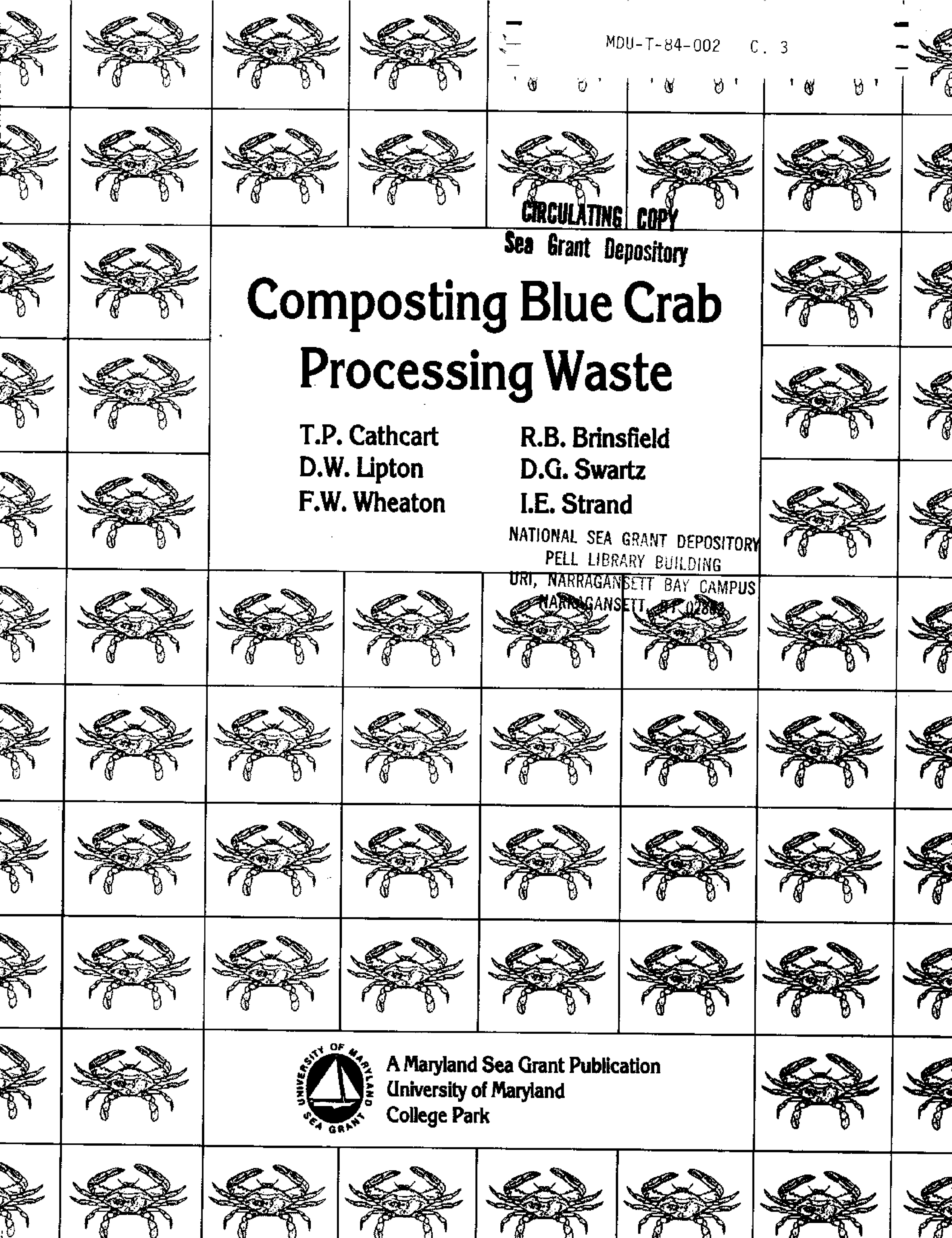

Composting Blue Crab Processing Waste

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University of Maryland
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CONTENTS

INTRODUCTION

Solid waste from blue crab processing plants, consisting of shell, viscera and some meat, historically has been sent to dehydration plants on a daily basis. The waste was dried and ground at the dehydration plant and sold as an animal feed supplement. In 1980 air pollution regulation requirements, economic conditions and other factors combined to cause closure of the dehydrating plants, leaving the processors with no disposal method for the crab waste (crab scrap).

Crab scrap is a rapidly decomposing product which, if not disposed of daily, will generate highly noxious odors and will attract flies, rodents, and other undesirable creatures. To prevent potential health hazards, the processing plants were allowed to dispose of their crab scrap in county landfills. However, this method of disposal is considered only temporary because: 1) the material is difficult to handle in the landfill, and 2) health authorities are concerned about possible ground water pollution around the landfill area with either bacteria or possibly nitrogen derived from the crab scrap. The landfills available near crab processing plants are generally located in areas having a high water table, a factor increasing the risk of ground water pollution.

Several alternative solutions have been proposed for disposal and/or utilization of wastes generated from shellfish processing operations. Kifer and Bauersfeld (1969) quantified the amino acid content of blue crab meal and conducted chick feeding studies with it. They found that crab meal was an effective feed for broiler chickens. They did not, however, consider crab waste before it was ground and dehydrated. Crab meal generally is of lower value for animal feed than is shrimp meal (Jordon Co., 1979). The high calcium content of crab meal limits its use in broiler chicken feed.

Chitin extraction has been proposed by several authors (Knecht and Hibbert, 1926; Perceval and Nelson, 1979; Hattis and Murray, 1977 as one possible use of crab waste. The extraction process uses strong basic and acidic solutions to free the chitin from the crab shells and results in saleable products in the form of: 1) chitosan, or chitin, 2) protein, 3) calcium chloride, and 4) sodium acetate (Jordan Co., 1979). The economics of this process are apparently dependent on the supply of raw crab waste, transportation costs, energy costs, and other factors. A private corporation investigated the possibility of locating a chitin extraction plant on Maryland's Eastern Shore, but decided not to pursue plans beyond early investigations (Wieland, 1979).

Direct land application has been used to dispose of waste from king crab processing operations. Crab waste has been used as a soil fertilizer by researchers at Oregon State University. Table 1 shows the composition of crab waste measured in these studies (Costa, 1977; Jordan Co., 1979). Problems associated with crab waste spread on land varied from fly and odor problems to an excess of sodium. Excessive sodium destroys soil structure, which lowers productivity and, if applied as saline water, can result in soil sterility.

Several crab processors have suggested returning the solid crab waste to the Bay. They argue it will serve as fish food. However, regulatory and management officials indicate that such overboard dumping would be in violation of the 1898 and 1972 federal pollution acts, unless it can be shown that the material does not constitue "pollution" and/or does not have any detrimental effects on the receiving waters.

TABLE 1. NUTRIENT VALUE OF ONE TON OF FRESH CRAB WASTE (JORDAN CO., 1979)

COMPOUND	LB/TON OF CRAB WASTE
Nitrogen	32
Phosphate (P_2O_5)	24
Potash (K_2O)	5.9
Sulfur	3.7
Lime	300
Magnesium	6.6
Boron	0.03
Water	1280

Recent tests of overboard dumping of crab scrap have shown it to be unfeasible because: 1) much of the crab scrap floats, resulting in a surface covering that is unsightly and odorous; 2) the crab scrap has a high oxygen demand which quickly lowers the water oxygen content; and 3) garbage is often thrown into the crab scrap while it is being collected at the processing plant and, with overboard dumping, some of this also floats (Krantz, 1983).

Other proposed uses of crab waste include: rendering plant raw material (Darrow, 1970); laying hen calcium supplement (Manning, 1929); whole shells used as ashtrays or other decorative items (Anonymous, 1956); whole shell backs used as containers for stuffed crab, as abrasives, as a filler for oil-well drilling mud and in winter tires (Dispain, 1965); adding texture to paints, and as a substitute for sawdust in pressed-wood paneling (Dispain, 1965). However, it appears there are serious economic, supply and technical constraints associated with using crab waste for these purposes.

Composting has also been suggested as a possible disposal method for blue crab scrap. Composting is the biochemical degradation of organic material to a sanitary, nuisance-free, humus-like material (Munincipal Refuse Disposal, 1970). The principals and methods of aerobic thermophillic composting have been outlined thoroughly elsewhere (Golueke, 1972; Finstein et al., 1980; Willson et al., 1980). Materials such as munincipal sewage sludge and refuse, cannery wastes, residue from plant and animal husbandry, and certain industrial wastes have been composted (Golueke, 1972; Dugan, 1973; Parr et al., 1978; Finstein et al., 1980; Willson et al., 1980; Hyde and Consolazio, 1982; Smyser, 1982; Chanyasak and Kubota, 1983). Published reports of composting of crab scrap do not appear to exist.

Composting as a waste management strategy has a number of advantages: 1) it generally requires only low technology; 2) the final product may have economic value which can help to defray disposal costs; 3) the final product is stable and produces no objectionable oders; and 4) the volume of the waste material is somewhat reduced by the composting process. Because of these potential advantages, the research described in this report was initiated to determine the optimum levels of composting variables and to determine the economics of composting versus some other disposal techniques.

OBJECTIVES

The objectives of the research were to:

1. Determine if it is possible to compost blue crab processing plant solid waste.
2. Determine the levels of composting variables which will give the most rapid composting and provide the most stable composted material.
3. Mathematically model the composting process based on laboratory results as an aid to scale-up of processes and equipment.
4. Determine the composition of the composted material and, if possible, estimate its market value.
5. Determine the economics of alternative markets or disposal strategies for the compost and compare it to other feasible alternative disposal methods.

METHODOLOGY

The study was carried out in four phases. Phase I was designed to determine the biological feasibility of composting crab scrap. Phase II developed solutions to some of the problems identified in Phase I. Phase III was designed to optimize the composting process by identifying the variables involved in composting and then determining their optimum levels for the most rapid production of a stable final product. Phase III results were summarized in mathematical models describing the composting process. Phase IV explored the economic aspects of composting by studying the economic factors involved and the nutrient value of the compost by and comparing composting with other disposal techniques.

Phase I

Phase I studies were conducted using one cubic meter bins constructed such that air could be forced up through the compost. Sawdust was mixed with the crab scrap to provide supplemental carbon. The ratio of crab scrap to sawdust was varied to achieve carbon-to-nitrogen (C:N) ratios of 8:1, 14:1, and 20:1. Temperatures were monitored at one-third and two-thirds of the one-meter depth using copper-constantan thermocouples. Air was supplied in excess to assure aerobic composting. Water was added manually as necessary to maintain the moisture content in the 50 to 60 percent range.

Phase II

Phase II was designed to solve the major problems encountered in Phase I. These problems centered around odor control and methods of data collection.

The odor problem encountered in phase I was a result of inorganic volatilization of ammonia (and/or related compounds). Previous investigations have determined that volatilization of ammonia occurs when there is insufficient organic carbon relative to nitrogen in the composting material. The low carbon-to-nitrogen (C:N) ratio prevents bacteria from using the nitrogen as fast as it becomes available. Since there was no apparent difference in amount of ammonia generated in high and low C:N batches (and since the sawdust showed little evidence of degradation), it was assumed that the carbon in the sawdust was relatively invulnerable to microbial attack.

Tests were conducted to determine whether another material might act as a better source of supplementary carbon. Selection criteria for the carbon source included: 1) evidence of greater carbon availability (i.e., less ammonia generated), 2) a high C:N ratio, 3) low cost, and 4) ready availability in areas, such as Maryland's Eastern Shore, where crab processing plants are located. Materials tested included sawdust, peat, straw, and cotton waste from a mattress factory. The tests were conducted in $0.15 m^3$ aerated chambers (Figure 1). Performance in the compost chamber was compared visually (i.e., degradation of the material) and by odor generation.

A second method of controlling ammonia volatilization was through pH control. Ammonia occurs in both the soluable $NH^+{}_4$ form and as relatively insoluble NH_3 gas. The equilibrium reaction (Equation 1)

$$NH^+{}_4 + OH^- \rightleftarrows NH_3 + H_2O \qquad (1)$$

is highly pH dependent with the equilibrium shifting toward NH_3 as pH rises. Maintenance of low pH in the composting material minimizes the amount of ammonia in the NH_3 form and limits gas volatilization.

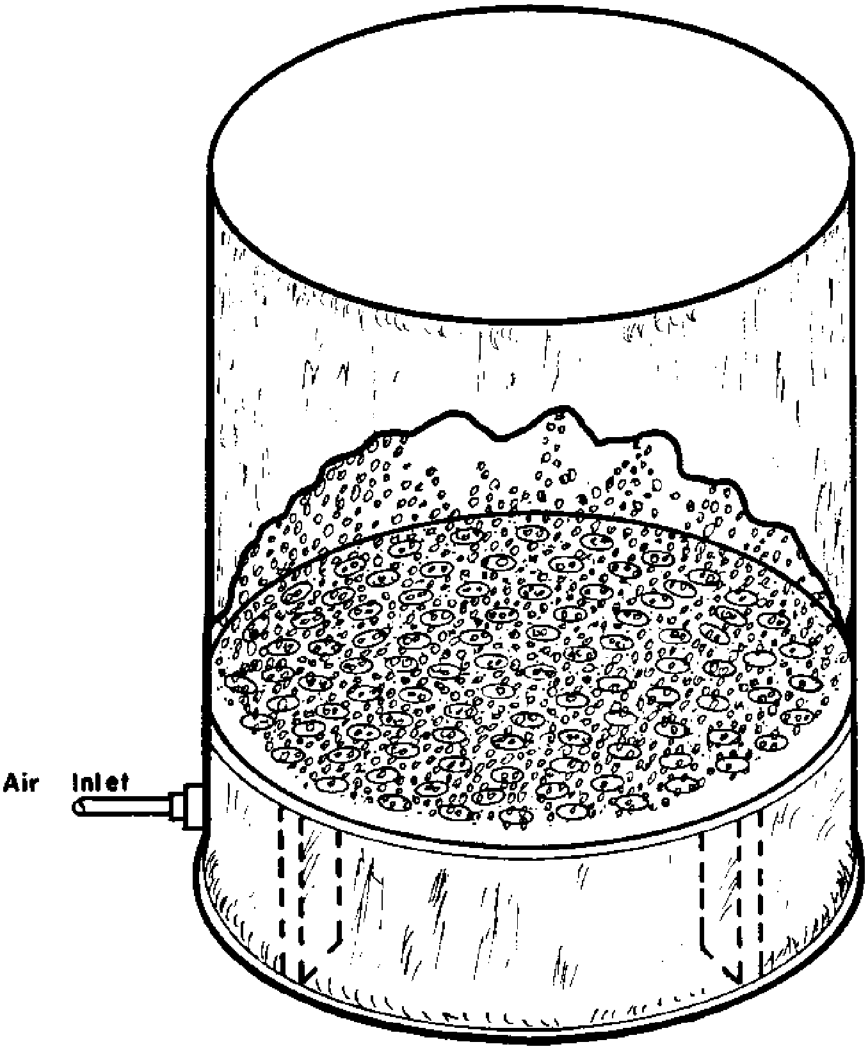

Figure 1. Chamber used for experimental composting studies.

Tests were undertaken to determine the feasibility of controlling compost pH and to compare the effectiveness of various pH-moderating agents. Tests were of two types: 1) beaker tests, and 2) 0.15m^3 chamber tests. The beaker tests were conducted using 200 ml beakers containing 20 g of water, a 20 g (dry weight) sample of crab scrap and sawdust, and a pH moderating agent. Each beaker was stirred daily to provide ventilation. Beakers which became anaerobic were discarded. A small sample was removed from each beaker daily and its pH measured using the 0.01M calcium chloride method (Methods of Soil Analysis, 1965). The change in sample pH with time provided an indication of how effective the agent was in controlling pH.

A more rigorous (although, by necessity, more limited) test consisted of combining crab scrap, sawdust (or peat), and a known quantity of a moderating agent in a 0.15m^3 chamber and allowing composting to proceed. Temperature, oxygen concentration, moisture content, and pH were monitored daily. Changes in the appearance of the composting material, as well as noticable ammonia generation, were noted. Loss of dry matter during the entire test was also determined. This mode of testing was more rigorous than the beaker experiments, in that composting temperatures reached 71°C (160°F). High temperature pushes the equilibrium reaction (Equation 1) to the right. In the tests, this exacerbated ammonia volatilitation and placed a greater demand on the moderating agent being tested. This test was limited in scope, however, by the maximum number (10) of chambers that were available at any one time.

The two types of pH control tests were conducted using a variety of pH control materials including: glacial acetic acid, nitric acid, sulfuric acid, ferrous sulfate and elemental sulfur.

As mentioned, Phase II was also concerned with developing a method for measuring the composting rate. Temperature provides only a qualitative indication of compost activity. At high temperature (i.e., greater than 55-60° C) the heat given off by microorganisms may become an inhibiting factor (Finstein et al., 1980). Thus, chamber temperature could not be used as a quantitative measure of composting rate.

Dry matter mass loss during composting is a good measure of composting rate. By weighing the compost chamber contents before and after composting and adjusting the weights to a dry matter basis using moisture contents, the dry matter loss can be determined. However, the experimental set-up prohibited measuring weight of the chamber contents during composting. Although dry matter loss was determined at the end of the composting period, it was desirable to monitor a parameter which would give composting rate during the composting process.

Carbon dioxide, an aerobic respiratory end product, is also a good indicator of composting rate and has been used as such by other researchers (Finstein et al., 1980). Determining an evolution rate for carbon dioxide then became the problem. Air was forced up through the compost during the regular composting cycle. An attempt was made to monitor the CO_2 content of the air. However, air flow varied with time and chamber operating parameters. If continuous CO_2 concentrations could have been determined, this system would have worked well. However, budget restrictions prevented purchase of the necessary equipment. Forcing air at a constant rate up through the compost coupled with grab sample extraction using a hypodermic syringe was also attempted. Unfortunately, when the air flow was high enough to flush residual CO_2 out of the chamber, evaporative cooling lowered the composting temperature. The lowered temperature shocked the bacteria in the chamber causing a reduction in their metabolic rate. Therefore, the CO_2 evolution rate thus measured was lower than that which occurred prior to application of the high flushing air flow.

Further experimentation showed that if the flow of air was reversed (i.e., flow was top to bottom during sampling), the cooling problem was restricted to approximately 2°C. This may have been because the incoming air provided a force that opposed the natural convective force of the heated air within the compost, inhibiting instead of promoting heat loss. Thus CO_2 sampling was accomplished by eliminating the normal air flow to the chamber and creating a slight vacuum on the bottom of the chamber. Air flow was thus reversed. Figure 2 shows a typical example of the CO_2 concentration as a function of time during sampling. A complete flush of the chamber required the air flow be reversed and held at a constant rate for about 3 hours before steady state conditions were achieved.

Once steady state conditions were achieved, the flushing gas was sampled with a hypodermic syringe. The gas was washed through a phosphoric acid bath to remove the ammonia and injected into a gas partitioner. Using the CO_2 concentration from the gas partitioner and knowing air flow and air temperature at the sampling time, we determined CO_2 evolution by calculation.

