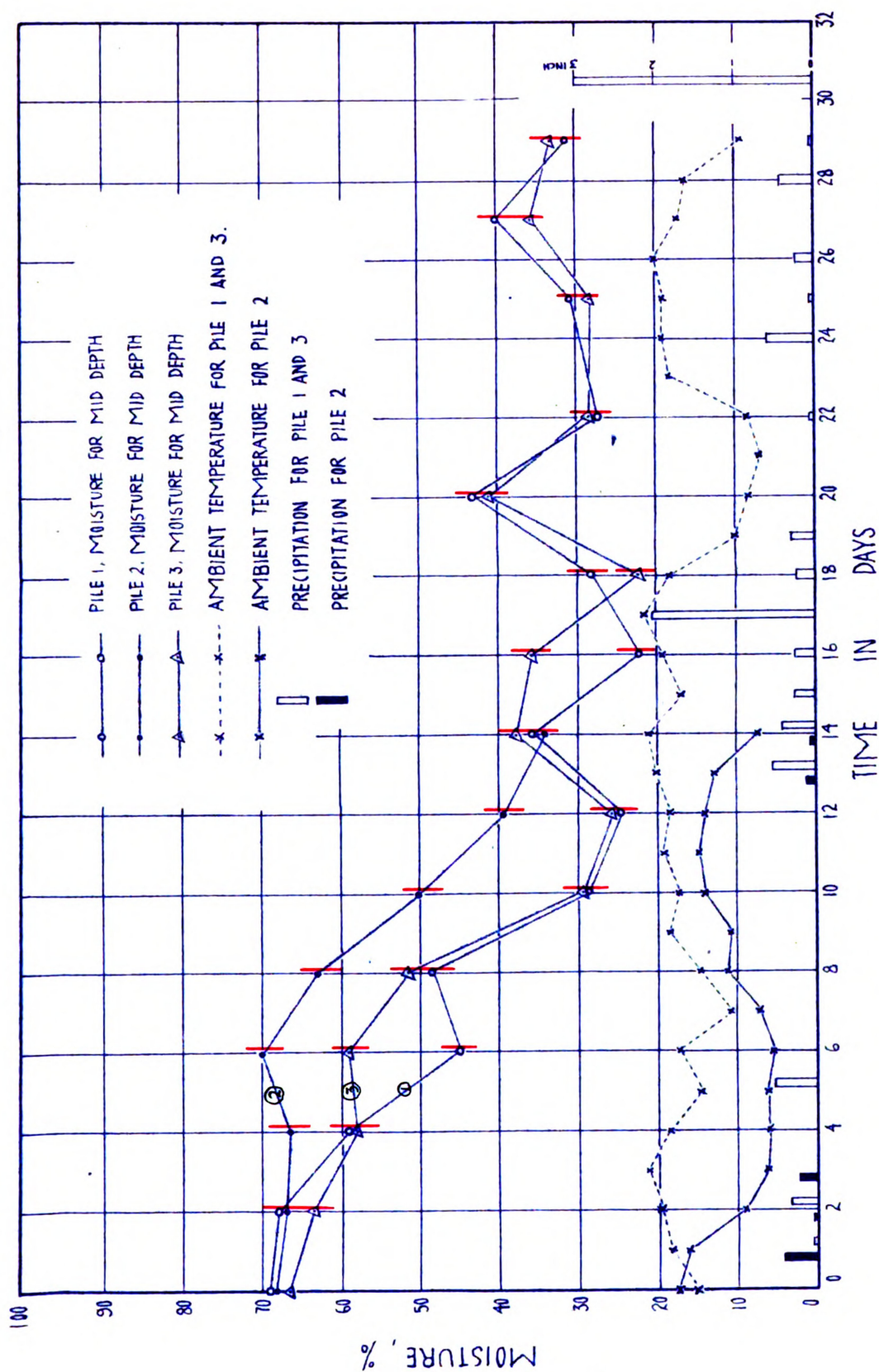


FIGURE 20. MOISTURE CURVES FOR MID DEPTH OF COMPOSTING MATERIAL IN EXPERIMENT 5.

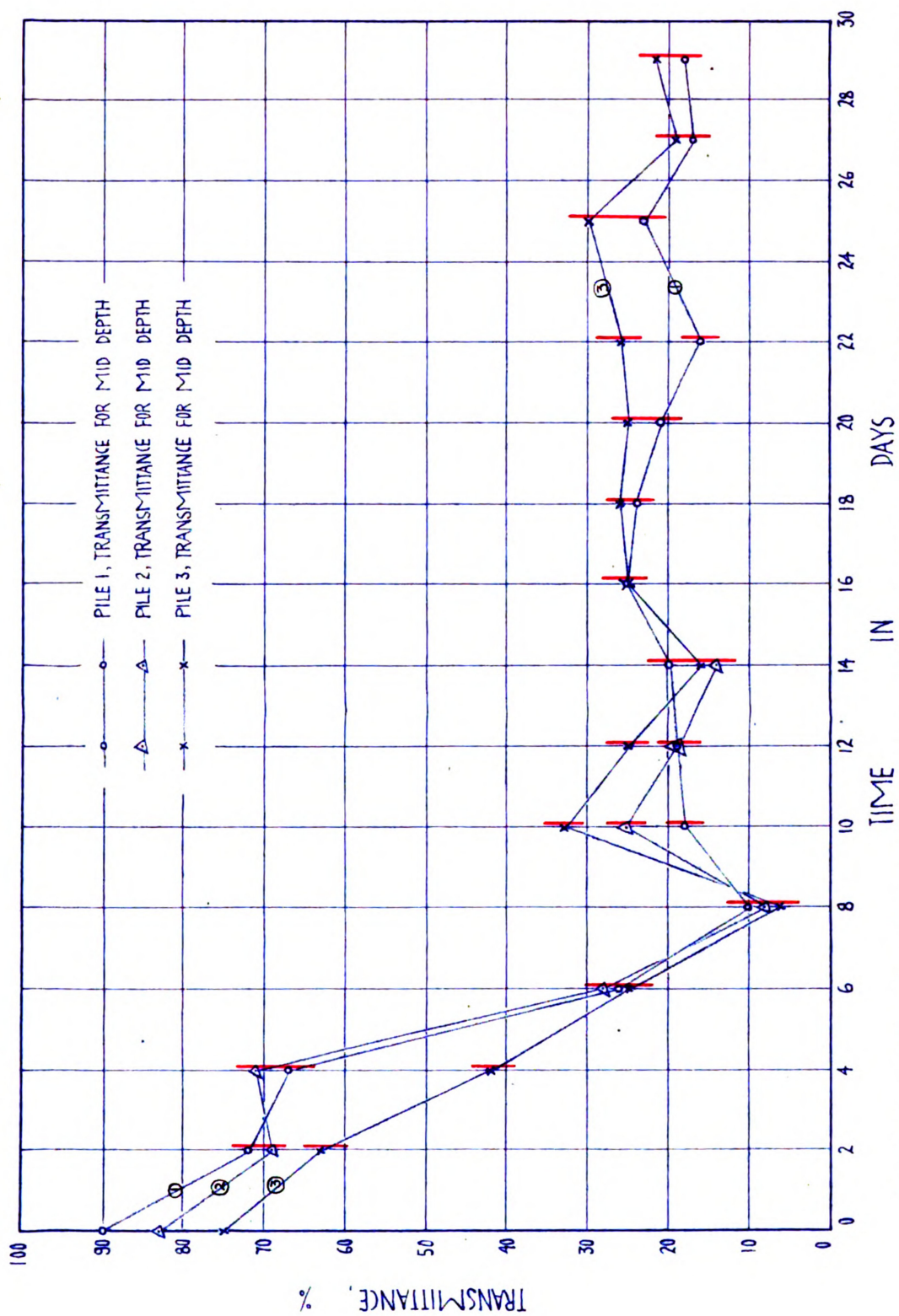


FIGURE 21. GREEN FILTER COLOR TRANSMITTANCE FOR MID DEPTH OF COMPOSTING MATERIAL IN EXPERIMENT 5.

started at 90 per cent and finished at about 20 per cent. Pile No. 2 started from 83 per cent and ended at 14 per cent. This suggested that Pile No. 2 still needed additional curing time.

The initial percentage color transmittance appears to change with the quantity of seeding and with the time of storage before the piles were started. Seeding with large amounts of end product dropped the transmittance because the end products have a low transmittance naturally. The garbage decomposed biologically during storage time, with resulting change in transmittance.

Experiment 5 indicated:

1. With high moisture content during the initial period, coarse material appeared to be more suitable for composting than finely ground material. This is probably because the coarse material has better structural strength and more voids in contact with the air than fine material.
2. The fine material seemed to be more suitable for final stage composting because the fine material has relatively larger surface area in contact with air than coarser material.
3. Half-inch balls were formed by fork turning. Such piles were more readily influenced by outside conditions. Rainfall penetrated the pile from top to bottom during a rainy period; wind and sunshine reduced moisture rapidly, and a loss of heat was common due to poor insulation. Anaerobic decomposition existed near the center of the balls, accompanied by a foul odor and less complete composting.

Experiment 6

Experiment 6 was designed to study the composting of raw sludge

cake. Two tons of raw primary sludge vacuum filter cake* were secured for study from the Saginaw, Michigan, sewage treatment plant. The material and methods of treatment used in each pile is listed in Table IX.

TABLE IX

Summary of Methods of Treatment
and Material Used in Experiment 6

Pile No.	Material	Treatment
1.	500# raw sludge cake, 2,000# raw garbage, 150# partially composted garbage.	Turned every day with shredder.
2.	1,500# raw sludge cake, 700# raw garbage, 150# partially composted garbage.	" " "
3.	2,000# raw sludge cake, 150# partially composted garbage.	" " "
4.	2,700# raw garbage, 150# partially composted garbage.	" " "

Temperature changes during the first day varied over a wide range in the three piles. The highest temperature was 62°C in Pile No. 1 and the lowest was 24°C in Pile No. 3. This last temperature was the same as the ambient temperature on that day, as shown in Figure 22. The slow rise in temperature of Pile No. 3 in the first day was doubtless due to the sticky nature of the sludge cake. Pile No. 3 was very wet and practically voidless after shredding. By the end of the second day the temperature of the sludge pile (Pile No. 3) rose to 54°C, only a few degrees less than the other three piles.

Unfortunately, the shredder was broken by the sticky sludge cake at the end of the second day. It was, therefore, necessary to use forks to turn all these piles for the next several days. A slow temperature drop curve of the sludge pile was maintained, probably resulting from the fork turning.