Phase III

Phase III methodology varied considerably from Phase I because the objective of Phase III was optimization of composting variables. Composting was conducted in $0.2m^3$ plastic barrels similar to that shown in Figure 1. The basic experimental setup is shown in block diagram

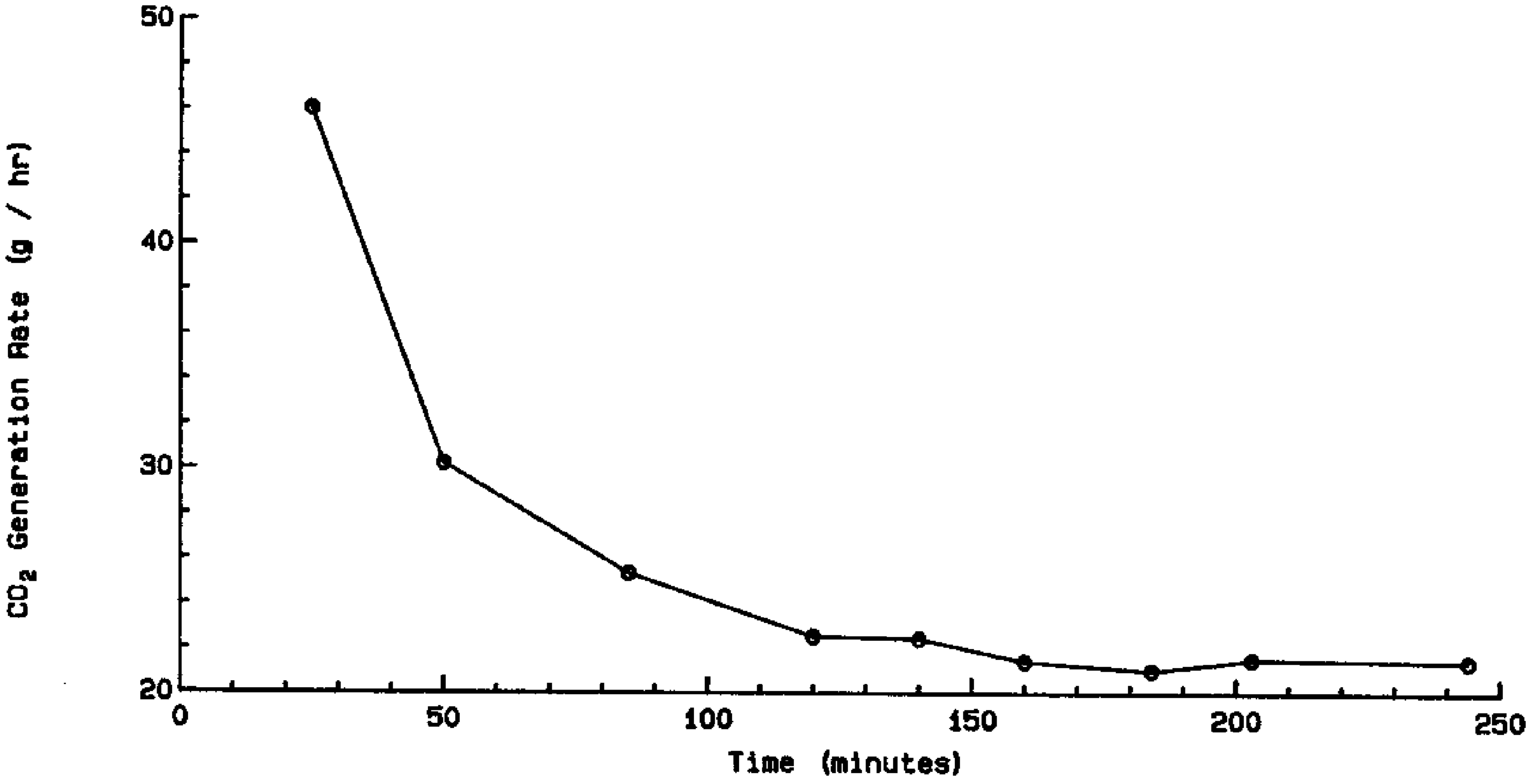

Figure 2. Carbon dioxide concentration in exhaust gases versus time during a CO_2 sampling period.

form in Figure 3. Air for the composting system was supplied by an air compressor and pressure tank. A filter removed oil from the air while a pressure regulator dropped the line pressure from the 420 to 690 k Pa (60 to 100 psi) compressor output to approximately 34 k Pa (5 psi). Air was distributed to the eight experimental chambers by a manifold. Downstream from the mainfold a solenoid valve controlled air flow (on or off). The solenoid-operated valve opened or closed in response to a signal from the relay-timer control system. (The control circuit is described in more detail below.) Air then passed through a totalizing gas meter, which provided a measure of the total flow of air to the chamber. To ensure equal flow rates to all chambers, an indicating flow meter was used to visually set flow rates. Pinch clamps on the tygon tubing lines were adjusted to achieve equal flow to all chambers. Air entered the bottom of the chamber and was distributed by the distribution plate, Figure 1.

The distribution plate consisted of a plywood disk sealed to the chamber sidewalls. Holes (each 0.95cm [3/8 inch] in diameter) were drilled through the plate on 5cm (2 inch) centers. This distributed air over the entire bottom of the chamber, providing a more uniform flow up through the chamber.

The chamber was kept covered with screening to prevent fly access. Air exited through the port in the chamber sidewall located above the top of the compost. A thermister placed in the center of the compost sensed temperature and provided a signal to the control system.

The control system was designed to maintain any desired temperature in the compost chamber. Once the controller temperature was selected, the controller opened or closed the solenoid valve on the air line in response to the thermister output. If compost temperature was above the set point, air was allowed to flow through the chamber. Evaporative

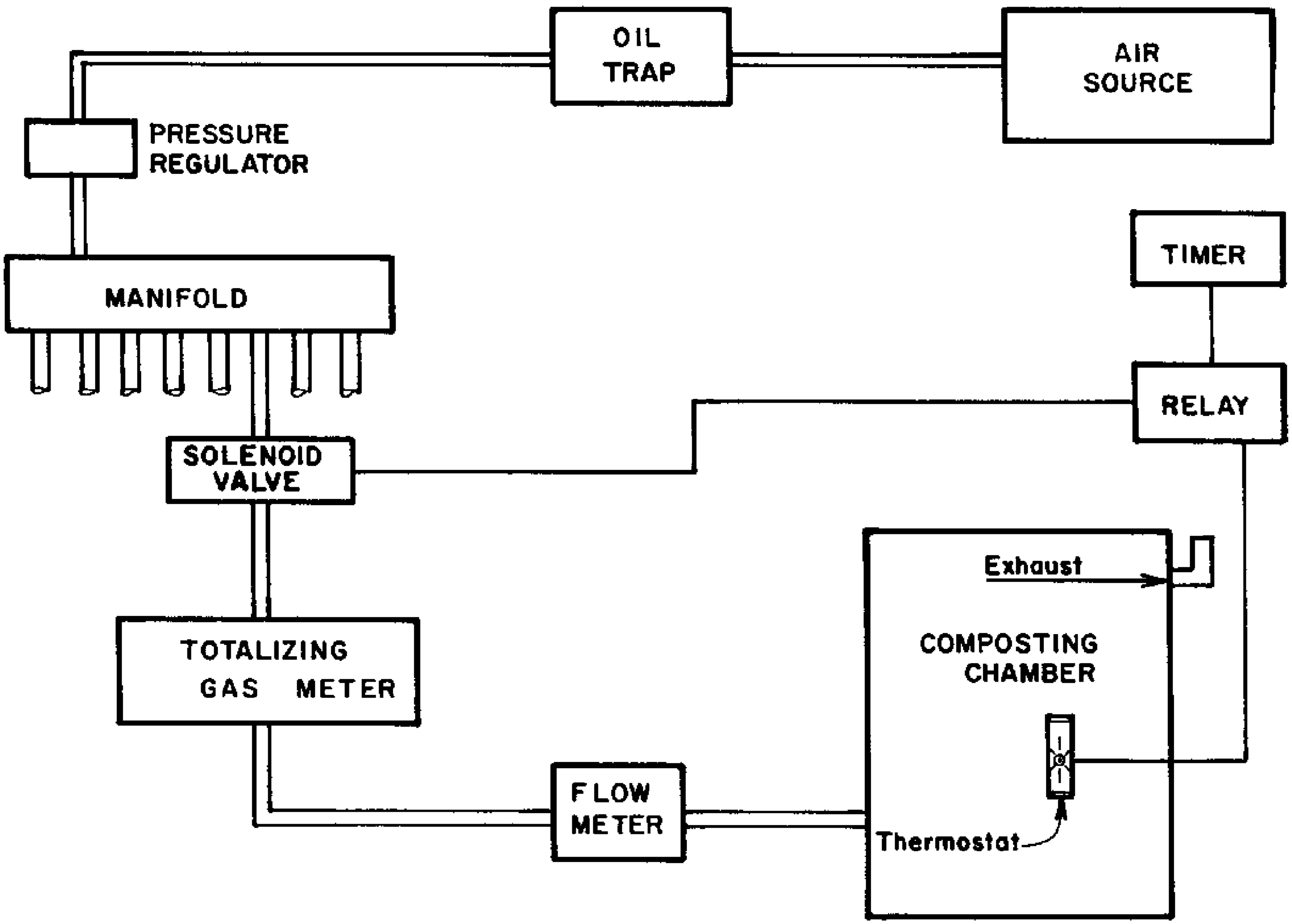

Figure 3. Schematic of the experimental crab scrap composting system.

cooling caused the temperature of the chambers to decrease. If the compost temperature was below the controller set-point, the solenoid valve remained closed, allowing the metabolic heat generated by bacteria within the compost to heat the chamber. Experiments showed that very low air flows provided enough air to maintain aerobic conditions within the compost chamber. Thus, a timer was incorporated into the control system such that it could override the control circuit. The timer was set to open the solenoid valve on the air line for 15 seconds every 15 minutes. If the controller had the valve open for temperature control, the timer was not activated. If the controller had the valve closed, the timer opened it only for the 15 seconds necessary to keep the chamber aerobic.

The optimizing tests were conducted as follows. The desired C:N ratio, moisture content and temperature in each barrel were determined from the statistical design. Since the moisture content of the crab scrap and straw as received was quite uniform, the proportion of crab scrap, chopped straw and water required for each batch could be calculated. These calculated values were then used to prepare the batch. A sample from the batch was taken to determine the actual moisture content and C:N ratio. Because moisture was measured by oven drying at 104°C, there was a minimum lag time of 24 hours between setting up a batch and determining the actual moisture content. Similar time lags were experienced in determining other parameters.

The required quantities of crab scrap, chopped straw and water were weighed out. The crab scrap and straw were mixed in a portable cement mixer, water was added and additional mixing performed. The mixture was then transferred to the composting barrels which already had the air lines and temperature sensors in place. A sample of the mixture was taken to determine actual moisture content, C:N ratio and other parameters. Fiberglass insulation (8.9cm [3 1/2 inches] thick) was wrapped over the sides and top of the barrels to minimize heat loss. The air system was activated and the controller set-point for each barrel adjusted to the desired temperature.

Composting was allowed to proceed for 21 days. Carbon dioxide evolution rate was determined and moisture content samples were withdrawn approximately every other day. Moisture content was adjusted by calculating the water required to bring the moisture content to the desired level and then manually adding the water. After some practice this method allowed reasonable control over moisture content.

After the 21-day composting period the barrels were carefully emptied, the compost weighed, and moisture content determined. Samples were also taken for later analysis of other parameters. Dry weight loss of the composted material was determined using the initial and final weights and moisture content.

Statistical Design

Three independent variables were considered: composting temperature, composting moisture content, and carbon-to-nitrogen ratio (C:N). Using a factorial design for these tests was unrealistic due to the time and resources necessary to conduct such a large number of tests. Thus, a composite rotatable design (Cochran and Cox, 1966) was used. Two analyses were then conducted, one for unshredded crab scrap and one for shredded crab scrap. Final results were expressed as a response surface with the dependent variable being the amount of carbon dioxide generated per unit of initial dry mass placed into the composter (Y). The polynominal description of the response surface was of the form:

$y = a + b_1x_1 + b_2x_1^2 + b_3x_2 + b_4x_2^2 + b_5x_3 + b_6x_3^2$

$x_1, x_2, x_3,$ = independent variables

$b_1, b_2, \ldots, b_6$ = regression coefficients

Analytical Methods

It was necessary to determine the nitrogen, calcium, phosphorous, potassium and carbon contents of the raw products used for composting as well as that of the stabilized compost. Calcium and potassium were determined with an atomic absorption spectrophotometer. Nitrogen and total phosphorus were determined by the Maryland State Chemist's Laboratory using the total Kjedahal method for nitrogen (Standard Methods, 1975) and the procedure using quinaldine red indicator and an autoanalyzer for phosphorus (AOAC, 1980).

Carbon was partitioned into organic, total and inorganic. Total carbon was first determined using a high-temperature induction furnace (Methods of Soil Analysis, 1965). Organic carbon was then determined using the same procedure, except the ground sample was treated with 1 N hydrochloric acid prior to analysis. The hydrochloric acid drove the carbonate off as carbon dioxide, leaving only the organic fraction. The sample was then corrected for the amount of chlorine added. The difference between the total carbon values of samples treated with acid and those not treated gave the inorganic carbon fraction.

All samples used for carbon, nitrogen, phosphorous, calcium and potassium analysis were oven dried at 104°C and ground to a 20 mesh or smaller particle size in a Wyle mill prior to analysis. Samples used for carbon analysis were redried after grinding and prior to analysis.

Moisture content was determined in all analysis by oven drying at 104°C (Standard Methods, 1975). Carbon dioxide concentrations were determined as discussed in Phase II.

Phase IV

The final phase of the project was designed to assess the economic aspects of composting and to compare composting with other possible disposal alternatives. Information from the first three phases of this project and from material requirements and economics of large scale composting of municiple sewage sludge (Colacicco et al., 1977; Kasper and Derr, 1981) was used to make first-order approximations of the costs and possible returns associated with composting blue crab scrap.

RESULTS

Phase I

Phase I showed that a mixture of blue crab scrap and sawdust could be composted at any carbon-nitrogen ratio between 8:1 and 20:1. It was also shown that moisture contents below 40 percent (wet basis) and above 70 percent did not compost well or simply would not compost. The final product, formed after 21 to 35 days, was stable and gave off few, if any, odors. The stabilized compost looked much like sawdust with a few crab shell pieces in it.

The $1m^3$ bin experiments also showed that during the composting process large amounts of ammonia and other noxious compounds were given off. Differences in the C:N ratio did not appear to effect ammonia generation. The compost pH was also shown to rapidly rise to 8.5 or higher. Results showed that odor control was an absolute must if composting were to be a commercially viable process.

Phase II

The jar and compost chamber tests of Phase II showed that odors could be controlled by maintaining the compost pH below about 7.5 to 8.0. The organic (e.g., acetic acid) and inorganic acids (e.g., sulfuric acid) could be used to control pH during composting if used with a supplementary carbon source. Mixtures consisting solely of crab scrap and a pH-moderating agent required toxic levels of a control agent to prevent odor release. Strong acids, however, are highly corrosive and quite dangerous for untrained workers (such as might handle it in the crab industry) to handle. The acids have to be mixed with the compost and they must be added to the compost every few days to maintain the pH. The cost and volume of acids required make the treatment a rather expensive process.

Granular or powdered sulfur can be mixed with the compost when the crab scrap and carbon source are initially mixed. Sulfur will control the pH during the entire composting period, except during the first 8 or 9 days after it is applied. Sulfur apparently dissolves so slowly that 8 or 9 days are required to actively control pH. This is a major detriment because the compost will generate the most odor between the second and the tenth day. Thus, sulfur appears to be a beneficial and cost effective pH control agent only if combined with something else for short-term control.

Ferrous sulfate is a byproduct of several industrial processes and is marketed in commercial grades at very reasonable prices (i.e., about $.10/lb.). Ferrous sulfate has proven to be effective in controlling compost pH over the entire composting cycle with only a single initial application. It presently appears that some combination of ferrous sulfate and elemental sulfur may provide optimum pH control. The ferrous sulfate will control pH for the initial 8 to 9 days with the elemental sulfur becoming active after that time. The most desirable combination of the two agents will depend on the relative cost of each.

Figure 4 shows the effect of 0, 5 and 10 percent ferrous sulfate addition on compost pH. Only the 10 percent addition maintains the pH below 8.0 throughout the 8-day test period shown in Figure 4.

Figure 5 shows the effect of ferrous sulfate addition on the total mass change in a blue crab scrap/chopped straw compost system. Mass change after 20 days of composting is directly proportional to the amount of ferrous sulfate added. This relationship indicates that composting is more complete if the pH is controlled with 10 percent (of crab scrap weight) ferrous sulfate.

Carbon-Nitrogen Ratio

The carbon-nitrogen ratio has a significant influence on composting. Figure 6 represents temperature-time plots for four mixtures of straw and crab scrap having different C:N ratios. Most literature on sewage sludge composting suggests the C:N ratio should be between 20:1 and 30:1. Figure 6 shows relatively little difference between 18:1, 24:1 and 30:1 ratios. The 15:1 ratio shows a distinctly different temperature curve, especially after 5 days of composting.

Figure 7 details the pH versus time curves for a typical compost run without pH control at four different C:N ratios. None of the pH curves stayed below the desirable pH of 8.0 all of the time, but the highest C:N ratio (28:1) tended to be lower than either the 18:1 or the 15:1 curves. Ammonia volatilization was apparent at all C:N ratios.

Mass change data, Figure 8, shows a C:N ratio of 24:1 provides the

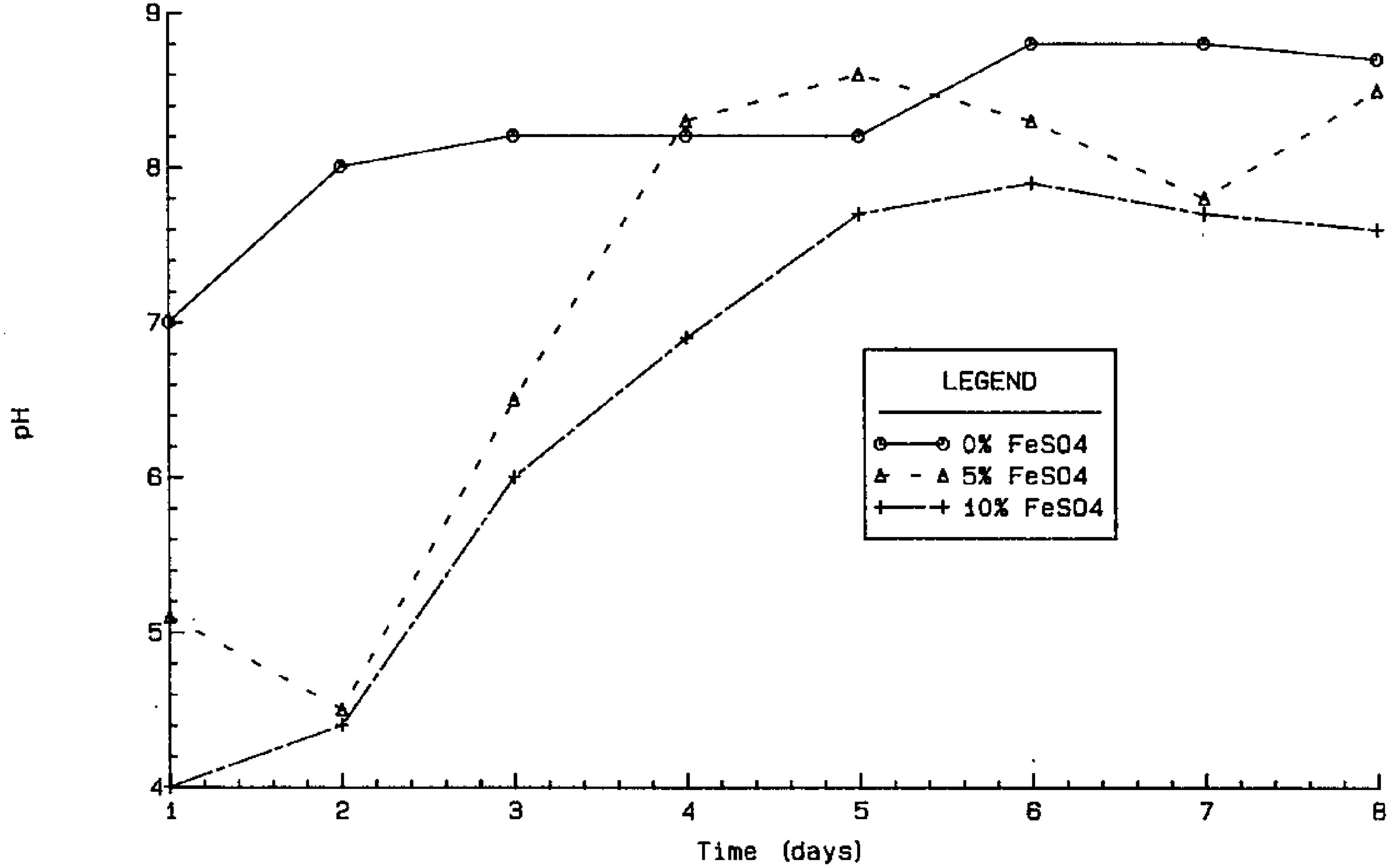

Figure 4. The effect of ferrous sulfate addition on compsot pH.