*Saginaw sludge (a primary sludge without secondary treatment): Monthly variation in filtration rate (Aug.)=7.68-8.40 lb./ft.²/hour; Average filtration rate=7.5 lb./ft.²/hour (dry solids). Dosage of chemicals on Aug. 23: FeCl₃ (dry wt. as FeCl₃)-1.4 per cent; Lime (dry wt. as CaO)-5.4 per cent. Yearly average dosage of chemicals: FeCl₃-1.48 per cent, Lime - 5.60 per cent.

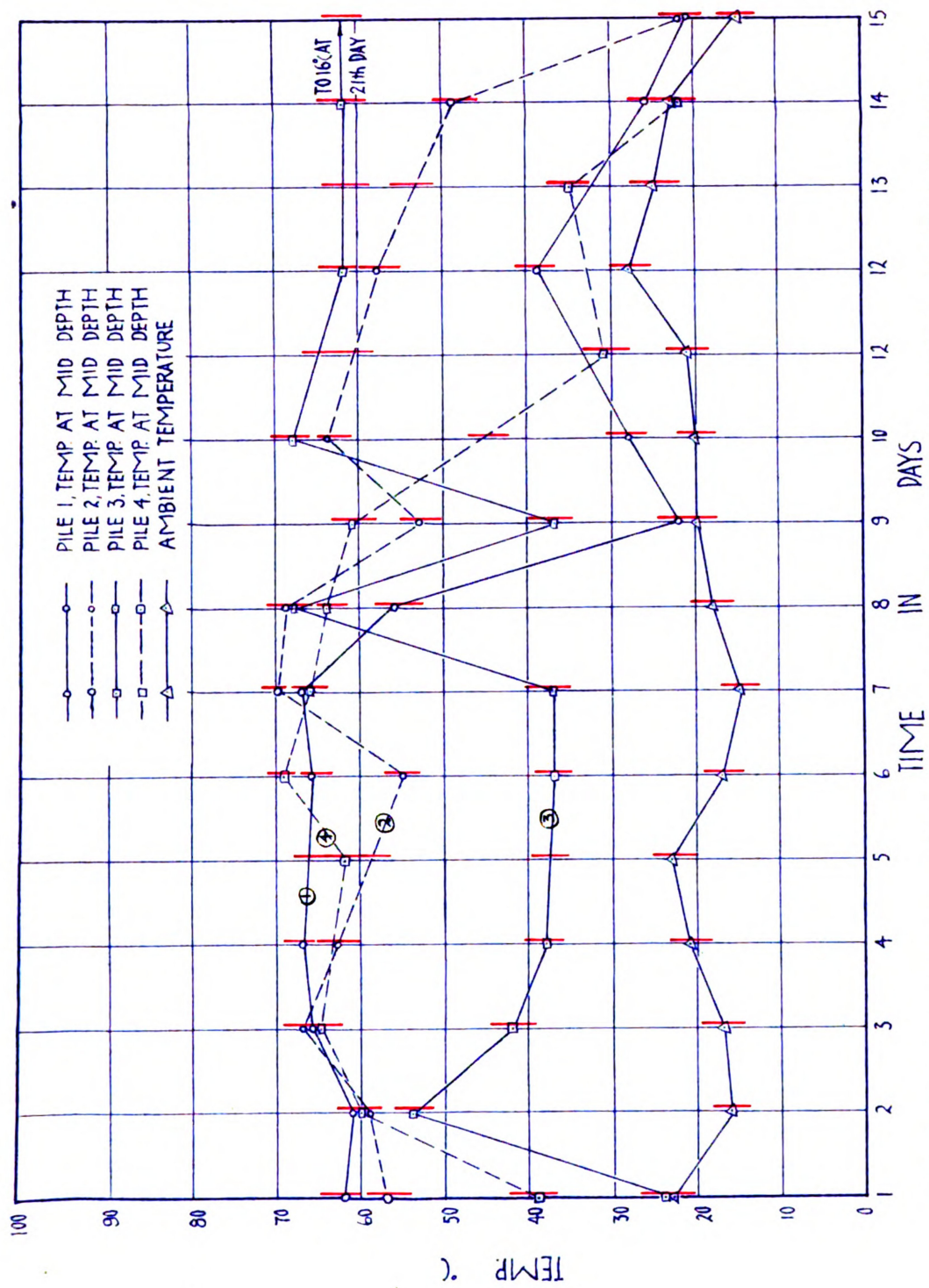


FIGURE 22. TEMPERATURE CURVES FOR MID DEPTH OF COMPOSTING MATERIAL IN EXPERIMENT 6.

Half-inch balls were observed in Pile No. 3, but these balls were of an entirely different composition than those of Experiment 5. These sludge balls had a hard crust outside and a watery sludge inside. This condition maintained the moisture content and could be the reason that the temperature remained at a high level for a long time.

Piles No. 1, 2 and 4 showed a temperature drop to about 20°C due to the rapid moisture loss on the fourteenth day (as shown in Figure 23).

The initial pH of Piles No. 1, 2 and 3 was high and remained around 8.0 throughout the entire period. The high initial pH value of raw sludge was due to lime added for filtering. The pH curve of Pile No. 4 follows the regular pattern but without any initial drop, probably due to good aeration at the beginning. The pH curves were shown in Figure 24.

One interesting phenomenon noted during this experiment was the reversal of the percentage of color transmittance as compared to the results observed with garbage. The green filter value of Pile No. 3 (sludge composting pile) changed from high to low at the middle composting stage and then rose again to a value much higher than at the beginning. This relationship is shown in Figure 25.

Color transmittance of sludge compost changes with a reverse direction to garbage compost, probably due to the introduction of a $-\text{CH}_2$ group in the unsaturated chain which causes some shift of the absorption band in the sludge substance (See Section V). Though change of color transmittance of sludge and garbage cannot be compared the changes noted were of value in recording changes which took place during composting. This could well be investigated in the future research.

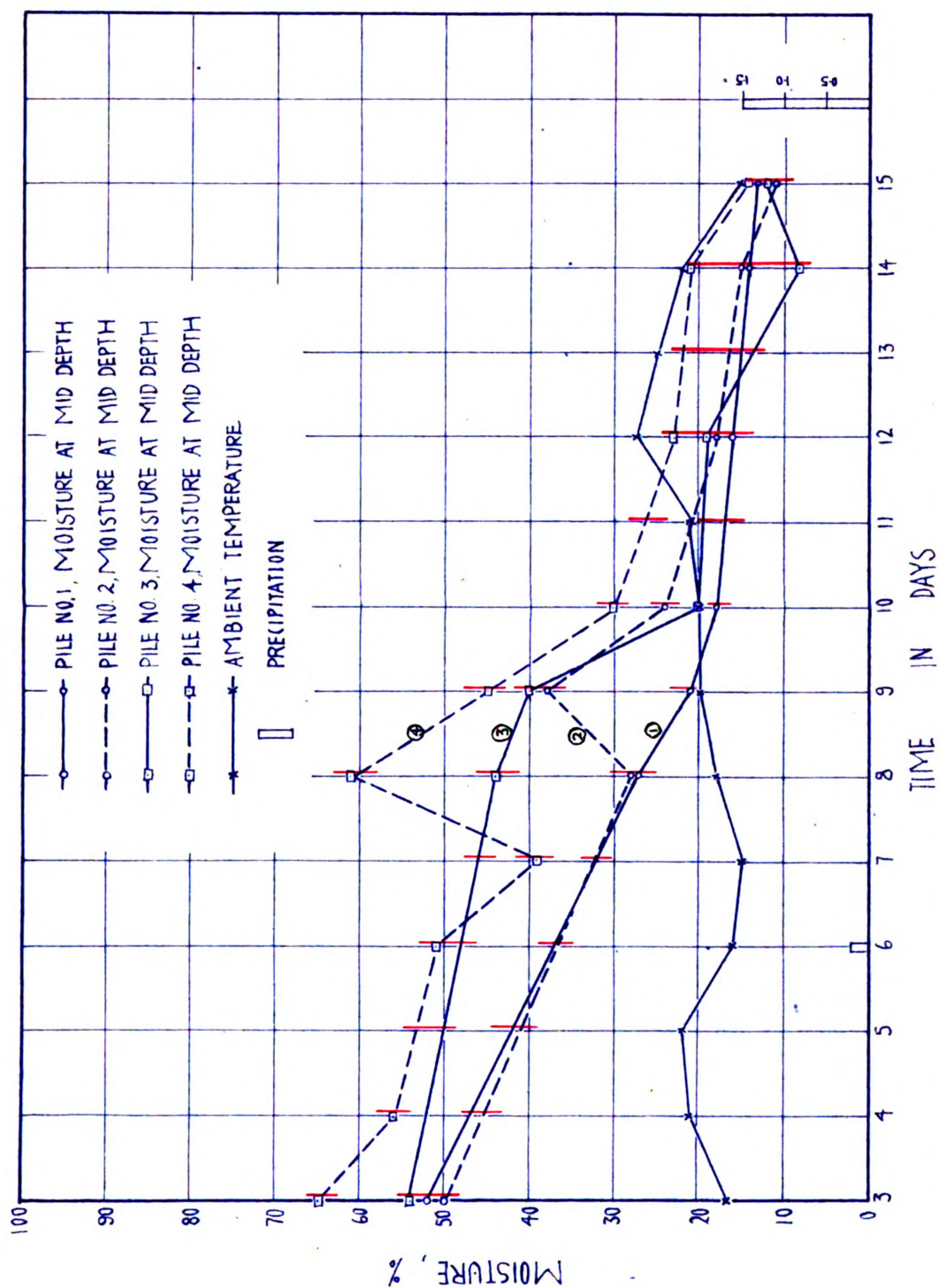


FIGURE 23. MOISTURE CURVES FOR MID DEPTH OF COMPOSTING MATERIAL IN EXPERIMENT 6.