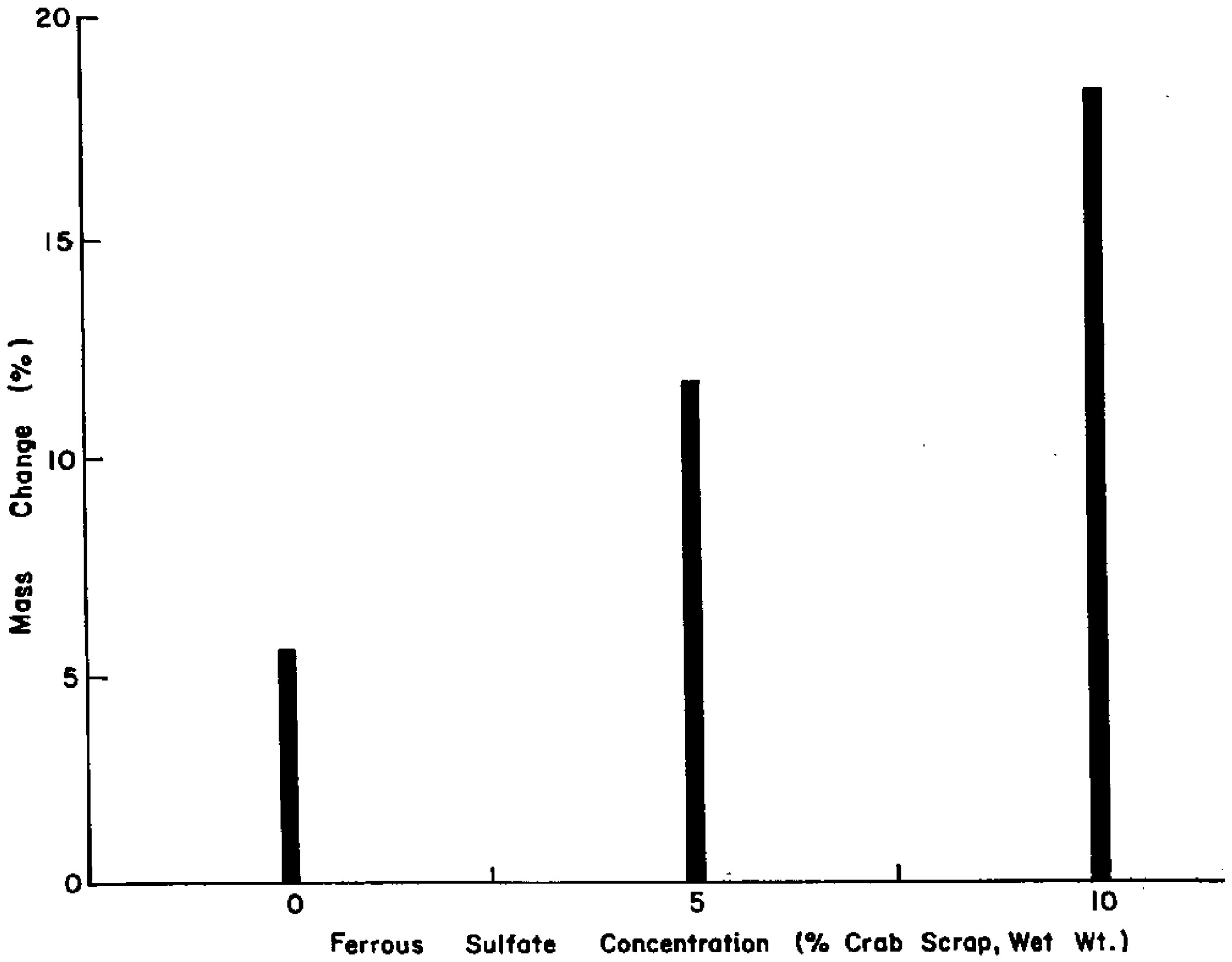

Figure 5. Dry matter weight loss as a function of ferrous sulfate addition to the composting system.

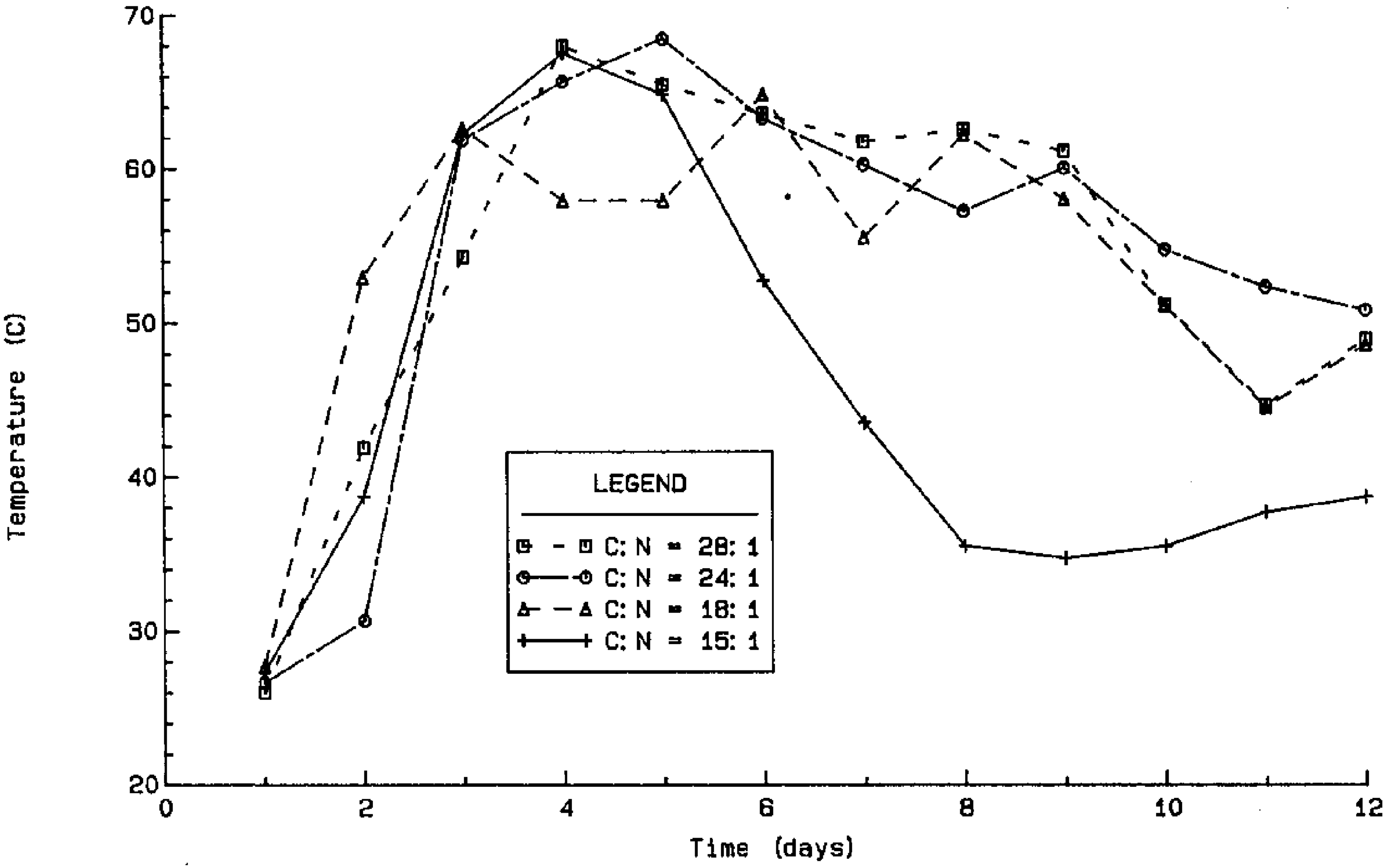

Figure 6.. Effect of various carbon-nitrogen ratios on composting temperature.

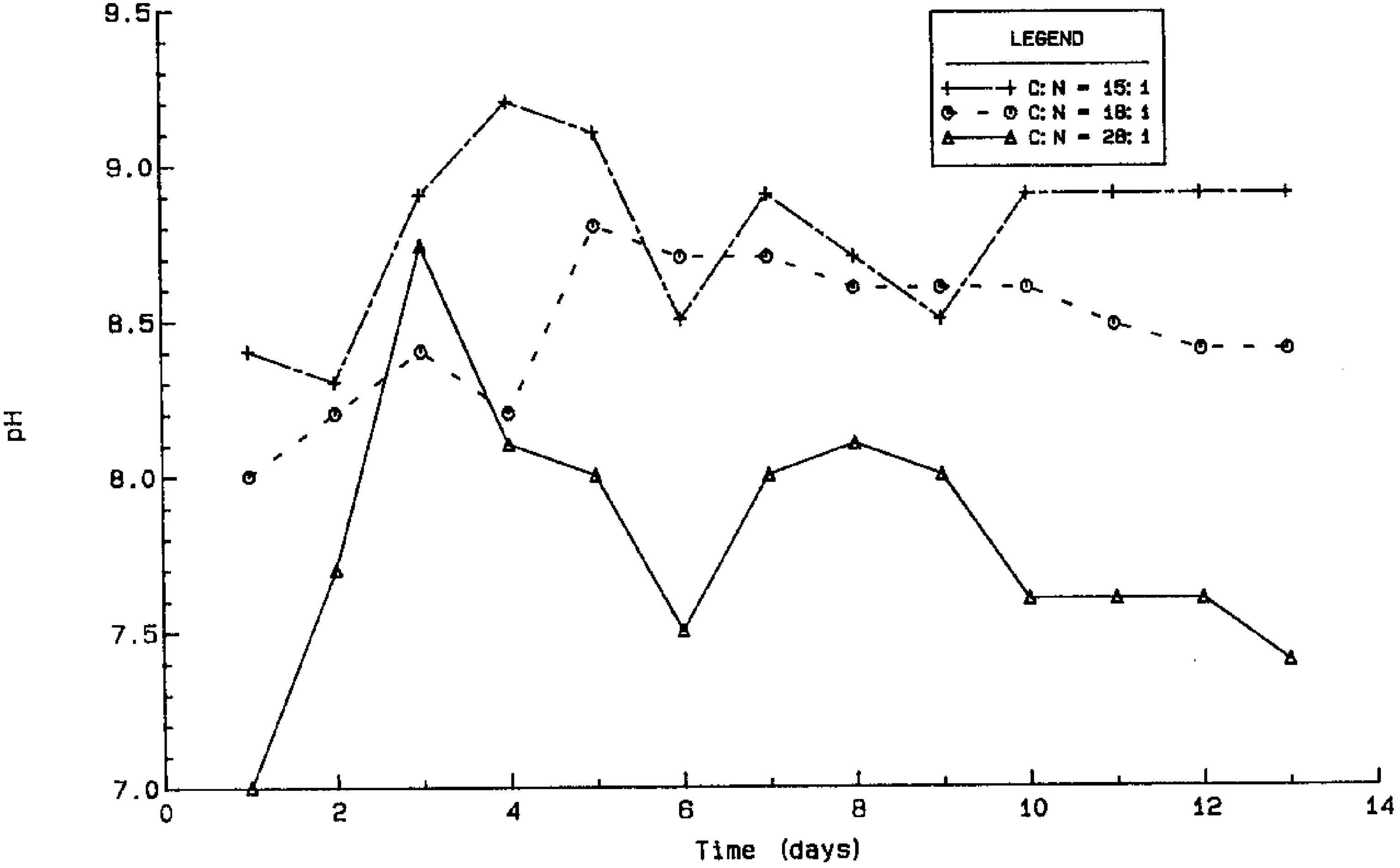

Figure 7. Effect of carbon-nitrogen ratios on pH of the composting system.

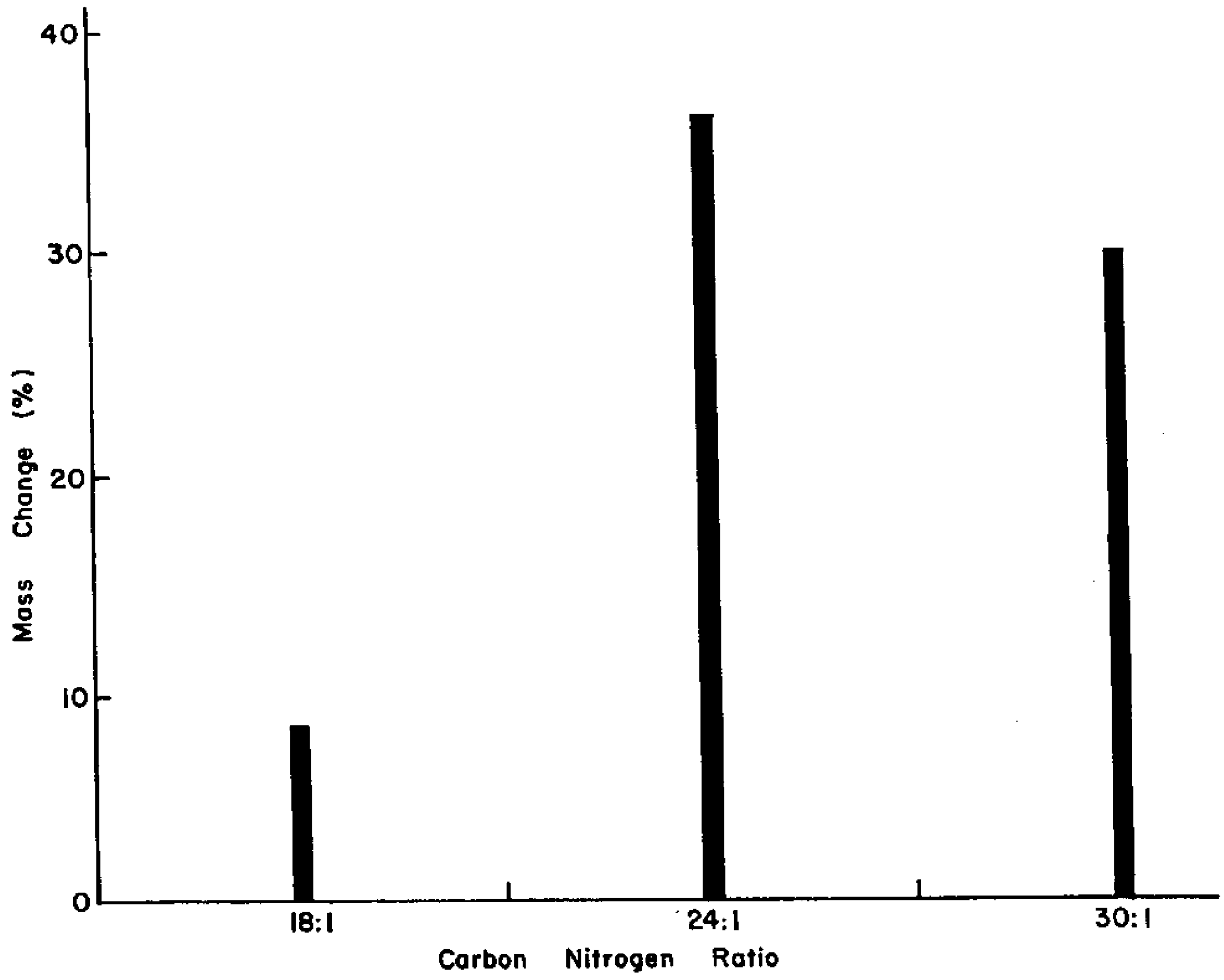

Figure 8. Dry matter weight loss during composting as a function of carbon-nitrogen ratio.

greatest percent reduction in dry matter with the 30:1 ratio being only slightly lower.

Carbon Availability

Carbon availability was a concern when using sawdust as in Phase I. Tests using peat, cotton waste and chopped straw as carbon sources were conducted. Peat and cotton waste were rejected because of limited availability or high transportation costs.

Chopped straw appeared to be superior to sawdust as a carbon source. It showed obvious evidence of degradation during composting. Additionally, it mixed well with the crab scrap, was readily available in almost all areas where blue crabs are processed and was reasonably inexpensive. Its low nitrogen content gave it a very high C:N ratio (60:1 or higher) which made it an excellent carbon source. During composting, the chopped straw broke down into tiny fibers, probably lignin. Peat and cotton waste both appeared to be good sources of organic carbon. Peat, however, is considerably more expensive than straw. The small particle size of the cotton waste created anaerobic pockets within the compost. Because of its desirable characteristics and the above-mentioned disadvantages of peat and cotton waste, chopped straw was used for all subsequent experiments.

Recycling

Preliminary experiments were conducted to determine if the stabilized compost could be used in place of new straw with later batches of crab scrap. Although only a single experiment was conducted, due to time and funding limitations, it appears the stabilized compost will work very well as a substitute for straw for up to 7 recyclings. The elemental sulfur remaining in the compost appears to control pH of subsequent composting cycles. Reuse reduces both the sulfur and straw requirements. Recycling could have significant economic benefits, because it not only reduces straw and sulfur requirements but also reduces transportation costs for both the straw and some of the compost.

Moisture Content

Figure 9 shows the effect of various moisture contents on temperature of the compost system. The 40 percent moisture compost chamber shows a significant decrease in heat production, particularly after 3 days, as compared to the 60 percent moisture content compost chamber.

Phase III

Figure 10 represents a plot of temperature versus time for 2 experimental combinations: one limited to a maximum temperature of 45°C and the other allowed to reach 60°C. The initiation of composting results in a rapid temperature increase. Once compost temperature reaches the set-point, the controller prevents further increases and thus maintains a relatively constant temperature until metabolic self-heating diminishes to the point that the compost temperature declines.

The amount of time that any batch remained at the set-point was inversely related to the maximum temperature allowed (i.e., the hotter the compost, the shorter the time at the set point). This is certainly, at least in part, a function of the amount and availability of food for the composting microorganisms and the higher heat loss through chamber walls at the higher temperatures. It requires more energy to maintain a high temperature than to maintain a lower one. Work by other researchers (Finstein et al., 1980) suggests that the actual period of maximum temperature may also be related to the inhibiting effect of temperatures

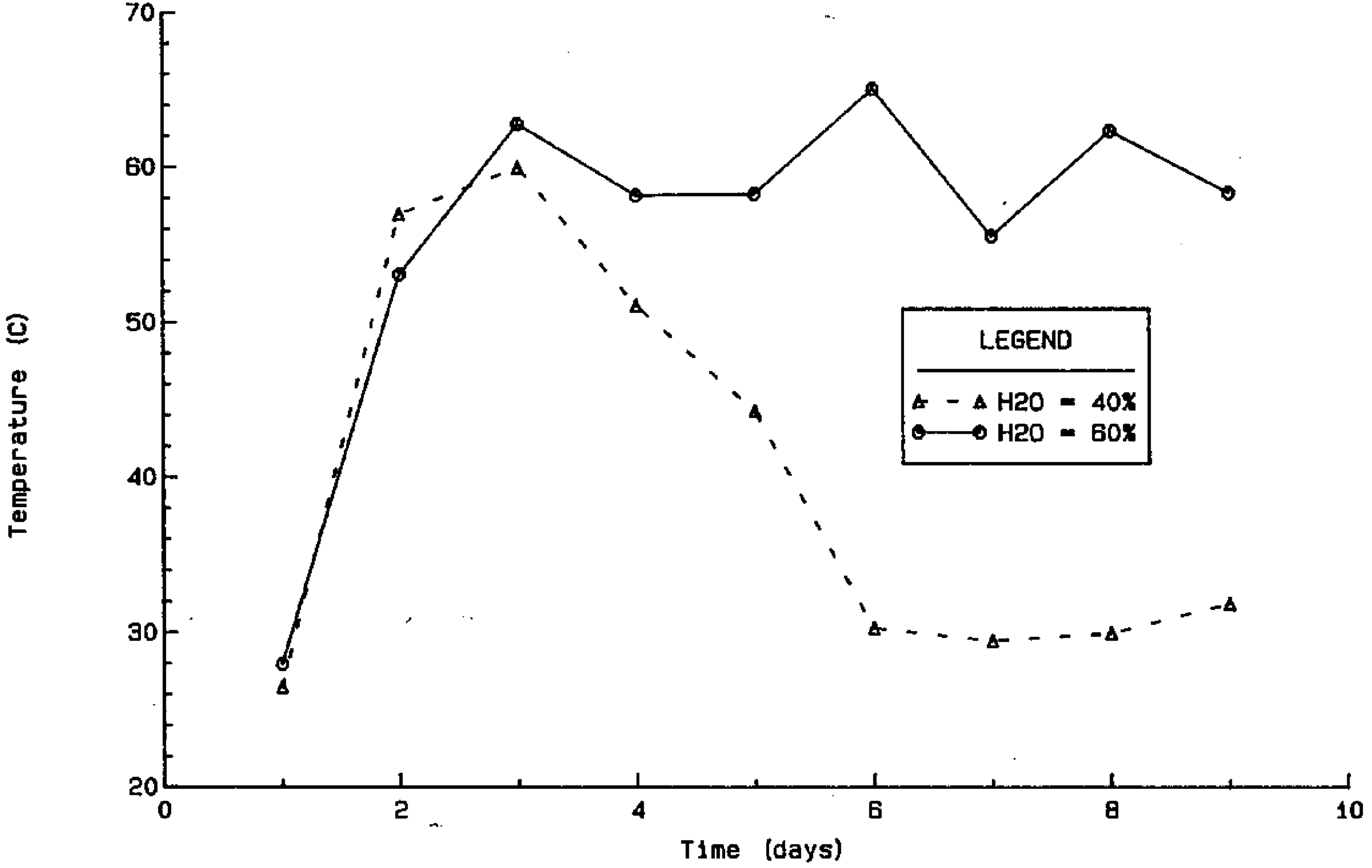

Figure 9. Effect of moisture content on composting temperature.

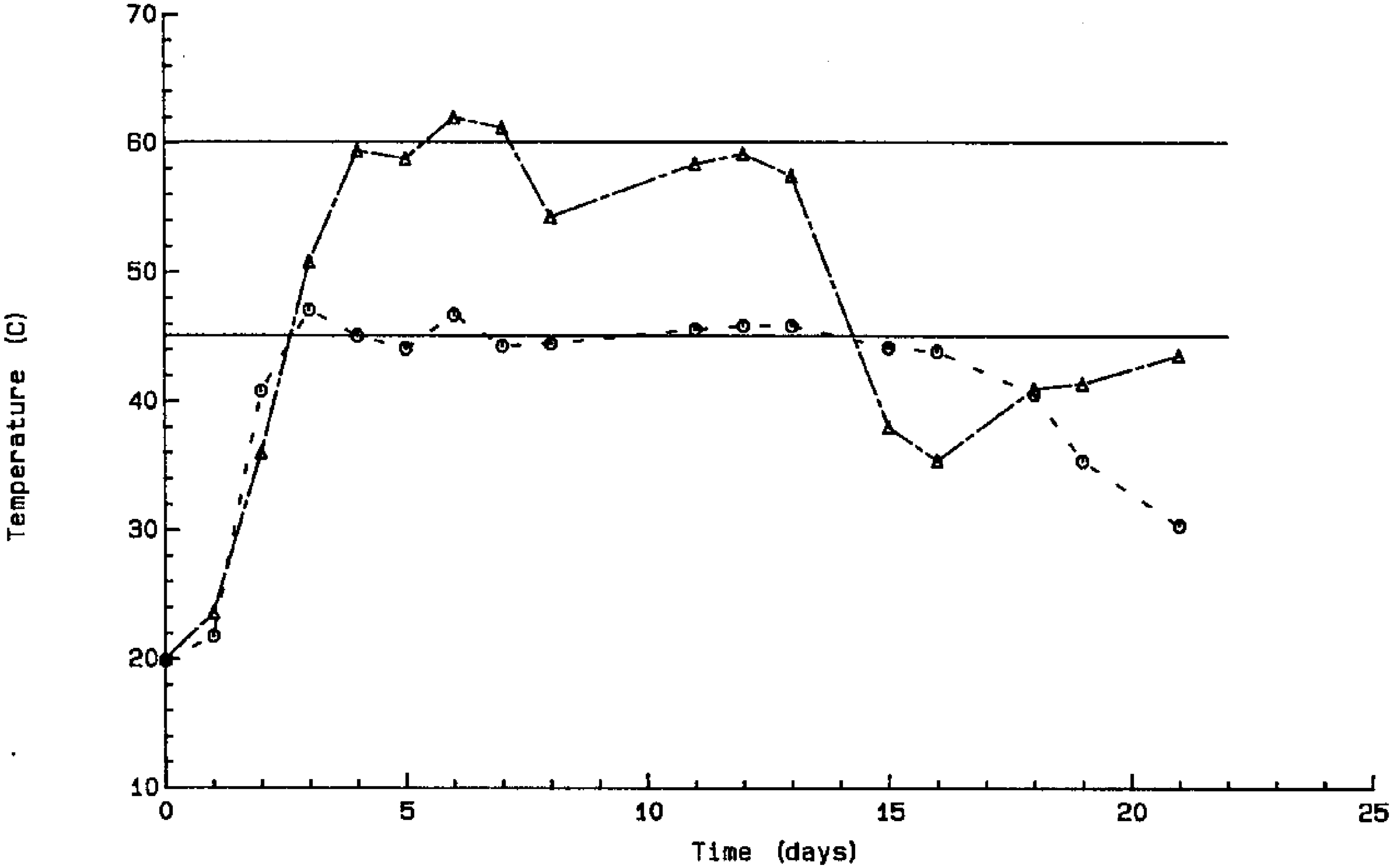

Figure 10. Temperature-time relationship for compost batches showing the effect of temperature control.

other than optimum on the microbiota.

Figure 11 illustrates a typical curve of CO_2 evolution rate versus time for composting crab scrap. Initiation of composting resulted in a dramatic increase in CO_2 generation rate. The utilization of available organic material by the composting microbiota caused a progressive decrease in CO_2 generation, which became especially pronounced near the end of the composting period. Total CO_2 evolved for each experimental combination was determined by integrating rate versus time curve under each CO_2 generation rate.

Tables 2 and 3 provide a summary of the independent variable values (i.e., C:N ratio, set-point temperature, and moisture content) used in each experimental combination. The composting rate (i.e., the dependent variable) is shown as well.

Nuisance odors were not apparent in composting material having a C:N ratio greater than 14:1. In batches having C:N ratios lower than 14:1, ammonia generation was a problem. This was especially true during the first week of composting. For this reason, the lowest C:N ratios tested should not be considered as useful options, at least at the level of pH control attempted in this project.

Shredded Crab Scrap Compost Model

Statistical analysis of the shredded crab scrap data indicated that the carbon-nitrogen ratio is not a significant term in the mathematical model of compost rate. Multiple regression of the data yielded the polynomial given below (Equation 2) which had an R^2 of 0.70.

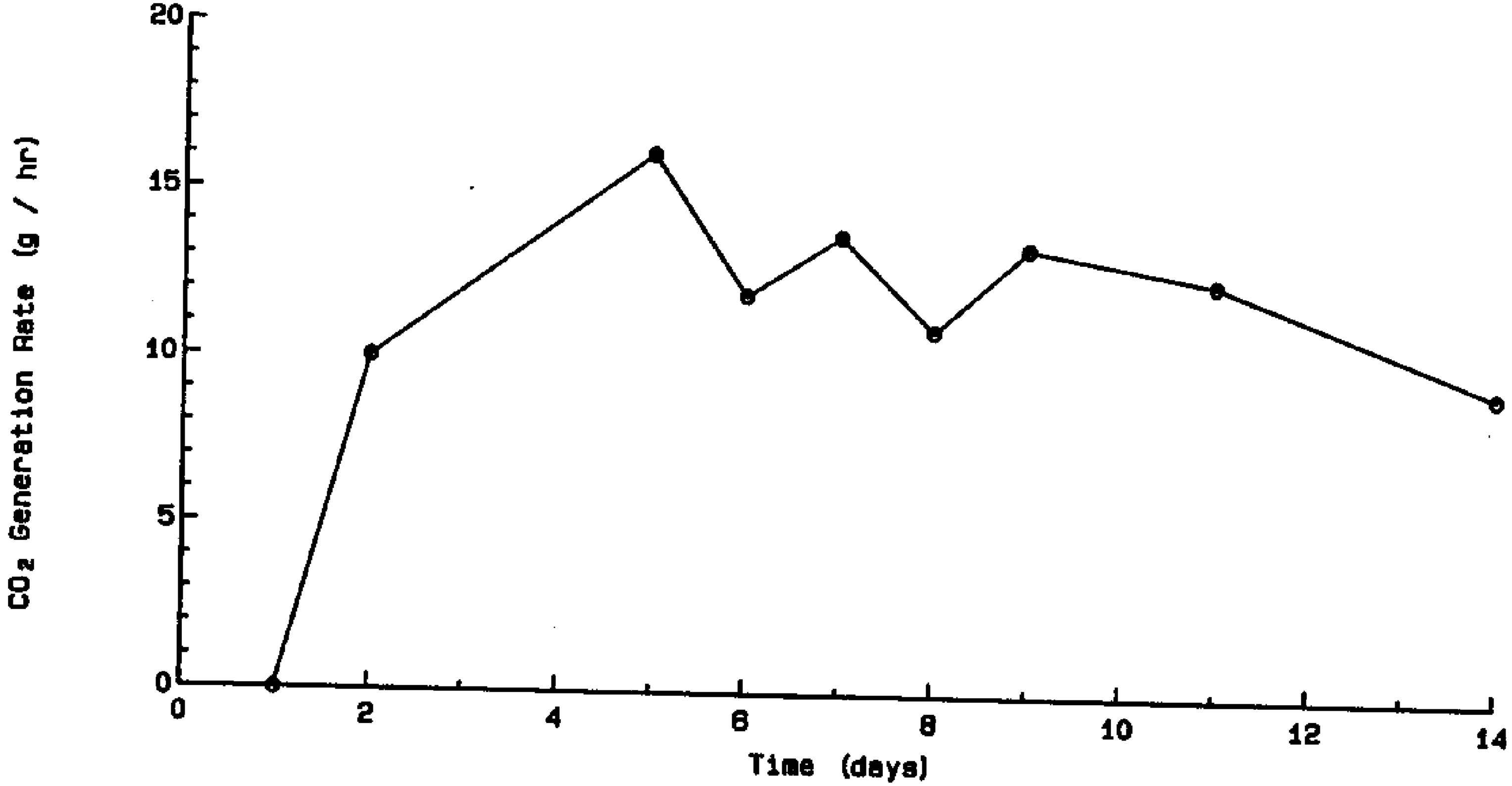

Figure 11. Carbon dioxide generation rate versus time for one batch of composting crab scrap.

Table 2. VALUES OF INDEPENDENT AND DEPENDENT (Y) VARIABLES USED IN THE OPTIMIZING TESTS OF COMPOSTING VARIABLES WHILE COMPOSTING A MIXTURE OF UNSHREDDED CRAB SCRAP AND CHOPPED STRAW.

Test No.	C:N[a]	Temperature (^oC)	Moisture Content (% wet wt)	Y[b]
1	11.5	50.0	54.0	41.6
2	13.8	46.6	51.0	49.2
3	13.6	61.9	48.0	51.0
4	13.6	44.8	63.0	43.3
5	13.6	59.2	62.0	58.0
6	18.5	41.9	53.0	41.6
7	19.5	53.4	52.0	48.0
8	18.5	54.2	57.0	53.2
9	18.5	54.1	56.0	48.9
10	18.5	51.9	53.0	51.0
11	18.5	63.1	53.0	55.0
12	20.0	50.7	43.0	42.5
13	20.0	52.7	67.0	56.6
14	25.0	41.2	46.0	53.8
15	23.4	58.9	46.0	48.4
16	24.5	46.2	65.0	52.1
17	25.0	61.4	60.5	52.9
18	26.7	55.2	58.0	62.8

[a] C:N = Carbon to Nitrogen ratio (dimensionless)

[b] Y = kg of CO_2 evolved during the 21 day composting period per kg of initial dry matter placed in the compost vessel

Table 3. VALUES OF INDEPENDENT AND DEPENDENT (Y) VARIABLES USED IN THE OPTIMIZING OF COMPARING VARIABLES TESTS WHILE COMPOSTING A MIXTURE OF SHREDDED CRAB SCRAP AND CHOPPED STRAW.

Test No.	C:N[a]	Temperature (°C)	Moisture Content (% wet wt)	Y[b]
19	10.4	50.8	57.0	55.9
20	13.6	45.7	47.0	52.9
21	15.0	62.4	49.0	50.4
22	13.6	44.9	64.0	52.7
23	13.6	59.3	65.0	55.5
24	19.5	53.8	40.0	43.1
25	18.8	52.0	58.0	57.6
26	18.8	53.4	56.0	62.6
27	18.5	54.1	59.0	54.1
28	18.5	52.9	56.0	62.1
29	18.5	52.8	55.0	52.9
30	19.5	51.7	66.0	46.8
31	18.5	40.5	55.0	34.6
32	18.5	64.3	55.0	54.2
33	23.4	46.2	50.0	51.3
34	25.0	63.7	46.0	51.2
35	24.5	44.6	65.0	42.9
36	24.5	62.2	60.0	54.2
37	28.5	52.8	56.0	60.1

[a] C:N = Carbon to Nitrogen ratio (dimensionless)

[b] Y = kg of CO_2 evolved during the 21 day composting period per kg of initial dry matter placed in the compost vessel

$$Y = -367 + 9.05\,T + 6.28\,H - 0.081\,T^2 - 0.057\,H^2 \tag{2}$$

Y = Compost Rate ([kg CO_2 generated/kg initial dry matter] x 100)

C = carbon-nitrogen ratio (dimensionless)

H = moisture content (percent, wet basis)

T = temperature (C)

Figure 12 shows the graph of predicted versus observed compost rate for the shredded crab scrap polynomial. The response surface developed from the model is shown in Figure 13. Maximum compost rate was found at a temperature of 55-56°C and a moisture content of 55 percent. The region at which response is 95 percent (or higher) of maximum is illustrated in Figure 14.

Temperature and moisture content optimums of the shredded crab scrap model agreed with published reports of other authors. The lack of significance of the C:N term was rather interesting. However, in this experiment compost pH was controlled. Therefore, ammonia was maintained in the soluble NH_4^+ form (usable by microorganisms) instead of lost as insoluble ammonia gas. As a result, microbe activity was maximized (at least with respect to nitrogen) while the inhibiting effect of nitrogen loss and ammonia release were largely avoided. Since the rationale for a high C:N ratio is to provide carbon to the microorganisms as the nitrogen becomes available (and before it is lost), use of a pH moderating agent may be viewed as a method for holding nitrogen until less readily available carbon may be attacked. In this context, compost activity would not be expected to vary much with C:N ratio.

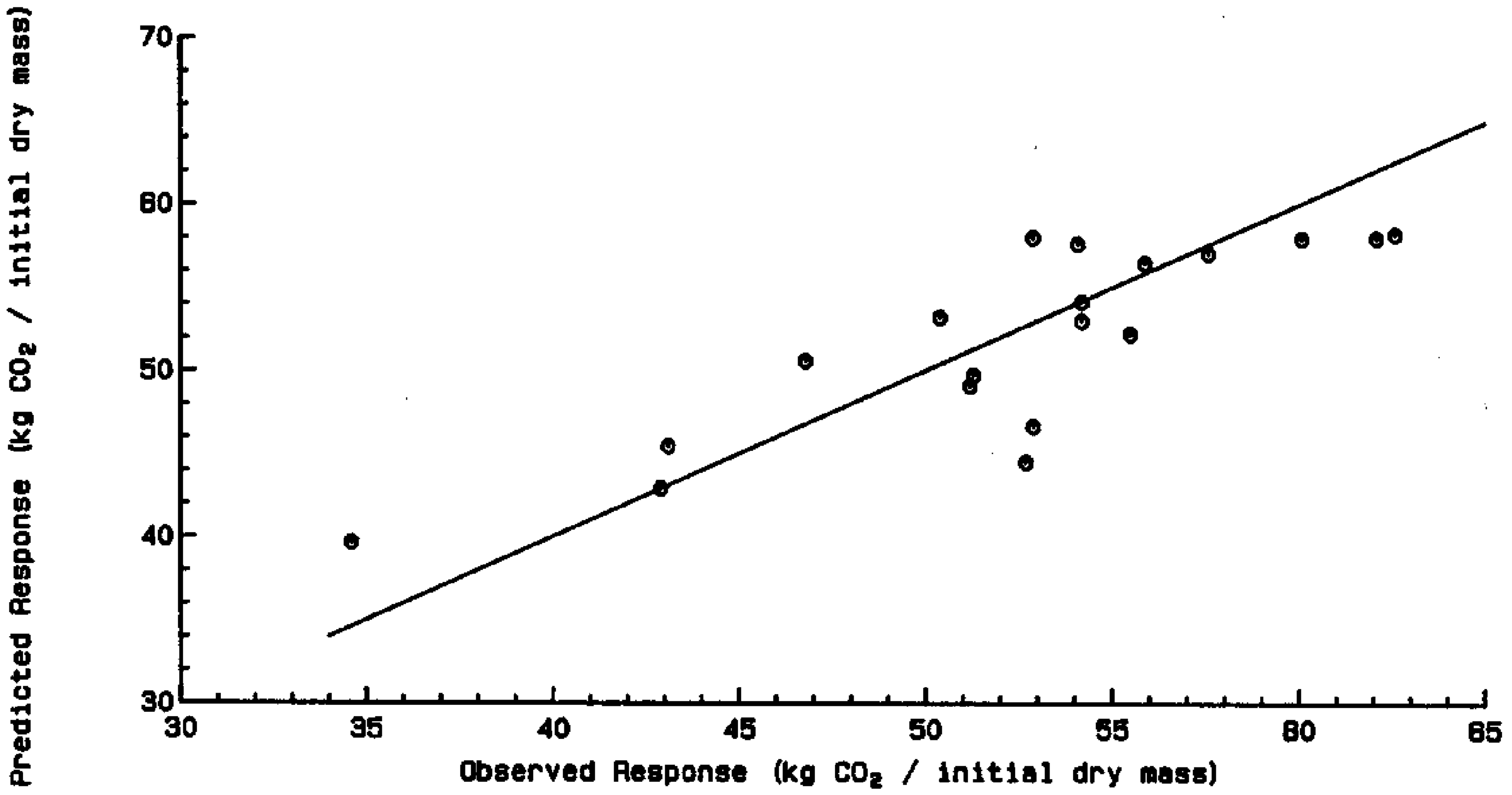

Figure 12. Predicted versus observed response for shredded crab scrap-chopped straw model.

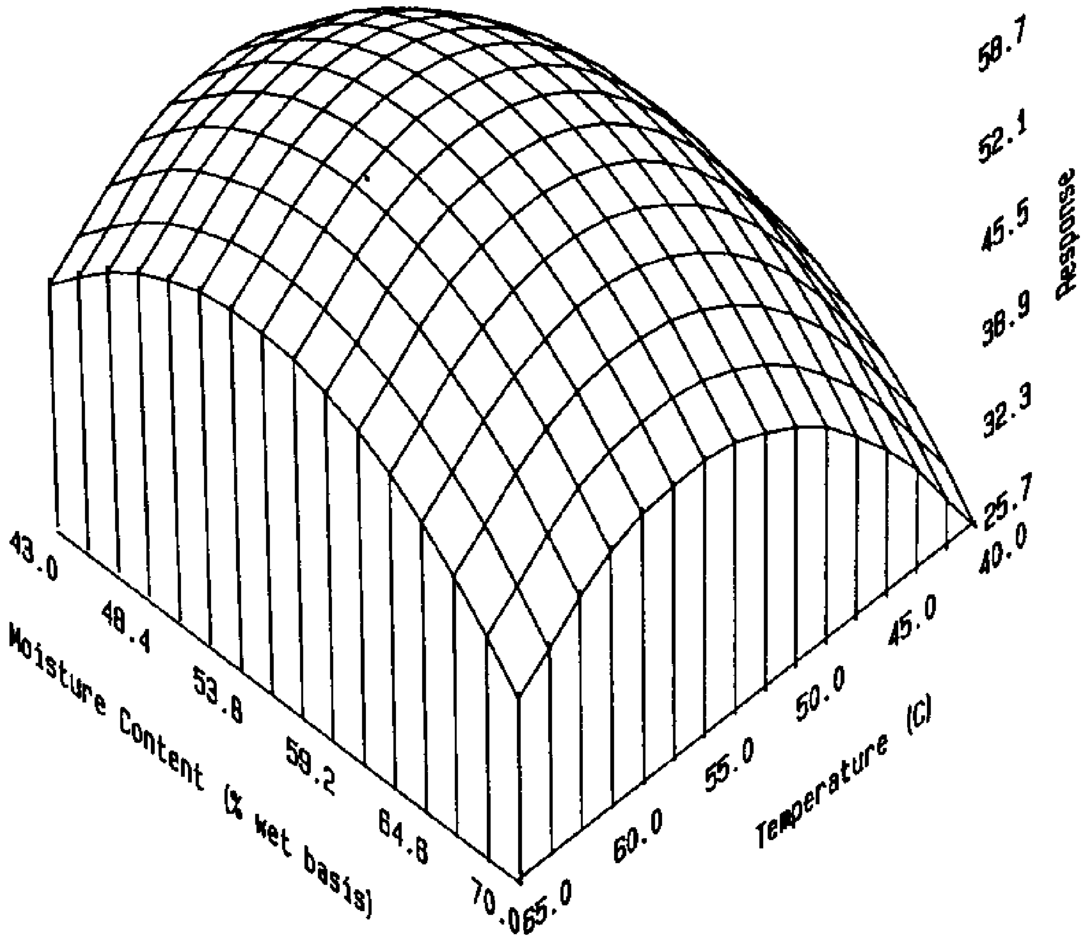

Figure 13. Response surface based on the shredded crab scrap compost model; response = compost rate (kg CO_2/kg of initial dry mass).