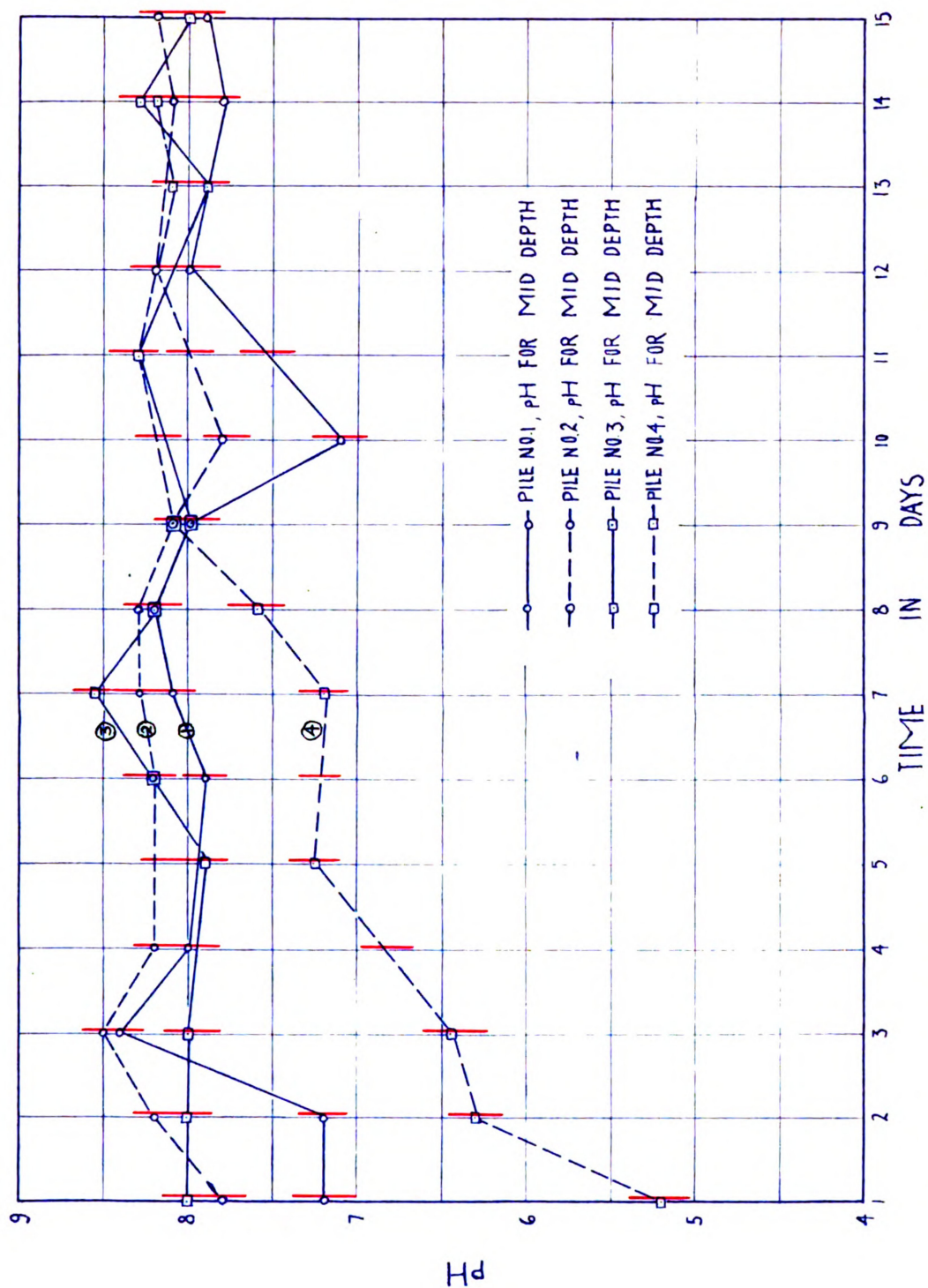


FIGURE 24. pH CURVES FOR MID DEPTH OF COMPOSTING MATERIAL IN EXPERIMENT 6.