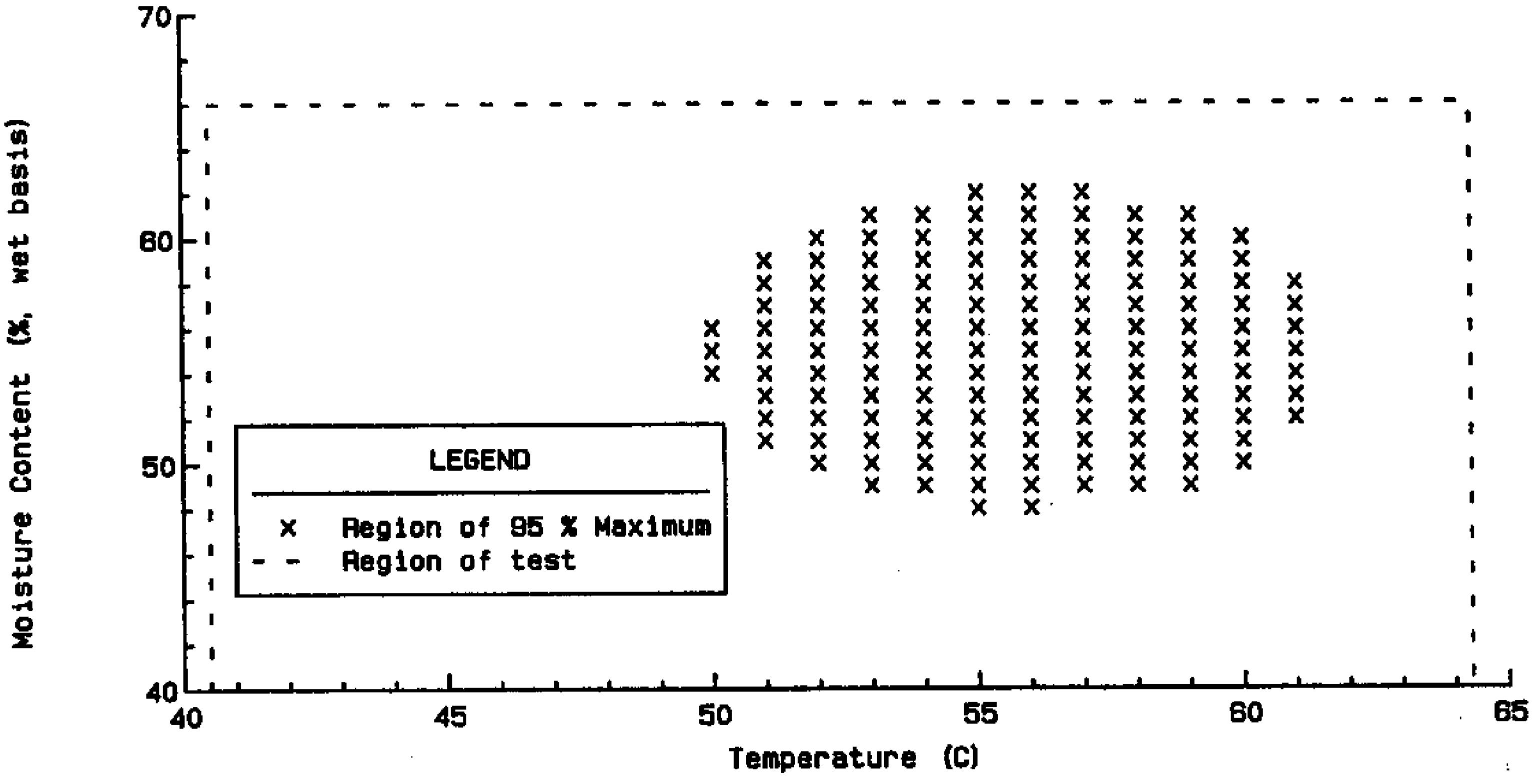

Figure 14. Region in which shredded crab scrap compost rate is at least 95% of the maximum predicted by the model.

Unshredded Crab Scrap Compost Model

The unshredded crab scrap data was used to develop the polynomial given in Equation 3. The R^2 value for this equation is 0.72.

$$Y = 24.0 + 0.084\ C^2 - 0.009\ H^2 - 0.052\ CT + 0.026\ TH \qquad (3)$$

Figure 15 shows the graph of predicted versus observed compost rate for this model. Since C:N ratio, temperature, and moisture content are all significant ($P < .05$), the resulting response surface is not representable in three dimensions. Figurre 16 represents a "slice" taken through the fourth dimensional surface at a moisture content of 60 percent. The maximum compost rate for the model as a whole was found at a C:N ratio of 11.5:1, a moisture content of 67 percent, and a temperature of 63°C. This is not however, a practical optimum as noted earlier.

The optimum C:N ratio for unshredded crab scrap compost contradicts virtually all prior published reports. That significant biological activity can occur at such a low C:N ratio is probably due to the use of the pH-moderating agent. Its superior composting rate, relative to mid-range C:N ratios may be an anomaly in the model. It is possible that the carbon in straw is more resistant to microbial attack than the carbon from crab scrap. If this is true, then the response variable, compost rate, may be biased in favor of batches having a high crab scrap content (i.e., a low C:N ratio). Whatever the reason, the 11.5:1 C:N ratio is not practical due to the ammonia generation problem mentioned above. The region for which compost rate is 95 percent or greater of maximum, and for which the C:N ratio is greater than 14:1, is shown in Figure 17. The optimum variable values for C:N ratios

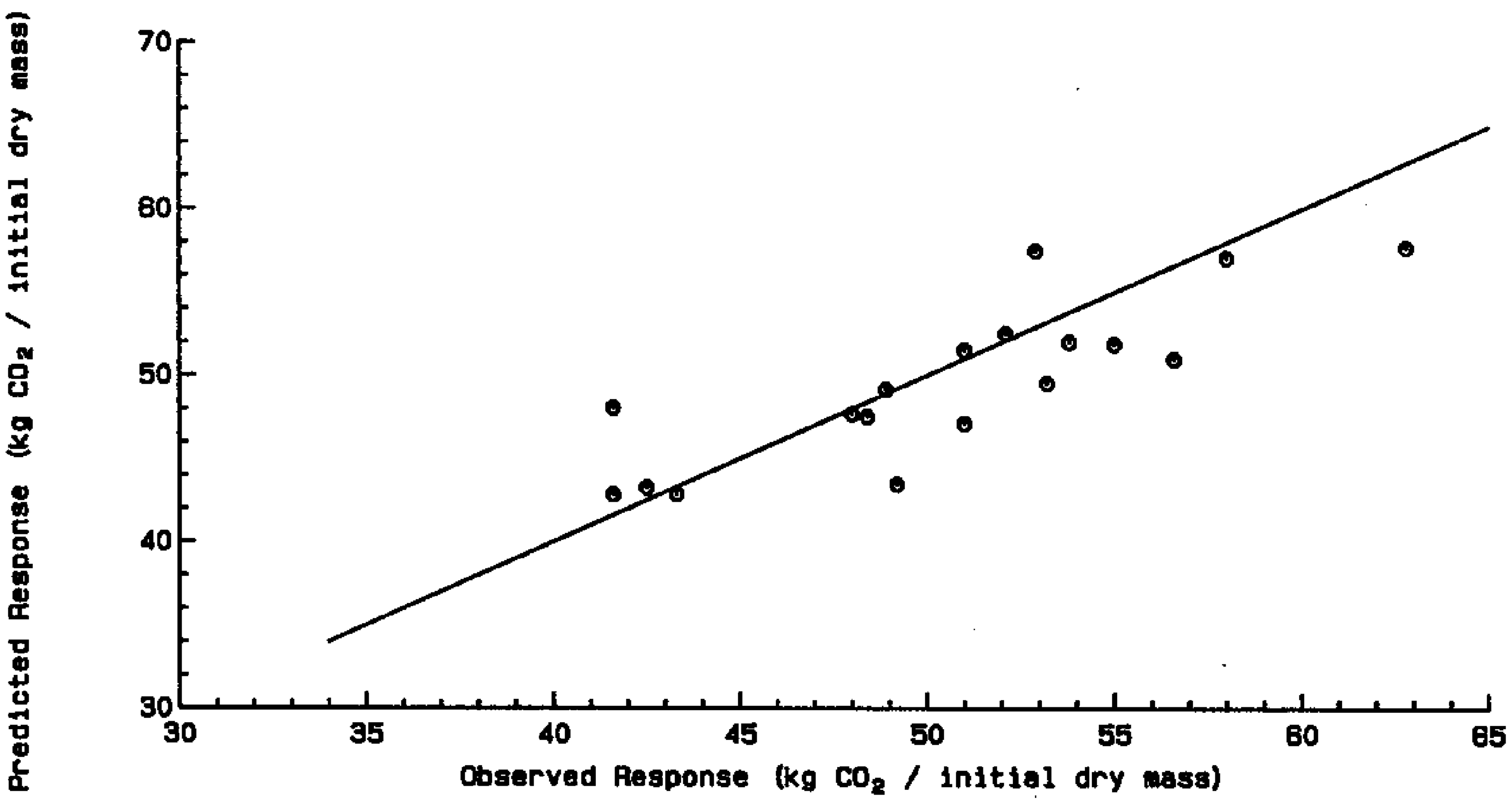

Figure 15. Predicted versus observed response for the unshredded crab scrap-chopped straw model.

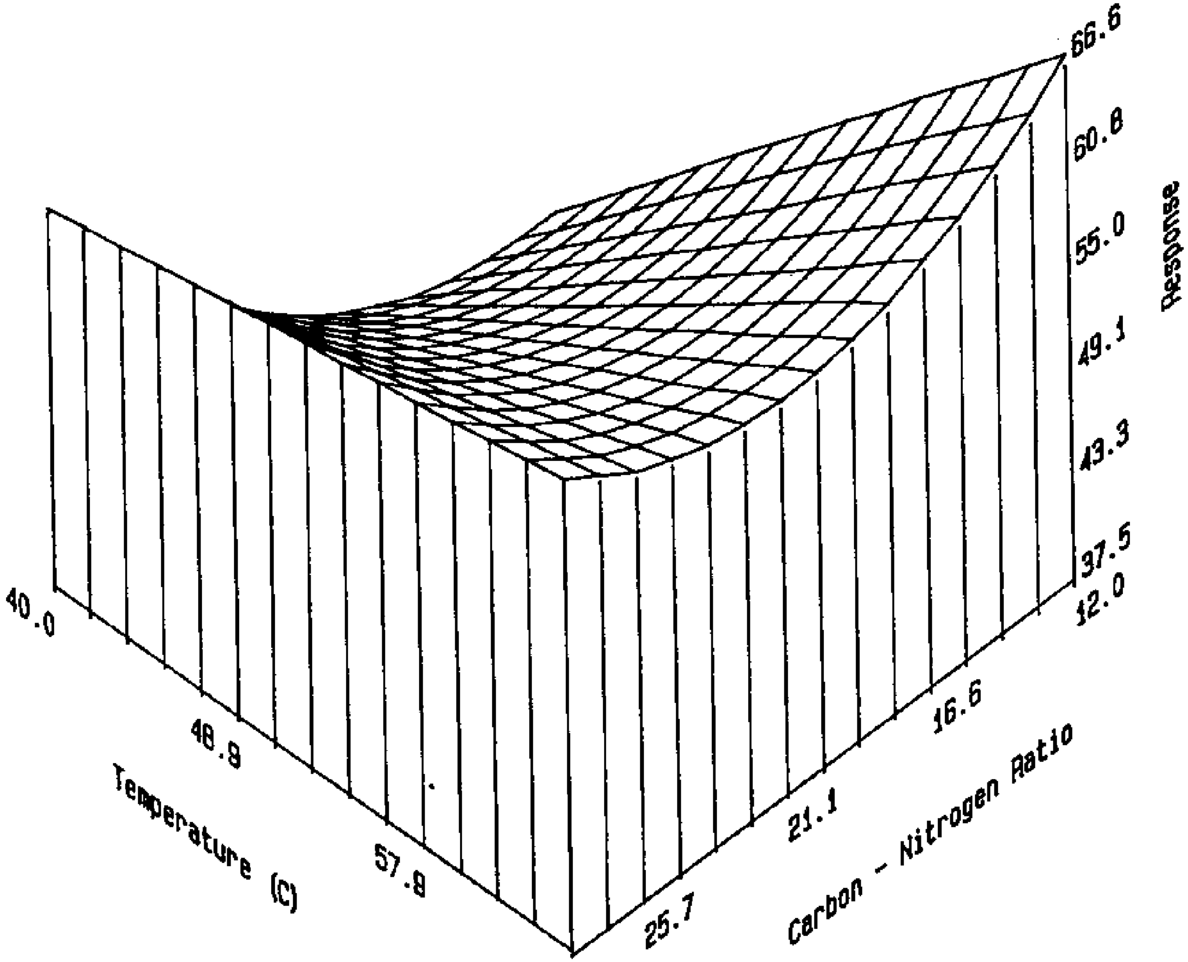

Figure 16. Response surface based on the unshredded crab scrap compost model (moisture content = 60%); response = compost rate (kg CO_2/kg initial dry matter).

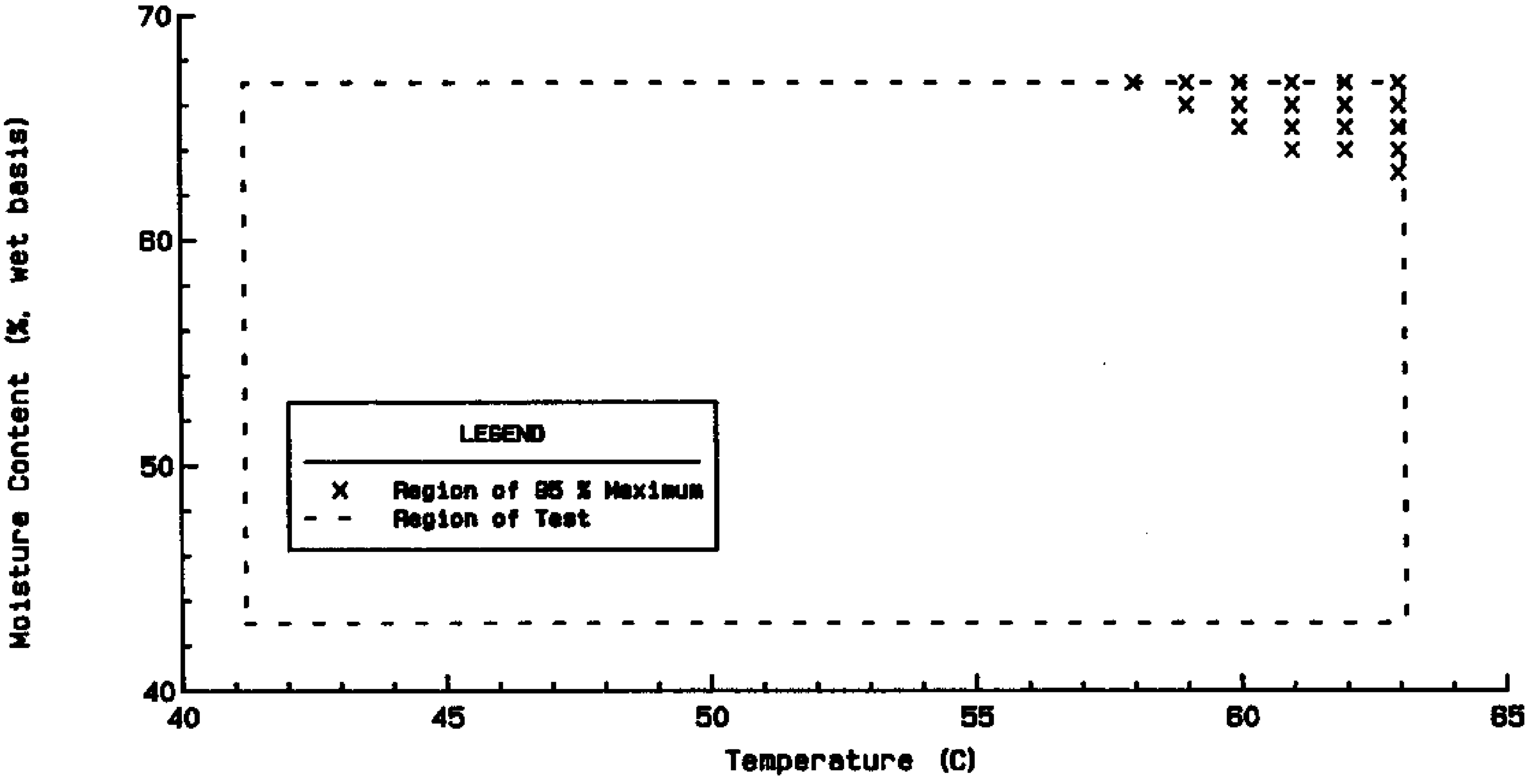

Figure 17. Region in which unshredded crab scrap composting rate is at least 95% of th maximum predicted by the model (C:N ratio = 25.5-26.5:1).

above 14:1 are: 67 percent moisture content, 63°C and 26.7:1 C:N ratio. These optimums were the highest values tested for all parameters studied.

Comparison of Shredded and Unshredded Models

Since both shredded and unshredded crab scrap compost are composed of the same materials, it is probable that differences in temperature and moisture content optimums are traceable to the shredding process. A mixture of shredded crab scrap and straw is relatively homogeneous. Nutrients are evenly distributed throughout the material, as is the anhydrous acid (ferrous sulfate). The potential for ammonia generation is therefore limited. This is not the case for a mixture of unshredded crab scrap and straw. Most nitrogen, in such a mixture, is concentrated within discrete regions (i.e., pieces of crab scrap) which are often partially enclosed in impermeable shell material. Isolated from most of the straw and only peripherally in contact with anhydrous acid, conditions are ripe for locally high pH and consequent generation of ammonia. This condition may effect optimum temperature and moisture content in two ways. First, it may cause dessication of the crab scrap. Water is an end product of aerobic degradation. Finstein and his associates (1980) have used this fact to explain why temperature control maximizes availability of water when compost temperature is maintained at 45-55° C using forced aeration. Secondly, ammonia generation can inhibit the activity of microorganisms. If this occurs, water production will diminish, causing (or exacerbating), net removal of water from the crab scrap. There is evidence that dessication did occur more readily in the unshredded than in the shredded crab scrap compost. Visual examination of pieces of crab scrap that were enclosed in shell (e.g., claws and parts of the carapace) revealed that meat and viscera were not always completely degraded at the end of the composting period. Rather, they were often partially intact and quite dry. Presumably, net transport of water diminished the moisture content of such pieces to the point where degradation was inhibited.

Analysis of aeration rates showed that the total air flow through the shredded crab scrap-chopped straw mixtures were significantly greater ($P<.05$) than it was through the unshredded crab scrap-chopped straw mixtures. The higher air flow was necessary to control temperature in the shredded compost mixture, a fact tending to indicate the composting rate was more rapid in the shredded than in the unshredded mixtures. Unfortunately, insufficient data is available to determine if these apparent differences in composting rates are real or a result of inherent variability within the composting system.

A possible explanation of the high optimum values for the independent variables in the unshredded systems concerns nitrogen conservation. In unshredded compost, most nutrients are concentrated away from the straw. Yet it was noticed that the straw was readily degraded. Since mixtures consisting soley of straw and water degrade very slowly, some mechanisms of nitrogen diffusion in the compost must be postulated. Given the condition of ammonia generation described above, it seems probable that some generated ammonia may have been reionized as it came into contact with the straw-water-acid mixture surrounding each piece of crab scrap. In fact, the mixture may be thought of as a natural ammonia trap. Its efficiency is proportional to the amount of straw and water (since the amount of acid per unit of crab scrap was constant) that it contains and to the amount of time that the ammonia remains in the compost. This interpretation not only explains the high moisture and high temperature (i.e., low aeration rate) optimums encountered, but it may partly explain the high C:N ratio optimum as well. Unfortunately, there is insufficient evidence to determine what, validity if any, such an interpretation may have.

Comparison of the two models for crab scrap compost rate indicates that the maximum response for unshredded compost may be greater than that of the compost using shredded crab scrap. It is difficult to determine, however, how much of the difference may be due to random varibility in the models. Comparison of the actual observed responses (Tables 2 and 3) using analysis of variance shows no significant difference between the shredded and unshredded crab scrap data at the 0.10 level.

Phase IV

Nutrient Content

Phase IV included the economic analysis of the composting process. The first step of the analysis was to determine the compost nutrient value as a fertilizer. Analyses indicated that the straw contained about 1.5 percent potassium (dry weight basis), 0.5 percent phosphorus, 1.0 percent nitrogen and 0.3 percent calcium. The raw crab scrap contained about 0.60 percent potassium, 3.5 percent phosphorus, 6 percent nitrogen and 13.0 percent calcium. Because the compost was composed of a mixture of crab scrap and straw in various proportions, the nutrient content of the compost varied. The nitrogen content varied between 1.8 and 2.8 percent, phosphorus between 1.6 and 2.7 percent, potassium between 1.2 and 2.3 percent, and calcium between about 4 and 10.5 percent. The percentage of potassium in the compost exceeds the initial percentage of potassium in either raw product. However, during composting there is significant loss of dry matter which will change the percentage in the compost relative to straw and crab scrap.

Composting Costs

The economic aspects of composting are estimated in this section. The values given here are based on the best data available. However, care must be taken in making comparisons between the various waste disposal techniques discussed, because waste disposal often has costs external to the industry (e.g., odors, environmental degradation, etc.) that should be considered. For example, the costs of offshore dumping of crab scrap, presented in a later section, do not include the potential harm to the dumping area's appearance and usefulness. On the other hand, dumping might produce external gains should dumping supply a limiting nutrient which then causes increased primary, and in turn, increased fish production. Composting, compared to other means of waste disposal, is relatively free of most external costs. Therefore, even if the private costs of composting are greater than alternative disposal methods, it may still make sense to compost if the alternative methods produce external costs.

Without an actual pilot crab scrap composting operation, it is necessary to extrapolate from laboratory experiments the requirements for a commercial-scale composting facility. The experiences of sewage sludge composting studies (Colacicco et al., 1980; and Kasper and Derr, 1981) are also used. A description of a proposed crab-compost process, based on small-scale experiments, is offered and then expanded to a large-scale operation. Judgment is used to account for differences in requirements between laboratory and commercial scale and between sludge and crab scrap processes. The costs presented are intended to represent the maximum costs of production so that any individual attempting to compost may not incur all costs as presented here.

Capacity Requirements

The first question is what size composting operation should be considered? A 1980 survey of Maryland crab processors by Maryland Sea Grant showed that the average processor produces over two tons of crab scrap per day or 236 tons of crab scrap a year (Brinsfield, 1981). The survey also showed that the two largest crab scrap producing counties in Maryland, Somerset and Dorchester, handled over 30 tons of crab scrap a day, or 3,500 tons per year. Based on these results, we estimated the costs for composting facilities with the capacity to handle 3 tons and 40 tons per day. This corresponds to one composting operation per processor or one per county, respectively. Since crab scrap is deposited in two landfills in each county, the costs for a 20-ton-per-day capacity operation corresponding to a composting operation at each landfill are estimated. Thus, the three sizes considered correspond to a process for a single picking operation, one for a county level operation and one for a region-wide operation.

Capital Costs

Land: The composting configuration envisioned is one in which there are separate daily compost piles. The area required for each pile is a function of the density of the crab/straw mixture and the height of the pile. Since 14-18 days of aeration are required for a stable product, at least 14 aerated piles will be needed, plus space for natural aeration (curing). Space is also required for working and for storage of equipment and materials.

Kasper and Derr (1981) estimated area size requirements for five different size sludge composting operations (Table 4). Although crab waste is less dense than sludge, composting crab scrap requires less area per ton because 14-18 days aeration is needed as opposed to 21 days for sludge. Additionally, it maybe feasible to recharge crab scrap compost many times thereby lessening the need for supplemental carbon and hence storage space.

Based on the above factors, the sludge composting area requirements were decreased by 40 percent to obtain estimates for crab scrap composting area requirements. It is estimated that a 3-ton-per-day operation would require about 1.2 acres of land. The land requirement may make this size operation impractical in densely populated areas, especially because a buffer area might be required to shield surrounding inhabited areas. The three-ton-per-day operation would be more practical for isolated processors.

The larger operations do not require a proportional increase in land requirements due to the fact that larger piles would take up less space than increasing the number of piles, and there is not a proportional increase in other equipment requiring space. Assuming similar economies of size as in sludge composting, a 20-ton-per-day crab scrap composting operation would require about 4.5 acres and the 40-ton per-day about 6.5 acres.

Murray and DuPaul (1981) did not include land costs in their analysis of a crab meat plant due to the high variability in land prices in areas of close proximity. For this study, land prices on Maryland's Eastern Shore are estimated at $3,000 per acre for higher elevation tillable land. The small three-ton per day composting operation would not have the flexibility in choice of land.

Table 4. AREA REQUIREMENTS FOR DEWATERING AND COMPOSTING SEWAGE SLUDGE (Source: Kasper and Derr, 1981).

Design Capacity (Dry tons/day)	Actively Used Area (acres/dry ton)
3	.66
13	.36
26	.21
50	.17
100	.16

The larger 20 and 40-ton per day operations would have to operate in the higher elevations where there is from five to eight feet to the water table. The lower water table is required due to leaching of undesirable material from the larger operations. This land might be near or in a landfill.

Site Preparation: Experience with other material composting technologies has shown that the composting site requires a hard surface. The surface acts as an operating pad for the heavy machinery and prevents soil from being mixed with the compost. The surface can also be used to control runoff. Although concrete is the surface usually used in composting, asphalt is less expensive. If the operator is cautious, the asphalt pad could last up to ten years. A cubic foot of asphalt weighs approximately 150 pounds. At $20 per ton, one acre of a six-inch thick asphalt pad will cost $32,500. Labor costs for laying asphalt were estimated at $8,900/acre.

Equipment: Experiments with crab scrap composting have demonstrated that it may be beneficial to shred the straw and the crab scrap before composting. In this analysis it was assumed that shredding would be performed. For the 3-ton per day operation, a shredder of the size used by a home gardener, costing $1,000, would be adequate. Larger composting operations would require a commercial-size shredder which costs approximately $8,000.

Equipment is also required for the mixing and transfer of materials during the composting operation. This function can be handled at the small composting site by a 40 hp tractor with the proper front-end loading accessories. The cost of this rig is approximately $13,000. At the 20-ton per day site, two similar sized tractors would be required. At the 40-ton-per-day site a front-end loader with a three-to-four-cu. yd. bucket capacity would be sufficient. The cost of this sized front-end loader can range from $30,000 to $85,000. A representative cost of $50,000 was used in this analysis.

Additional equipment is necessary for aeration of the compost piles. Each pile requires its own blower so its aeration rate can be independently controlled. The smallest industrial blowers available are 1/3 hp and are sufficient to aerate approximately 20 wet tons of material. The blowers with timers and wiring will cost about $150 each. The 40-ton/day operation will require one hp blowers. These will cost approximately $200 each.

The blowers will be connected to aeration pipes in each pile. Extrapolating from the Camden, New Jersey, sludge composting facility

(Kasper and Derr, 1981), 45, 100, and 200 feet of pipe per pile will be needed for the 3, 20 and 40-ton-per-day operations, respectively. If the pipe is removed from the pile after composting so that it is not damaged by machinery, PVC pipe can be used. The cost of four-inch diameter PVC pipe is approximately $215 per 100 foot section. Costs of installing the equipment were not included in the analysis.

Variable Costs

For this analysis it is assumed that the crab scrap and straw are to the crab scrap at a ratio of 1:1. Ferrous sulfate ($FeSO_4$) is added to the compost at a ratio of 0.1:1, $FeSO_4$ to crab scrap. The annual requirement for straw in a 3-ton-per-day operation is 236 tons, 750 tons for the 20-ton-per-day plant, and 3,500 tons of straw for the 40-ton-per-day plant. Recharging, which allows the straw to be used many times over, would significantly reduce straw or other carbon source requirements. It was estimated that a 3, 20 and 40-ton-per-day composting operation would require annually: 5 tons $FeSO_4$, 34 tons $FeSO_4$ and 67 tons $FeSO_4$, respectively. The cost of straw is approximately $50 per ton and $FeSO_4$ costs $0.10 per pound.

Labor: Most of the labor required in composting is required for transferring the material. A 3-ton-per-day operation would only require one-half a man-year of skilled labor, while the larger operations would require one man-year. An annual salary of $18,000, which includes fringe benefits, was used for the analysis.

Fuel and Electricity: The fuel and electricity requirements were estimated based on the Kasper and Derr (1981) study. An amount of $3,000 per year was used for the 3-ton-per-day analysis. For the 20 and 40-ton per day operations $10,000 and $20,000/year were used, respectively.

Maintenance, Repair, and Insurance: Since it is difficult to estimate maintenance costs without studying plants in operation, the information from other composting studies was used. In these studies, maintenance, repair, and insurance usually amount to about ten percent of total capital costs. Thus, ten percent of capital costs was used in this analysis.

Summary of Costs: Table 5 summarizes the estimated costs used in this analysis and their sources. Tables 6, 7, and 8 are the estimated costs associated with the operation of the three different sized composting operations.

Composting exhibits considerable economies of size from the 3-ton-per-day to the 40-ton-per-day operation. Average costs per ton of compost produced were $131, $74, and $64 for the 3, 20, and 40-ton-per-day capacity plants, respectively. This is based on average production over the year. Plants operating at full capacity could reduce average costs.

The most significant capital cost is the installment of the asphalt pad. Future experiments should focus on the necessity of a pad and if there are ways to make the pad size requirement smaller. In the 3-ton-per-day operation, the pad adds about $21 per ton to the cost of producing compost, and it adds about $7 per ton in the 40-ton-per-day operation.

Significant composting costs are labor and the cost of straw. The three-ton/day operation is labor intensive, with labor accounting for $27 of the average cost/ton of compost. The costs of compost production contributed by labor drops to $0.36 per ton in the 40-ton per day operation.

Table 5. COST ESTIMATES OF COMPONENTS OF COMPOSTING OPERATION

Component	Estimated Cost	Source
Land	$3,000/acre	Eastern Shore Realtors
Asphalt Pad		University of MD
Materials	$20/ton	Asphalt Institute
Labor	$8,500/acre	Engelsman, 1983
Blowers (1/3 hp)	$102	Industrial Equipment Dealers
(1 hp)	$156	
Pipe (PVC) 4"-dia, Sch. 40	$216/100 feet	Pipe Suppliers
Shredder		
Garden	$1,000	Farm Equipment Dealers
Commercial	$8,000	
Tractor	$13,000	Magazine Ads
Front-End Loader	$30,000 - $84,000	Kasper and Derr, 1981
Straw	$50/ton	Feed Dealers
$FeSO_4$	$0.10/ton	Chemical Suppliers

Table 6. COSTS FOR A 3-TON PER DAY CRAB SCRAP COMPOSTING FACILITY

	Quantity	Cost	Annualized Cost[1]	% of Annual Cost
Capital Costs				
Land	1.2 acres	$ 3,600	$ 499	5.0
Asphalt Pad	1.2 acres	50,200	6,953	70.5
Blowers & Timers	14	2,100	291	2.9
Pipe (PVC)	630 feet	1,300	180	1.8
Garden Shredder	1	1,000	139	1.4
Tractor	1	13,000	1,800	18.2
Total-Capital Costs		$71,200	$ 9,861	
Operating Costs				% of Composting Cost
Straw	236 tons	$11,800		34.9
$FeSO_4$	5 tons	1,000		2.9
Labor	0.5 man-year	9,000		26.6
Fuel & Elec.	-	3,000		8.8
Maint., Repair, & Insurance	10% of fixed costs	7,000		20.7
Miscellaneous	-	2,000		5.9
Total Operating Costs		$33,800		
Total Annual Costs		$43,611		
Average Cost/Ton Crab Scrap		$ 185		
Average Cost/Ton Compost[2]		$ 131		

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[1] At 12.5% interest for 10 years corresponding to the expected life of the asphalt pad.

[2] Assuming a 30% mass loss

Table 7. COSTS FOR A 20-TON/DAY CRAB SCRAP COMPOSTING FACILITY

	Quantity	Cost	Annualized Cost[1]	% of Annual Cost
Capital Costs				
Land	4.5 acres	$ 13,500	$ 1,879	5.6
Asphalt Pad	4.5 acres	184,500	25,554	77.8
Blowers & Timers	14	2,100	291	0.8
Pipe (PVC)	1,400 feet	3,025	419	1.2
Shredder	1	8,000	1,108	3.3
Tractors	2	26,000	3,601	10.9
Total-Capital Costs		$237,125	$32,843	
Operating Costs				% of Composting Cost
Straw	1750 tons	$ 87,500		58.3
$FeSO_4$	34 tons	6,800		4.5
Labor	1 man-years	18,000		12.0
Fuel & Elec.	-	10,000		6.6
Maint., Repair, & Insurance	10% of fixed costs	23,700		15.8
Misscellaneous	-	4,000		2.6
Total Operating Costs		$150,000		
Total Annual Costs		$182,843		
Average Cost/ton Crab Scrap		$ 104		
Average Cost/ton Compost[2]		$ 74		

---

[1] At 12.5% interest for 10 years

[2] Assuming a 30% mass loss

Table 8. COSTS FOR A 40-TON/DAY CRAB SCRAP COMPOSTING OPERATION

	Quantity	Cost	Annualized Cost[1]	% of Annual Cost
Capital Costs				
Land	6.5 acres	$ 19,500	$ 2,700	5.5
Asphalt Pad	6.5 acres	266,500	36,911	75.5
Blowers & Timers	14	2,800	388	0.7
Pipe (PVC)	2,800 feet	6,020	833	1.7
Shredder	1	8,000	1,108	2.2
Front End Loader	1	50,000	6,925	14.1
Total-Capital Costs		$352,820	$48,867	
Operating Costs				% of Composting Cost
Straw	3,500 tons	$175,000		65.6
$FeSO_4$	67 tons	13,400		5.0
Labor	1 man-years	18,000		6.7
Fuel & Elec.	-	20,000		7.5
Maint., Repairs, & Insurance	10% of fixed costs	35,000		13.1
Miscellaneous	-	5,000		1.8
Total Operating Costs		$266,400		
Total Annual Costs		$315,267		
Average Cost/Ton Crab Scrap		$ 90		
Average Cost/Ton Compost[2]		$ 64		

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[1] At 12.5% interest for 10 years

[2] Assuming a 30% mass loss

Due to the large quantities of straw required for composting, costs will be very sensitive to the price of straw and the amount of straw needed. Future experiments should concentrate on recharging and the amount of straw and chemicals needed during a year. Less expensive carbon sources that are seasonably available, such as dead leaves or corn husks, might be used in place of straw. Their impact on the composting process needs to be evaluated. Straw contributes $36/ton to the cost of producing compost in the 3-ton-per-day operation, and $35/ton in the 40-ton/day operation.

Another significant area to examine is mass loss, which has ranged from 20-40% in our experiments. Mass loss results in a higher cost per ton of compost produced.

Comparison with Other Disposal Methods

Table 9 summarizes the costs of various methods of crab scrap disposal. The least expensive methods of disposal—direct farmland application, landfill and offshore dumpings as mentioned earlier—have external costs associated with them which are not reflected in these figures. On the other hand, composting and crab meal production have potential positive benefits which could result in lower net costs or even profits. Potential returns from crab scrap composting will be examined in the next section.

The transportation costs of moving the crab scrap from producer to disposer are not included in the cost estimates of composting, meal production, offshore dumping or farmland application. Transportation costs can be approximated by the costs of landfill disposal and delivery to crab meal plant, as given in Table 9.

Table 9. ESTIMATED COSTS OF CRAB SCRAP DISPOSAL

Method	Costs			Source
Composting[1,2]	$131 ton (330)	$74 ton (2474)	$64 ton (4947)	this study
Landfill	$27.56 day		$16.80 ton	Maryland Sea Grant Survey (1981)
Direct Farmland Application	$14.00 day		$ 5.28 ton	Maryland Sea Grant Survey (1981)
Crab Meal Production[3]	$155.96 ton (600)	$92.71 ton (1200)	$71.62 ton (1800)	Murray and DuPaul (1981)
Offshore Dumping[4,5]	$75.00 day		$33.50 ton	G. Krantz (pers.comm.)
Delivery to Crab Meal Plant (free pickup)	$6.41 (Hampton Roads, ton VA)		$10.30 (Accomack, VA) ton	Coale (1981)

[1] $/day are average per processor.
[2] Numbers in parenthesis correspond to tons of output per year.
[3] Costs/ton of finished product before sale.
[4] Very rough estimate based on experimental dumping by the State of Maryland in 1982.
[5] Adjusted to 1981 dollars by Producer Price Index for prices paid by farmers.

Value of Composted Crab Scrap

There are several ways of estimating the value of the finished product from the composting operation. One method is to sum the known values of the components making up the compost. This method is demonstrated in Table 10, where a value of $9 to $15 is calculated for a ton of compost.

The value of compost on the market will depend on whether it is sold in bulk or bagged. Experience with sewage sludge indicates that bagged compost has a value of $35 per dry ton net of bagging costs. On a bulk basis, sewage sludge compost had an average value of $14.26 in 1978 (Kasper and Derr, 1981).

If it is found that crab compost can be substituted for more valuable products, such as potting soils, fertilizer, topsoil, mulch, etc., the value of the compost will be enhanced. For example, the price paid by farmers for 10-10-10 fertilizer in 1980 was $151 per ton. McHugh (1981) analyzed the use of sewage sludge compost as an addition to potting media for vegetable seedlings. Commercial potting mixes averaged $2.60 per cubic foot or in the neighborhood of $150 per ton.

Comparison of Net Costs of Composting to Other Crab Scrap Products

Table 11 summarized estimated values of various crab scrap products. This table is compared with Table 9 to determine the least net cost method of crab scrap disposal (Table 12). For plant sizes of 1,200 and 1,800 tons of crab meal, there is a net profit of $7.28 per ton and $28.40 per ton, respectively, based on a value of $100 per ton for crab meal. There is currently a crab meal plant operating in Virginia. This alternative should be reexamined for Maryland. Even a

Table 10. ESTIMATE OF CRAB SCRAP COMPOST VALUE (COMPONENT METHOD)

Component	Lbs./Ton Compost (wet weight)	Component[1] Value ($/lb)	Component Value/Ton of Compost (wet weight)
N	14 - 22	$0.28	$3.92 - $ 6.16
P	13 - 22	0.26	3.38 - 5.72
K	10 - 18	0.15	1.50 - 2.70
Ca	32 - 84	0.007[2]	0.22 - 0.59
		Total Value/Ton	$9.02 - $15.17

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[1] Source: Agricultural Prices 1981, Crop Reporting Board

[2] Value is for Applied $CaCO_3$

Table 11. ESTIMATED VALUE OF CRAB SCRAP PRODUCTS

Product	Value	Source
Crab Meal	$100/ton Meal (15 Month Average $131/ton) (1/80-3/81)	Murray and DuPaul (1981)
Liquid Fish Fertilizer	$100/ton crab scrap	
Chitin	$150/ton crab scrap $250/ton crab	Fryer (1981)
Direct Land Application	$15-20/ton crab scrap	Brinsfield (1981)
Compost[4]	1) $ 12/ton[1] 2) $ 35/ton[2] 3) $150/ton[3]	this study

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[1] Component Method using the average value

[2] Perfect Substitute for Sewage Sludge

[3] Substitute for potting soils, fertilizers, etc. (average)

[4] Adjusted to 1981 dollars by Producer Price Index

Table 12. ESTIMATED NET COST (VALUE) PER TON FOR DIFFERENT METHODS OF CRAB SCRAP DISPOSAL

Method	Net Cost (Value) ton
Composting[2]	\$52 - (\$86)
Landfill	\$16.80
Direct Farmland Application	(\$12.22)
Crab Meal Production[3]	(\$28.38)
Offshore Dumping	\$33.50

[1] In 1981 dollars

[2] Assuming 4947 ton/year plant and a range in value for compost of from \$12 to \$150/ ton

[3] Assuming an 1800 ton/year operation and \$100/ton value for meal

less successful crab meal operation may be a lower cost alternative to disposal than landfill or offshore dumping. Direct farmland application is also profitable at $10-$15/ton (excluding external costs), but is limited to certain seasons. Liquid fish fertilizer and chitin production has the highest value of any product produced from crab waste.

The potential net cost of crab scrap composting varies widely ($58 per ton cost to $86 per ton profit) depending on the size of operation and the price of the compost product. All sized operations were able to yield a profit if the compost could be used as household potting soil (at $150.00 per ton price). When the more likely prices of $12 per ton or $35 per ton were used, all sized operations lost money. The least costly was the 40-ton-per-day plant, which lost $29 per ton with a $35 per ton price and lost $52 per ton with a $12 per ton price.

Although the analysis here is based on extremely rough estimates, the key to making crab scrap composting economically successful is in achieving a high-quality product through somewhat centralized production. Most cost savings occurred by increasing operations to 20 tons per day. However, these cost savings were not sufficient to yield a profit if a poor quality output were produced. High quality fertilizer (at a price of $150 per ton) appears necessary to make the operation privately successful. The degree to which centralized production and high quality can be achieved depends on local political acceptance of centralized plants and consumer acceptance of crab compost.