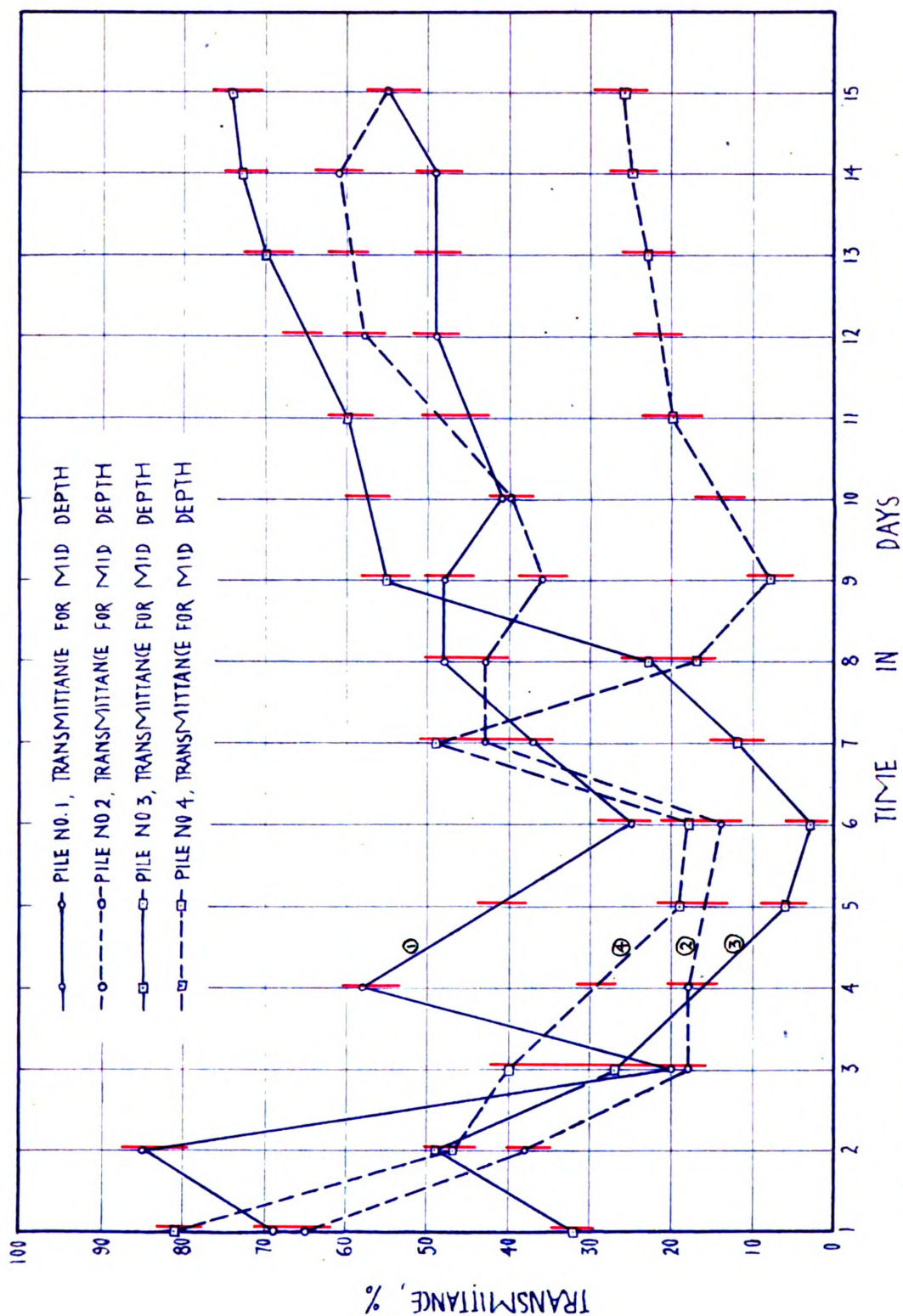


FIGURE 25. GREEN FILTER COLOR TRANSMITTANCE FOR MID DEPTH OF COMPOSTING MATERIAL IN EXPERIMENT 6.

Experiment 6 suggested:

1. An initial blending of sludge and partly composted garbage was useful as a means of increasing its porosity.
2. pH does not seem a reliable yardstick for judging the sludge composting because of the small change noted during the course of composting.
3. The change in the per cent transmittance of sludge apparently varies greatly from that of garbage during composting.

SECTION VIII

Discussion

Requirements of Ideal Windrow Composting

The time required for windrow composting was, in the main part, determined by the degree of aeration through turning. The degree of decomposition was also affected by particle size and moisture content. Therefore, the ideal composting pile may be characterized as follows:

1. Daily turning to secure good aeration.
2. Suitable moisture maintained throughout the composting period.
3. A material of good structural strength against compaction in the top layer to keep aeration voids open.
4. A material of very small particle size with relatively large surface area to absorb oxygen from the air.
5. Good insulation in the outside layer to speed up decomposition by thermophilic bacteria.

Experience gained during these experiments showed that a rapid moisture loss must be expected with frequent turnings. Hence aeration by turning the pile accompanied with suitable moisture adjustment, when necessary, seems indicated. For windrow composting it may be well to turn the pile after a rainfall so that the compost can recover some moisture from the wetted ground.

According to requirements 3 and 4, a treatment involving both turning and grinding may be desirable. Proper turning produces good aeration accompanied with heat and moisture loss. If this shredding operation were

followed by grinding, an increase in the contact area of composting material to the air could be obtained without loss of aeration voids.

Insulation on the outside layer of the pile would make the pile a closed cell and cause anaerobic decomposition in the inner layers. Therefore, it would appear that insulation should not be considered unless means are assured for moving the outside layer to the center of the pile when turning.

In windrow composting, the insulation usually comes from the pile size used. Too small size has poor insulation and too large size is always accompanied by a compaction due to weight of the material. In Experiment 2 a pile two to three feet high was well aerated by turning every third day. It would seem to be possible to build a long windrow pile with a trapezoidal section of four to five feet high and to aerate every day by turning without compaction. A trapezoidal form with an 8-foot base seems convenient for turning the pile with the Kemp soil shredder.

Value of Seeding and Re-seeding.

Although Experiment 4 showed little improvement due to seeding and re-seeding the garbage compost pile, the writer still believes that back seeding will play an important part in the future composting process. Thermophilic organisms do the major job on the decomposition of the waste material under a definite range of temperature. If an optimum temperature were kept favorable to thermophilic organisms, seeding should help the compost to cross the mesophilic stage and shorten the detention period at the beginning. Again, when the temperature rises to above 65° - $70^{\circ}\text{C}.$, some thermophilic organisms responsible for breaking down the waste will be killed and a temperature drop might result. This indicates that the

composting process might then be transferred to another mesophilic stage which would be much slower than the thermophilic stage for decomposition. These considerations suggest the following treatment methods:

1. Prevent the thermal death point to the lower temperature thermophilic organisms by controlling the temperature so as to remain within close limits (45° - 65° C).

2. Re-seed with thermophilic organisms, if the temperature is over 65° - 70° C, in order to keep the high-speed decomposition going on.