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APPENDIX A

DATA

Table A-1. CARBON DIOXIDE GENERATION RATE (g/hr) FOR UNSHREDDED CRAB SCRAP COMPOSTING

Test No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
C:N	11.5	13.8	13.6	13.6	13.6	18.5	19.5	18.5	18.5	18.5	18.5	20.0	20.0	25.0	23.4	24.5	25.0	26.7
Temp (°C)	50.0	46.6	61.9	44.8	59.2	41.9	53.4	54.2	54.1	51.9	63.1	50.7	52.7	41.2	58.9	46.2	61.4	55.2
Moisture Content (%)	54.0	51.0	48.0	63.0	62.0	53.0	52.0	57.0	56.0	53.0	53.0	43.0	67.0	46.0	46.0	65.0	60.5	58.0
Day																		
1	13	20	4		7			12		11	2	13	7		4		8	3
2				9		3	8		10					12		7		
3			16		20			18		15	15		11		16			13
4	16	12		15		10	14		20			11		14		11	20	
5			17		17			18		17	18		18		14			16
6	14			20		14			16			8		12			14	
7			13		19		13	11		11	19		14		13	11		14
8	12	9				7						13		10			12	
9			5	15	15		11		9		9				4	11		5
10	10	12				10		7		7		7	12	5			7	
11			28	5	16				5						5			8
12		11				7		7		14								
13	12		13	9	15		6		8		8	4	10	6	9	7	4	12
14						8				6								
15		7		7			5	8	7							7		
16	12									5		8	9	9			4	
17			7		4						7				6			9
18		7				7							6					
19	8		6	4	5		4	5	4		6	6		7	4	5	5	8
20						7												
21	7	5	5	4	5	6	4	3	3	3	3	5	4	6	3	6	6	5

Table A-2. CARBON DIOXIDE GENERATION RATE (g/hr) FOR SHREDDED CRAB SCRAP COMPOSTING

Test No.	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
C:N	10.4	13.6	15.0	13.6	13.6	19.5	18.8	18.8	18.5	18.5	18.5	19.5	18.5	18.5	23.4	25.0	24.5	24.5	28.5
Temp (°C)	50.8	45.7	62.4	44.9	59.3	53.8	52.0	53.4	54.1	52.9	52.8	51.7	40.5	64.3	46.2	63.7	44.6	62.2	52.8
Moisture Content (%)	57.0	47.0	49.0	64.0	65.0	40.0	58.0	56.0	59.0	56.0	55.0	66.0	55.0	55.0	50.0	46.0	65.0	60.0	56.0
Day																			
1		3	18	1	14		11	21	2		15			2		14			14
2	39					5				18		10	2		4		6	13	
3		9	19		20	8					17	11				13	9	18	19
4							13	15		24									
5	25	21	15	21	24				10		15			21		10			15
6										24			9		12				
7			9		15	5					14	13				6	12	8	9
8		14		20			17	14	23	15				9					
9	11					6						9	7		7		8	10	
10		14	8	20	11		14	19	18		7			17		5			5
11	17									7			13		9				
12		10		12	8		9	9	9		15			8					
13	7		17			7				7		8	6		6	14	6	9	6
14		7		7	11				7		9			8					
15					10	5	7	5		9	5	6	3		13		5	6	
16	10	13	5	7					6	6				7		7			9
17		14		8	8				6		5		7		10			7	
18			8			10	5	4					7		11	6			
19	15	14		8					6				7	7					
20																			
21	2	8	4	5	5	17	4	3	6	3	1	3	7	5	8	5	3	4	4

Table A-3. TOTAL AERATION AND TOTAL WATER ADDED TO UNSHREDDED CRAB SCRAP COMPOST DURING COMPOSTING PERIOD

Test No.	C:N	Temp (°C)	Moisture Content (% wet basis)	Total Aeration (m^3)	Total Water Added (kg)
1	11.5:1	50.0	54.0	44.96	12.3
2	13.8:1	46.6	51.0	58.80	4.5
3	13.6:1	61.9	48.0	9.49	5.9
4	13.6:1	44.8	63.0	96.40	4.3
5	13.6:1	59.2	62.0	28.10	11.2
6	18.5:1	41.9	53.0	90.21	10.0
7	19.5:1	53.4	52.0	36.33	10.4
8	18.5:1	54.2	57.0	20.75	6.4
9	18.5:1	54.1	56.0	31.88	5.9
10	18.5:1	51.9	53.0	28.34	4.5
11	18.5:1	63.1	53.0	5.88	7.5
12	20.0:1	50.7	43.0	27.13	2.7
13	20.0:1	52.7	67.0	57.29	14.8
14	25.0:1	41.2	46.0	57.97	3.9
15	23.4:1	58.9	46.0	9.36	4.6
16	24.5:1	46.2	65.0	31.37	6.8
17	25.0:1	61.4	61.0	11.35	14.6
18	26.7:1	55.2	58.0	17.47	6.6

Table A-4. TOTAL AERATION AND TOTAL WATER ADDED TO SHREDDED CRAB SCRAP COMPOST DURING THE COMPOSTING PERIOD

Test No.	C:N	Temp (^oC)	Moisture Content (% wet basis)	Total Aeration (m^3)	Total Water Added (kg)
19	10.4:1	50.8	57.0	90.96	7.3
20	13.6:1	45.7	47.0	83.39	5.0
21	15.0:1	62.4	49.0	41.36	3.2
22	13.6:1	44.9	64.0	108.24	4.5
23	13.6:1	59.3	65.0	27.20	4.3
24	19.5:1	53.8	40.0	25.45	6.6
25	18.8:1	52.0	58.0	56.97	8.9
26	18.8:1	53.4	56.0	44.34	3.2
27	18.5:1	54.1	59.0	35.46	2.7
28	18.5:1	52.9	56.0	29.23	3.2
29	18.5:1	52.8	55.0	43.87	4.1
30	19.5:1	51.7	66.0	30.36	9.1
31	18.5:1	40.5	55.0	109.26	4.5
32	18.5:1	64.3	55.0	12.25	6.1
33	23.4:1	46.2	50.0	61.39	2.7
34	25.0:1	63.7	46.0	9.17	3.5
35	24.5:1	44.6	65.0	79.27	5.9
36	24.5:1	62.2	60.0	17.90	10.4
37	28.5:1	52.8	56.0	25.45	4.1

Table A-5. DRY MASS CHANGE AND TOTAL CARBON DIOXIDE GENERATION FOR UNSHREDDED CRAB SCRAP COMPOST

Test No.	C:N	Temp. (°C)	Moisture Content (% wet basis)	Batch No.	Initial Dry Mass (kg)	Final Dry Mass (kg)	Change in Dry Mass (kg)	Change in Dry Mass (%)	CO_2 evolved (kg)	CO_2 evolved /unit change in Dry Mass (kg/kg)	CO_2 evolved /unit of Initial Dry Mass (x100) (kg/kg) (100)
1	11.5:1	50.0	54	B5 #2	13.98	9.13	4.85	34.7	5.82	1.28	41.6
2	13.8:1	46.6	51	B4 #2	10.91	8.13	2.77	25.5	5.37	1.93	49.2
3	13.6:1	61.9	48	B6 #3	11.46	8.56	2.90	25.3	5.85	2.02	51.0
4	13.6:1	44.8	63	B8 #5	11.16	7.27	3.89	34.9	4.83	1.24	43.3
5	13.6:1	59.2	62	B6 #8	11.02	7.93	3.10	28.1	6.39	2.06	58.0
6	18.5:1	41.9	53	B6 #2	9.12	7.21	1.91	20.9	3.79	1.98	41.6
7	19.5:1	53.4	52	B3 #8	8.38	5.14	3.24	38.6	4.02	1.24	48.0
8	18.5:1	54.2	57	B8 #3	8.95	6.25	2.67	29.9	4.76	1.78	53.2
9	18.5:1	54.1	56	B8 #6	9.20	6.32	2.88	31.4	4.50	1.56	48.9
10	18.5:1	51.9	53	B8 #7	8.88	6.10	2.78	31.3	4.53	1.63	51.0
11	18.5:1	63.1	53	B6 #6	8.96	6.03	2.93	32.7	4.93	1.68	55.0
12	20.0:1	50.7	43	B5 #4	9.26	7.20	2.06	22.2	3.94	1.91	42.5
13	20.0:1	52.7	67	B5 #7	8.99	5.68	3.32	36.9	5.09	1.53	56.6
14	25.0:1	41.2	46	B5 #5	8.33	5.73	2.60	31.2	4.48	1.72	53.8
15	23.4:1	58.9	46	B6 #4	8.35	6.40	1.94	23.3	4.04	2.08	48.4
16	24.5:1	46.2	65	B3 #5	7.69	5.05	2.64	34.3	4.01	1.52	52.1
17	25.0:1	61.4	61	B5 #1	8.30	5.30	3.00	36.2	4.39	1.45	52.9
18	26.7:1	55.2	58	B6 #5	7.79	5.07	2.72	34.9	4.89	1.80	62.8

Table A-6. DRY MASS CHANGE AND TOTAL CARBON DIOXIDE GENERATION FOR SHREDDED CRAB SCRAP COMPOST

Test No.	C:N	Temp. (°C)	Moisture Content (% wet basis)	Batch No.	Initial Dry Mass (kg)	Final Dry Mass (kg)	Change in Dry Mass		CO_2 evolved (kg)	CO_2 evolved /unit change in Dry Mass (kg/kg)	CO_2 evolved /unit of Initial Dry Mass (x100) (kg/kg) (100)
							(kg)	(%)			
19	10.4:1	50.8	57	B4 #3	14.80	10.77	4.03	27.2	8.28	2.06	55.9
20	13.6:1	45.7	47	B7 #5	11.43	7.88	3.55	31.1	6.05	1.71	52.9
21	15.0:1	62.4	49	B5 #3	10.94	7.27	3.67	33.6	5.51	1.50	50.4
22	13.6:1	44.9	64	B7 #6	11.13	7.73	3.40	30.5	5.86	1.72	52.7
23	13.6:1	59.3	65	B8 #4	11.12	7.44	3.68	33.1	6.17	1.67	55.5
24	19.5:1	53.8	40	B3 #3	8.43	4.52	3.91	46.5	3.63	0.93	43.1
25	18.8:1	52.0	58	B4 #4	8.98	5.42	3.56	39.6	5.17	1.46	57.6
26	18.8:1	53.4	56	B4 #7	8.86	6.02	2.84	32.0	5.55	1.96	62.6
27	18.5:1	54.1	59	B7 #1	9.02	6.72	2.30	25.5	4.88	2.13	54.1
28	18.5:1	52.9	56	B8 #1	9.17	6.22	2.95	32.2	5.69	1.92	62.1
29	18.5:1	52.8	55	B8 #8	9.08	6.51	2.57	28.4	4.80	1.86	52.9
30	19.5:1	51.7	66	B3 #7	8.54	5.34	3.20	37.4	4.00	1.25	46.8
31	18.5:1	40.5	55	B7 #8	9.11	6.62	2.49	27.4	3.15	1.26	34.6
32	18.5:1	64.3	55	B7 #4	9.18	6.25	2.93	31.9	4.98	1.70	54.2
33	23.4:1	46.2	50	B7 #3	8.27	6.25	2.02	24.4	4.24	2.10	51.3
34	25.0:1	63.7	46	B5 #8	8.38	5.67	2.71	32.3	4.29	1.59	51.2
35	24.5:1	44.6	65	B3 #1	7.80	5.08	2.72	34.9	3.35	1.23	42.9
36	24.5:1	62.2	60	B3 #4	7.93	5.49	2.44	30.7	4.30	1.77	54.2
37	28.5:1	52.8	56	B5 #6	7.66	4.39	3.27	42.7	4.60	1.41	60.1

Table A-7. RESULTS OF ALL CARBON AND KJELDAHL NITROGEN ANALYSIS FOR UNSHREDDED CRAB SCRAP BEFORE AND AFTER COMPOSTING ON A PERCENT DRY WEIGHT BASIS

Test No.	Before Composting			After Composting		
	Total Carbon	Organic Carbon	Kjeldahl Nitrogen	Total Carbon	Organic Carbon	Kjeldahl Nitrogen
1				33.4		2.2%
2						2.3%
3						2.6%
4	40.7		2.9	32.6		2.2%
5	37.5	36.3				
6	42.4		1.8			
7				38.6		2.8%
8			2.2			
11				37.3		
12						1.8%
13				36.7	34.1	2.3%
15				40.7		2.2%
18				40.5		2.5%

Table A-8. RESULTS OF ALL CARBON AND KJELDAHL NITROGEN ANALYSIS FOR SHREDDED CRAB SCRAP BEFORE AND AFTER COMPOSTING ON A PERCENT DRY WEIGHT BASIS

	Before Composting			After Composting		
Test No.	Total Carbon	Organic Carbon	Kjeldahl Nitrogen	Total Carbon	Organic Carbon	Kjeldahl Nitrogen
19		34.1	3.3	32.94	29.4	2.3%
20			1.9			
23				37.74	36.8	2.3%
25	41.4					
26				37.3	36.1	2.0%
27	38.8	38.4	2.4	35.6	34.9	1.9%
28						2.2%
29						2.4%
30				38.1	35.5	2.1%
32			1.8			
33			1.6			
36				40.1	40.0	2.1%
37	41.2			40.5	40.0	2.3%

Table A-9. NUTRIENT ANALYSIS OF CRAB SCRAP AND STRAW IN PERCENT DRY WEIGHT BASIS

Material	Total Carbon	Inorganic Carbon	Kjeldahl Nitrogen	Total Phosphorus	Potassium	Calcium
Crab Scrap	37.5	3.5	6.0	3.5	0.6	13.0
Straw	42.1	0	0.8	0.5	1.5	0.3

Table A-10. NUTRIENT ANALYSIS OF SHREDDED CRAB SCRAP-STRAW MIXTURES AFTER COMPOSTING

	Initial Composting									
Test No.	C:N (Organic Carbon)	Temp. (°C)	[H_2O] (% wet wt)	Total Carbon (% DW)	Organic Carbon (% DW)	Kjeldahl Nitrogen (% DW)	Total Phosphorus (% DW)	Potassium (% DW)	Calcium (% DW)	Final C:N (organic)
19	10.4:1	50.8	57	32.9	29.4	2.3	2.7	1.2	10.5	12.8:1
23	13.6:1	59.3	65	37.7	36.8	2.3	1.9	1.4	7.0	16.0:1
26	18.8:1	53.4	56	37.3	36.1	2.0	1.6	1.9	4.0	18.1:1
27	18.5:1	54.1	59	35.6	34.9	1.9	1.8	1.8	5.5	18.4:1
30	19.5:1	51.7	66	38.1	35.5	2.1	1.7	1.8	5.0	16.9:1
36	24.5:1	62.2	60	40.1	40.0	2.1	1.5	2.3	4.0	19.0:1
37	28.5:1	52.8	56	40.5	40.0	2.3	1.4	2.3	4.1	17.4:2

% DW = % dry weight basis

Table A-11. MOISTURE CONTENT OF UNSHREDDED CRAB SCRAP COMPOST

DURING THE COMPOSTING PERIOD IN PERCENT WET BASIS

Test No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
C:N	11.5	13.8	13.6	13.6	13.6	18.5	19.5	18.5	18.5	18.5	18.5	20.0	20.0	25.0	23.4	24.5	25.0	26.7
Temp (°C)	50.0	46.6	61.9	44.8	59.2	41.9	53.4	54.2	54.1	51.9	63.1	50.7	52.7	41.2	58.9	46.2	61.4	55.2
Moisture Content (%)	54.0	51.0	48.0	63.0	62.0	53.0	52.0	57.0	56.0	53.0	53.0	43.0	67.0	46.0	46.0	65.0	60.5	58.0
Day																		
1	57.0		44.0		67.0						54.3	53.0		41.0	48.0		51.0	56.0
2		46.0		65.0		54.0			54.2									
3	55.0						49.0	55.5		57.6		37.0	59.0	45.0		64.0	54.0	
4		47.0	40.0		59.0						49.9				41.0			49.0
5				64.0		50.0			60.8				71.0					
6	44.0	40.0						52.7		48.7		37.9		40.0			57.0	
7			50.0		55.0						52.0		68.0		47.0			56.0
8	61.0					49.0	54.0					43.7		52.0		67.0	67.0	
9		43.0																
10	47.0			65.0					57.2			44.0	62.0	51.0				
11		48.0	48.0		67.0		43.0	58.0		59.2	52.9				45.0	62.0	63.0	51.0
12				62.0		52.0			55.5									
13	46.0	58.0	42.0		66.0		44.0	59.1		56.2	55.8	49.0		47.0	50.0	58.0		59.0
14						55.0											54.0	
15	58.0											53.5		50.0				
16		56.0	54.0	60.0	61.0				52.8		50.6				46.0		59.0	52.0
17	64.0					50.0	59.0	60.8		52.0		41.0	76.0	48.0		69.0		
18		5[illegible].0	55.0		62.0						52.6				49.0			59.0
19						59.0												
20	60.0	53.0										41.0		41.0				
21	66.0	56.0	54.0	61.0	66.0	60.0	70.0	60.0	53.2	50.8	60.3	39.0	77.0	53.0	46.0	72.0	63.0	67.0

Table A-12. MOISTURE CONTENT OF SHREDDED CRAB SCRAP COMPOST

DURING THE COMPOSTING PERIOD IN PERCENT WET BASIS

Test No.	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
C:N	10.4	13.6	15.0	13.6	13.6	19.5	18.8	18.8	18.5	18.5	18.5	19.5	18.5	18.5	23.4	25.0	24.5	24.5	28.5
Temp (°C)	50.8	45.7	62.4	44.9	59.3	53.8	52.0	53.4	54.1	52.9	52.8	51.7	40.5	64.3	46.2	63.7	44.6	62.2	52.8
Moisture Content (%)	57.0	47.0	49.0	64.0	65.0	40.0	58.0	56.0	59.0	56.0	55.0	66.0	55.0	55.0	50.0	46.0	65.0	60.0	56.0
Day																			
1							52.0	52.0											
2		44.0		59.0					54.0					53.0					
3	59.0		44.0		67.0	40.0	47.0	49.0			52.0	68.0	52.0		45.0	43.0	65.0	61.0	48.0
4										49.0									
5	51.0	48.0	61.0	69.0			47.0	55.0	58.0					58.0		50.0			62.0
6					59.0						48.0		54.0		53.0				
7	56.0	43.0	41.0	62.0					53.0	61.0				50.0		40.0		61.0	49.0
8						33.0	63.0	60.0				63.0	62.0		43.0		69.0		
9		52.0		68.0					60.0					52.0					
10	50.0		46.0				48.0	55.0					54.0		55.0	46.0	59.0	68.0	53.0
11					62.0	31.0					64.0	55.0							
12	58.0	40.0	51.0	61.0			60.0	57.0	59.0	61.0				64.0		49.0		60.0	59.0
13					65.0	50.0						66.0	54.0		43.0		51.0		
14	65.0	51.0	55.0	64.0					57.0	55.0	59.0			55.0					62.0
15							63.0	56.0					54.0		57.0				
16		48.0		65.0					55.0					51.0		44.0		46.0	
17	62.0				71.0	30.0	66.0	58.0			54.0	69.0	54.0		56.0		69.0		57.0
18			47.0							53.0									
19	61.0						65.0	56.0											
20																			
21	60.0	59.0	56.0	64.0	66.0	58.0	67.0	60.0	59.0	60.0	58.0	76.0	56.0	60.0	52.0	55.0	71.0	72.0	65.0

Table A-13. THE pH OF UNSHREDDED CRAB SCRAP COMPOST DURING THE COMPOSTING PERIOD

Test No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
C:N	11.5	13.8	13.6	13.6	13.6	18.5	19.5	18.5	18.5	18.5	18.5	20.0	20.0	25.0	23.4	24.5	25.0	26.7
Temp (°C)	50.0	46.6	61.9	44.8	59.2	41.9	53.4	54.2	54.1	51.9	63.1	50.7	52.7	41.2	58.9	46.2	61.4	55.2
Moisture Content (%)	54.0	51.0	48.0	63.0	62.0	53.0	52.0	57.0	56.0	53.0	53.0	43.0	67.0	46.0	46.0	65.0	60.5	58.0
Day																		
1			3.95		4.95		5.30		5.15	4.40	4.95				4.75			4.90
2	7.30	6.25		4.95		4.00		6.00	6.25	5.35		7.20		7.20			7.10	
3	7.70	3.00					7.90					7.70		5.40			7.65	
4		4.45	4.80		5.50			6.75			5.45		7.75		6.70			6.95
5				7.20		3.40			7.15	7.05			7.70					
6		7.65					7.25		7.15	7.45								
7	8.25		7.55		8.25			7.35	7.40	7.40	7.80	7.60		7.40	7.35		7.80	6.95
8	8.30			7.70		6.55	7.85		7.40	6.50		7.50		7.25			7.05	
9		7.05						7.20	7.15	7.35								
10							7.55											
11		7.60	7.95		7.90						6.95		7.45		5.80			7.20
12				7.95		7.55		7.10	6.80	7.65								
13		8.05	7.95		8.05		7.60		6.95	7.40	7.50		7.75		6.75			7.20
14	8.25			7.85		7.65			7.30	7.25		7.40	8.25	7.55			6.20	
15							7.05	7.70	7.40	7.55								
16	8.75	7.80	7.90		8.05				7.25	7.45	7.05	7.75		7.60	7.40		7.65	6.95
17	8.80			8.05		8.05	7.00					8.05	8.25	8.15			8.00	
18		7.85						7.30										
19									7.80	7.45			8.30					
20	8.80	8.25							7.55	7.50		8.05		7.60			7.40	
21																		