Under the first condition, most pathogenic bacteria were killed because their death point is around 56° - 60° C, and at the same time the rapid decomposition can be maintained by the activity of thermophilic organisms. If it is not possible to control the temperature within those limits, a re-seeding with thermophilic organisms could probably be of some value to continue another thermophilic stage, after a satisfactory sterilization, to speed up the unfinished decomposition.

Fly Nuisance and Odor Problem in Windrow Composting.

Insects and eelworms can be killed at a relatively low temperature of 52° C.⁵ Experiments reported here showed that fly larvae escaped from unturned piles and created a serious fly nuisance together with a foul odor. If turning is not possible, a cover with sawdust, straw or sand to the pile may be good for fly control because the initial activity of young larvae was always observed at the surface of the new built piles.

Regularly turned compost piles resulted in no fly nuisance.

Laboratory Tests.

Any composted organic matter will break down in time but this time may not be short under all circumstances. Time has a close relation to

economics and it may be stated that "time means money". Therefore, every effort should be made to bring the composts to a good end product as soon as possible. For this reason tests for judging the compost are most important. The following tests have been studied in connection with this thesis:

1. Percentage of color transmittance (PCT).

PCT test is an easy and an accurate test. When using a green filter an initial garbage compost PCT of 65 to 90 drops to a value near 10 during the middle composting stage and then rises again to a final value of around 20. As previously mentioned, the instrument used in this test was a Klett-Summerson photoelectric colorimeter. This instrument is easily carried and is not time consuming. Although the use of PCT proved reasonably satisfactory, much improvement in technique is still necessary. Of the three tests reported here the PCT test was the most reliable and useful.

2. Oxidation-Reduction Potential (ORP).

The ORP test has long been used for control of sewage treatment plants but has not, to this writer's knowledge, been used as a garbage composting test. Judging by results obtained in Experiment 3, ORP seems to be a good means for telling the conditions resulting from aeration by turning. Unfortunately, the ORP test had to be dropped after Experiment 3 because of trouble with the instrument. Also, readings were time consuming due to a long period of instrument drift while making measurements. Difficulty was encountered in establishing a satisfactory procedure.

3. Hydrogen Ion Concentration (pH).

pH still seems to be a good indicator for garbage composting during the initial stages. pH rise from about 4.8 to 8.0 during the initial stages

and thus indicates the degree of composting. However, the test is not sensitive during the final stages and is of little value when working with lime-filtered sewage sludge.

SECTION IX

Summary and Conclusions

A number of experiments have been reported in connection with this thesis. Conclusions pertaining to these experiments and other factors in this thesis are listed below:

1. A windrow composting without turning may cause odor and fly nuisance. Unturned windrows required several months to compost. If no turning is possible, it is better to use coarser material and the piles should be located some distance from habited areas. An insecticide must be used continuously during warm weather for at least twenty days to kill the larvae and flies, since such piles tend to become infested with larvae.

2. Turning the pile every third day finishes the composting pile within eighteen days without nuisance. Under the same environmental conditions if the piles are turned every second day and every day, fourteen days and nine days respectively are required for completion.

SECTION X

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SECTION XI

APPENDIX

(A) Procedure for Obtaining Per Cent Transmittance*

I. Preparation of Sample - (This procedure open to further experimentation).

1. Weigh out 10 grams of sample.
2. Place this in 100 cc. water.
3. Shake by hand in an erlyenmyer flask 25 times.
4. Filter.
5. Place 10 cc. in a colorimeter tube and read, using a colorimeter.

II. Procedure for Using Colorimeter.

1. Set colorimeter to zero before turning on. This must be done before turning on the colorimeter. This is done by turning the pointer setting knob on top of the instrument until the pointer coincides with the line on the blank pointer scale.
2. Plug in electric cord outlet.
3. Turn on short circuit switch located at side of instrument.
4. Place a clean colorimeter tube containing distilled water in the instrument.
5. Turn the scale by means of the large knob on the front of the instrument until the scale reading is 0.
6. Switch on the colorimeter lamp by means of the lamp switch located on the front of the lamp housing.
7. Switching the lamp on will in general cause the pointer to move somewhat away from the line on the pointer scale. Turn the zero adjustment

*This procedure was prepared by Robert Line at M. S. C.

knob, which is located on the top of the colorimeter to the left of the test tube, one way or another until the pointer is brought back to the line on the pointer scale.

8. Allow the lamp to burn for a few minutes to permit the instrument to reach equilibrium. Again check the position of the pointer to be sure that it is on the line. If it is not, turn the zero adjustment knob carefully until the pointer is exactly on the line. The instrument is now ready for use.

9. To read an unknown solution remove the distilled water tube and place the colorimeter tube containing the unknown solution in the instrument. The pointer will be deflected from its position at the zero line. Turn the scale now until the pointer has been brought back exactly to the zero line. The reading on the scale at this point is the reading of the unknown solution.

10. Take readings using no filter, a red filter, a green filter and a blue filter on each sample.

11. The colorimeter scale is graduated in units proportional to the optical density. The actual numerical values represent the optical density divided by two, with the decimal point omitted. A scale reading of 250 corresponds to an optical density of 0.500. The formula relating scale reading and optical density is as follows:

$$\frac{1000 \times D}{2} = R$$

where D is density and R is the reading.

It is usually desirable to report the scale readings in terms of per cent transmittance. To convert the scale readings to per cent transmittance refer to the conversion table in back of the colorimeter handbook.

It is possible to calculate the per cent transmittance from the scale reading. This is done as follows:

(a) Obtain the optical density by multiplying the scale reading by 0.002.

(b) Subtract the optical density value from 2.000. The result is the logarithm of the per cent transmittance. From logarithm tables, obtain the value of the per cent transmittance.

(B) Procedure for pH Measurements in Composting
Investigations Using a Beckman H-2, M.S.C.*

I. General Procedure.

(a) Set switch on start. Connect power cord. During five-minute wait verify meter needle adjustment at 7.00.

(b) Standardize the meter by immersing electrodes in a standard buffer solution and switching to proper range. Adjust standardization needle until meter needle indicates exact buffer pH. Switch to neutral position and move pointer to mark needle position.

(c) When handling electrodes after start always keep switch in neutral position.

(d) Always rinse and wipe electrodes before measurements and set temperature dial at electrode temperature.

II. Measurement of pH.

Switch to neutral and readjust standardization control so needle rests at pointer position. Immerse electrodes in sample. Switch to proper range and read pH. Repeat buffer standardization occasionally during an extended series of measurements.

III. Preparation of sample.

If sample is a liquid no further treatment will be necessary.

If sample is a solid such as compost, place an amount of sample with an equal amount of distilled water (by volume). Stir, immerse electrodes, and take reading. After sampling, composting material may be kept in a tightly stoppered container for not more than 3 hours before a pH determination is made.

* This procedure was prepared by Robert Lipe at M. S. C.

(C) Procedure for Moisture and Ash Determinations
from Samples of Composting Material, M.S.C.*

In general, the same sample (in the same evaporating dish) shall be used for both moisture and ash determinations. After sampling, the material for these determinations may be kept in a tightly stoppered container for not more than six hours before the initial weight determination (for moisture content) is made. The procedures below apply only to material which has been ground before sampling.

Moisture: Remove from the sample all visible metal and all particles having any dimension greater than about one-half inch. However, if particles of any one type of material with greater dimensions than one-half inch (e.g., corn husks or grass) are present in amounts exceeding about ten per cent of the sample, retain these particles. Place at least 100 gm. (wet weight) of the sample thus sorted into a suitably marked porcelain evaporating dish of a known weight. Do not place any material higher than one-half inch below the top of the dish. Do not pack the sample into the dish. Weigh the dish of wet material immediately on a scale or balance accurate to 0.1 gm.; then place the dish into an electric oven held at a temperature not varying beyond the limits of 102° to 104° C. (or in 85° C sand bath for one hour followed by a 102° - 104°C. oven). Dry the sample for at least twenty-four hours and re-weigh to 0.1 gm. Moisture content is expressed in terms of a percentage of the original (wet) weight of the sample.

If material with an estimated moisture content greater than fifty per cent is placed in an evaporating dish to a depth of one inch or more, at

* This procedure was prepared by G. F. Mallison at M.S.C.

least forty-eight hours drying in a 102°- 104° C oven shall be necessary before determining the dry weight of the sample.

In the M. S. C. sanitary engineering laboratory, all wet samples shall be dried in a 85° C sand bath for one hour before these samples are introduced into a 102°- 104°C oven.

Ash: When the procedure above has been completed, place the dry weighed sample in an electric muffle furnace heated to a low red heat (650°to 700°C). After at least 3 hours in the furnace, remove the sample and weigh again to 0.1 gm. Ash content is based on the dry weight of the sample.

Footnote: If the original (wet) weight of a sample is less than 100 gm., all weight determinations for ash and moisture contents shall be made to 0.01 gm. on an analytical balance. Desiccator cooling of ashed or oven dried samples shall be necessary before weighing on an analytical balance.

$$\text{Computations: } \% \text{ Moisture} = \frac{\text{Wt. of wet sample} - \text{wt. of dry sample}}{\text{Wt. of wet sample}} \times 100$$

$$\% \text{ Ash} = \frac{\text{Wt. of ash}}{\text{Wt. of dry sample}} \times 100$$

(D) Technique - Oxidation-Reduction Potential*

The technique found to be most satisfactory in this laboratory for the measurement of Redux potential is as follows:

1. Set up a standard laboratory Beckman pH meter as follows:

(a) Remove 60th electrodes by removing lead lines from the back of the meter.

(b) Connect a Beckman No. 8970-13 High Temperature Reference Electrode in place of the standard Reference electrode. In order to do this it is necessary to use the Beckman Terminal Connector #700 which adapts pin-type terminals, such as those on metallic electrodes to the glass electrode jacket.

(c) In place of the general purpose glass electrode connect a special one sq. in. platinum electrode. Because of its large surface area this type of electrode was found to be much more satisfactory than one with a smaller surface area.

II. The Oxidation-Reduction Potential readings (in MEV) are taken as follows:

(a) Place the large platinum electrode in a large beaker. Care should be taken that the electrode does not touch the sides or bottom of the beaker.

(b) Place sample in the beaker so that entire electrode is covered by sample. This method was found to be more satisfactory than forcing the electrode down into the sample.

(c) Turn the control switch to the proper range in mev and take reading. This reading should be sub. from plus-245 which is

*This procedure was prepared by Robert Line, M. S. C.

the potential at room temperature of the reference electrode.

(d) If the platinum electrode is connected to the terminal connector the reading will be positive. If the reference electrode is connected to the terminal connector the reading will be negative.

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