Table A-14. THE pH OF SHREDDED CRAB SCRAP COMPOST DURING

THE COMPOSTING PERIOD

Test No.	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
C:N	10.4	13.6	15.0	13.6	13.6	19.5	18.8	18.8	18.5	18.5	18.5	19.5	18.5	18.5	23.4	25.0	24.5	24.5	28.5
Temp (°C)	50.8	45.7	62.4	44.9	59.3	53.8	52.0	53.4	54.1	52.9	52.8	51.7	40.5	64.3	46.2	63.7	44.6	62.2	52.8
Moisture Content (%)	57.0	47.0	49.0	64.0	65.0	40.0	58.0	56.0	59.0	56.0	55.0	66.0	55.0	55.0	50.0	46.0	65.0	60.0	56.0
Day																			
1		4.00				6.70	6.20	5.85			5.39			5.85	4.70			5.60	
2		7.85		7.85	6.75		7.20	7.75	6.95	6.85	7.40			6.15	6.95				
3	5.95					7.70	7.35	7.90										7.60	
4	7.85		8.00	7.85	8.25				7.60	7.85						5.95			7.50
5	8.10	7.45	8.25			7.70	7.60	7.60			7.15			6.85	6.15	6.50		7.75	7.65
6		7.40									6.85			6.95	6.40				
7	8.35	7.85		7.60	7.95				8.15	7.55	7.60			7.45	6.35				
8		7.75				7.75	6.95	7.30			7.55	7.80		7.25	7.15		6.20	7.20	
9		7.65		7.85	7.70				7.30	7.25	7.45			7.80	7.00				
10	7.95						7.05	7.80											
11			7.15			7.50					7.15			7.65	6.70	6.45		7.40	6.50
12	8.40	7.05		7.65	8.00		7.65	8.10	7.00	6.95	6.90			7.60	6.35				
13		7.15	8.40			7.25					7.30			7.80	6.80	6.95		7.60	7.35
14	8.35	7.55	8.45								7.55			7.70	7.00	7.55			7.60
15		7.75		8.00	8.15	6.35	8.05	7.75	7.35	7.55	7.65			7.05	6.95			7.25	
16		7.70																	
17	8.35						7.80	7.75								8.30			6.75
18			8.25	7.95	8.15	6.60			7.55	7.40	7.65			6.95	7.00			6.85	
19	8.20	7.45					7.30	8.05			7.40			6.85	6.80	7.95			7.10
20		7.60	8.10			7.10												6.95	
21	8.30																		

Table A-15. TEMPERATURE MEASURED IN UNSHREDDED CRAB SHELL-CHOPPED STRAW MIXTURES DURING COMPOSTING

Test No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
C:N	11.5	13.8	13.6	13.6	13.6	18.5	19.5	18.5	18.5	18.5	18.5	20.0	20.0	25.0	23.4	24.5	25.0	26.7
Temp (°C)	50.0	46.6	61.9	44.8	59.2	41.9	53.4	54.2	54.1	51.9	63.1	50.7	52.7	41.2	58.9	46.2	61.4	55.2
Moisture Content (%)	54.0	51.0	48.0	63.0	62.0	53.0	52.0	57.0	56.0	53.0	53.0	43.0	67.0	46.0	46.0	65.0	61.0	58.0
Day																		
1	17	40	20	15	18	20	29	16	15	15	17	21	20	22	20	35	22	18
2	26	48	23	31	23	18	48	35	38	38	19	33	30	28	23	43	34	20
3	50	43	36	46	36	21	53	52	50	51	32	50	45	49	40	48	53	26
4	54	51	50	47	52	35	52	55	55	54	51	48	55	46	54	47	59	55
5	55	51	59	46	64	44	53	50	56	52	61	53	56	45	58	45	61	56
6	52	52	58	45	63	43	53	56	52	52	62	50	56	46	56	44	53	54
7	54	53	61	45	61	44	53	49	52	50	63	48	51	43	56	43	53	53
8	45	50	61	47	60	44	53	50	45	53	60	48	53	46	53	43	52	50
9	48	48	54	48	58	41	53	40	41	41	53	54	50	44	50	47	49	49
10	50	46	59	47	57	41	51	52	52	51	53	48	50	43	45	45	49	37
11	48	49	57	45	52	40	49	52	53	51	57	44	47	38	51	44	47	43
12	49	41	39	45	57	40	50	51	51	48	47	40	48	38	49	43	45	52
13	48	48	39	43	60	38	49	45	45	40	43	38	50	37	42	40	40	48
14	48	50	37	41	46	41	43	36	38	33	45	36	51	37	37	40	36	41
15	44	52	36	39	44	40	42	32	37	36	44	34	48	31	35	36	32	37
16	41	50	35	36	39	38	44	30	31	31	43	33	45	37	34	36	33	35
17	49	43	40	36	36	41	45	31	30	26	40	42	45	32	33	36	35	34
18	51	38	41	32	35	40	41	28	27	26	39	53	44	35	32	34	41	33
19	44	33	41	30	33	39	40	26	26	25	38	45	41	34	30	33	41	31
20	39	25	41	28	35	37	37	26	25	25	36	40	36	37	29	31	39	27
21	39	18	43	25	36	34	36	25	25	24	33	38	35	26	25	32	39	23

Table A-16. TEMPERATURE MEASURED IN SHREDDED CRAB SHELL-CHOPPED STRAW

MIXTURES DURING COMPOSTING

Test No	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
C:N	10.4	13.6	15.0	13.6	13.6	19.5	18.8	18.8	18.5	18.5	18.5	19.5	18.5	18.5	23.4	25.0	24.5	24.5	28.5
Temp (°C)	50.8	45.7	62.4	44.9	59.3	53.8	52.0	53.4	54.1	52.9	52.8	51.7	40.5	64.3	46.2	63.7	44.6	62.2	52.8
Moisture Content (%)	57.0	47.0	49.0	64.0	65.0	40.0	58.0	56.0	56.0	56.0	55.0	66.0	55.0	55.0	50.0	46.0	65.0	60.0	56.0
Day																			
1	39	12	20	13	18	46	47	43	13	15	20	30	12	14	14	20	40	40	20
2	47	17	56	15	30	58	56	51	17	26	38	46	11	17	14	41	45	53	44
3	51	26	65	19	53	55	53	52	31	49	55	50	14	35	20	59	46	63	54
4	44	46	63	30	66	50	50	47	48	55	58	51	23	59	43	65	45	62	56
5	45	45	58	51	51	50	51	26	59	54	48	51	44	65	46	64	45	61	51
6	46	46	61	45	60	51	51	58	52	48	53	52	48	63	47	65	44	60	50
7	46	46	63	45	57	51	48	52	53	56	51	52	40	59	44	59	44	57	50
8	46	46	52	47	64	51	48	51	54	52	54	52	40	53	41	57	41	51	48
9	45	43	55	42	43	50	47	50	51	52	49	52	43	56	44	51	43	47	38
10	45	45	50	45	48	54	47	60	49	40	45	51	37	57	38	49	39	44	50
11	42	44	48	43	51	46	48	45	45	44	51	49	38	48	38	40	38	44	49
12	41	46	47	43	55	46	43	44	37	52	52	47	38	47	48	40	37	42	49
13	40	45	46	42	49	45	42	41	43	49	48	45	38	47	44	39	38	40	47
14	36	44	45	43	42	41	39	34	36	42	44	44	39	41	45	39	40	36	47
15	33	46	48	43	37	35	37	31	33	34	41	40	43	44	45	50	38	35	48
16	33	44	42	41	35	36	32	28	36	32	38	37	41	43	37	52	37	32	44
17	34	40	44	41	36	31	32	28	35	29	32	36	38	46	35	41	37	43	40
18	37	40	48	40	30	32	34	28	33	29	29	33	38	45	29	43	35	46	35
19	32	39	42	39	32	32	31	27	32	27	26	32	38	42	28	46	34	40	33
20	28	37	35	39	30	31	28	26	31	26	24	31	40	39	28	43	30	32	36
21	25	36	34	38	25	24	26	25	30	25	23	31	39	38	31	40	31	34	35

APPENDIX B

TIME - TEMPERATURE
PLOTS FOR
CRAB SCRAP - CHOPPED STRAW
COMPOSTING

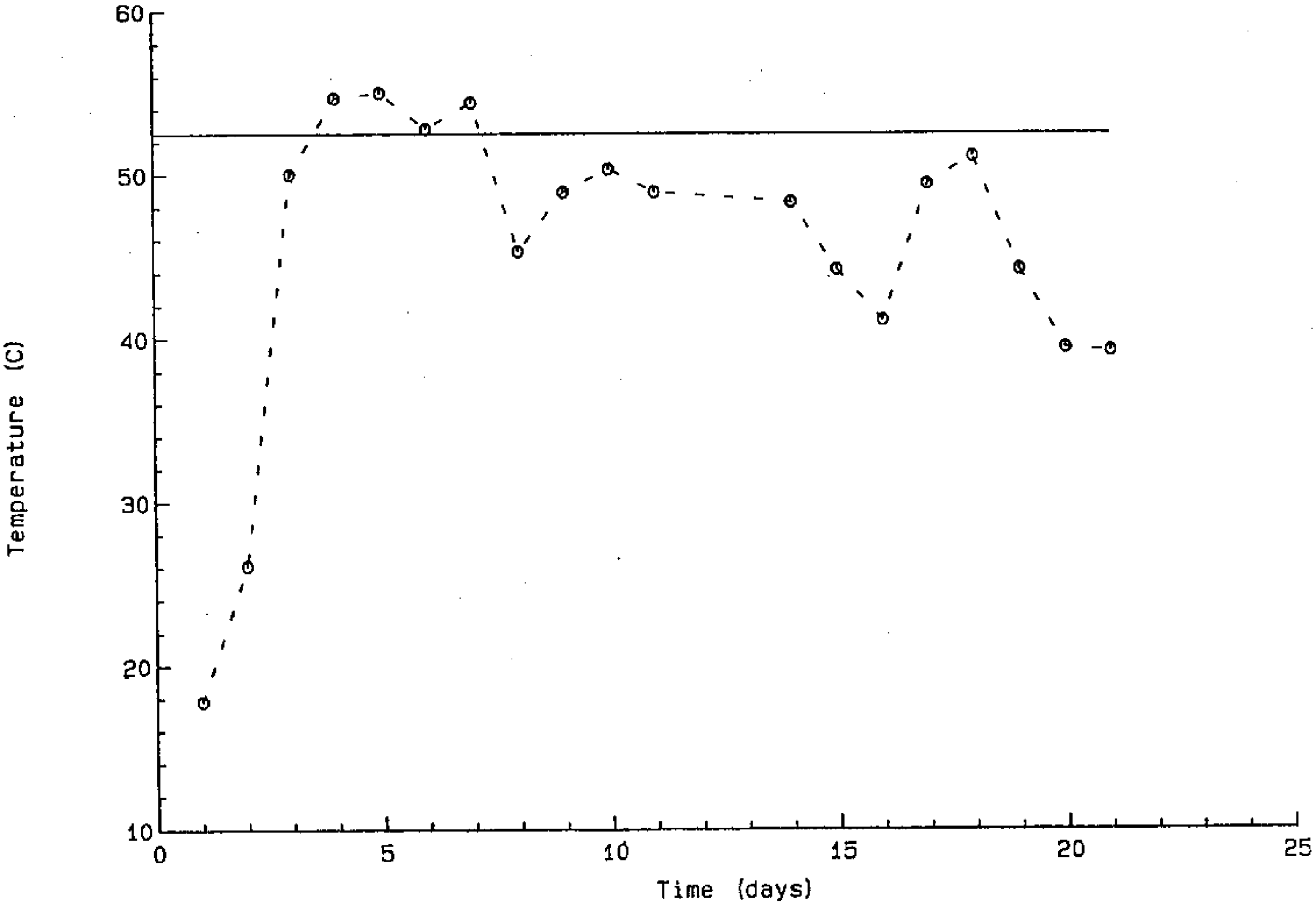

Figure B-1. Temperature record of test 1. The carbon-nitrogen ratio was 11.5:1 and the moisture content was 54% (wet basis).

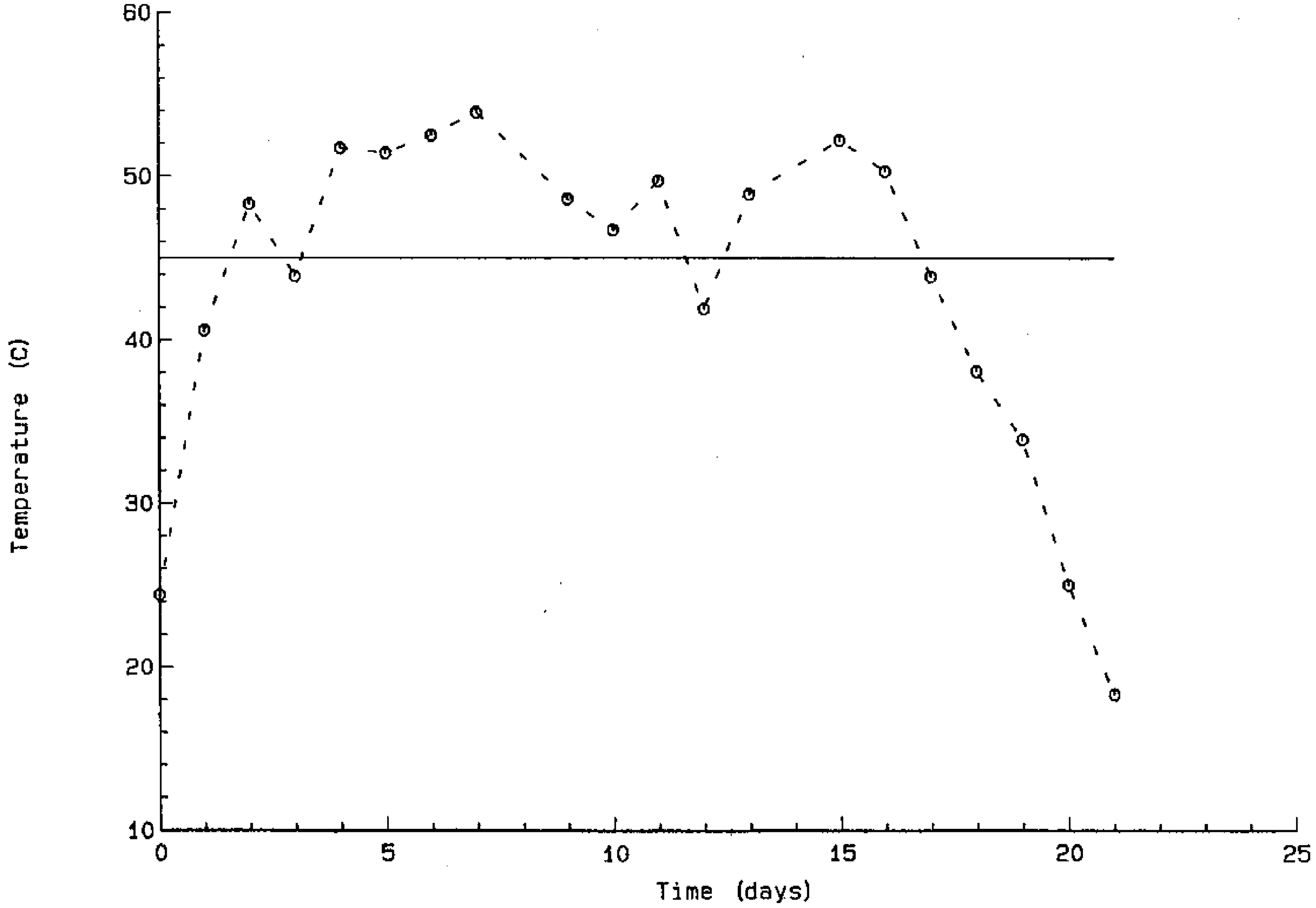

Figure B-2. Temperature record of test 2. The carbon-nitrogen ratio was 13.8:1 and the moisture content was 51% (wet basis).

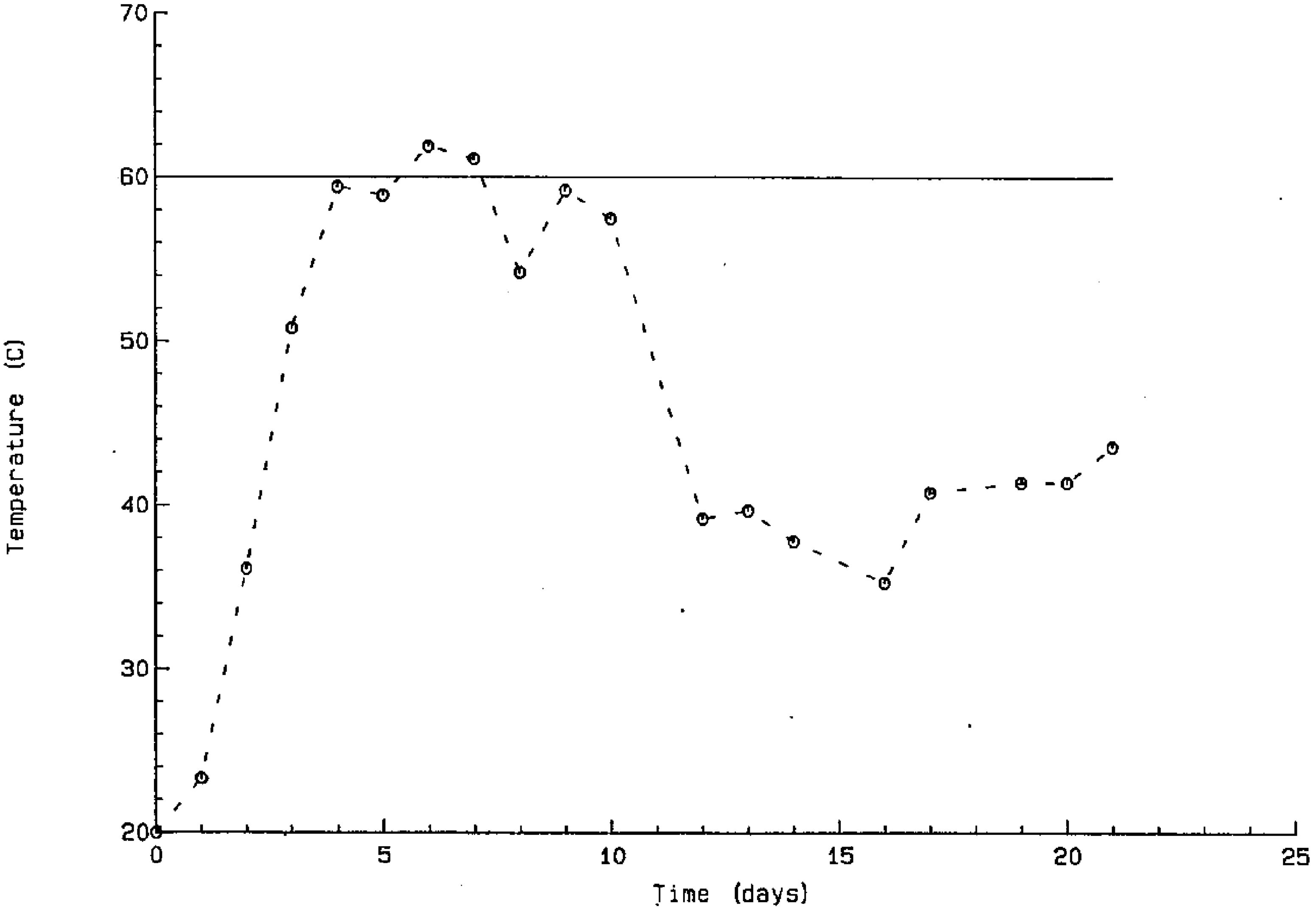

Figure B-3. Temperature record of test 3. The carbon-nitrogen ratio was 13.6:1 and the moisture content was 48% (wet basis).

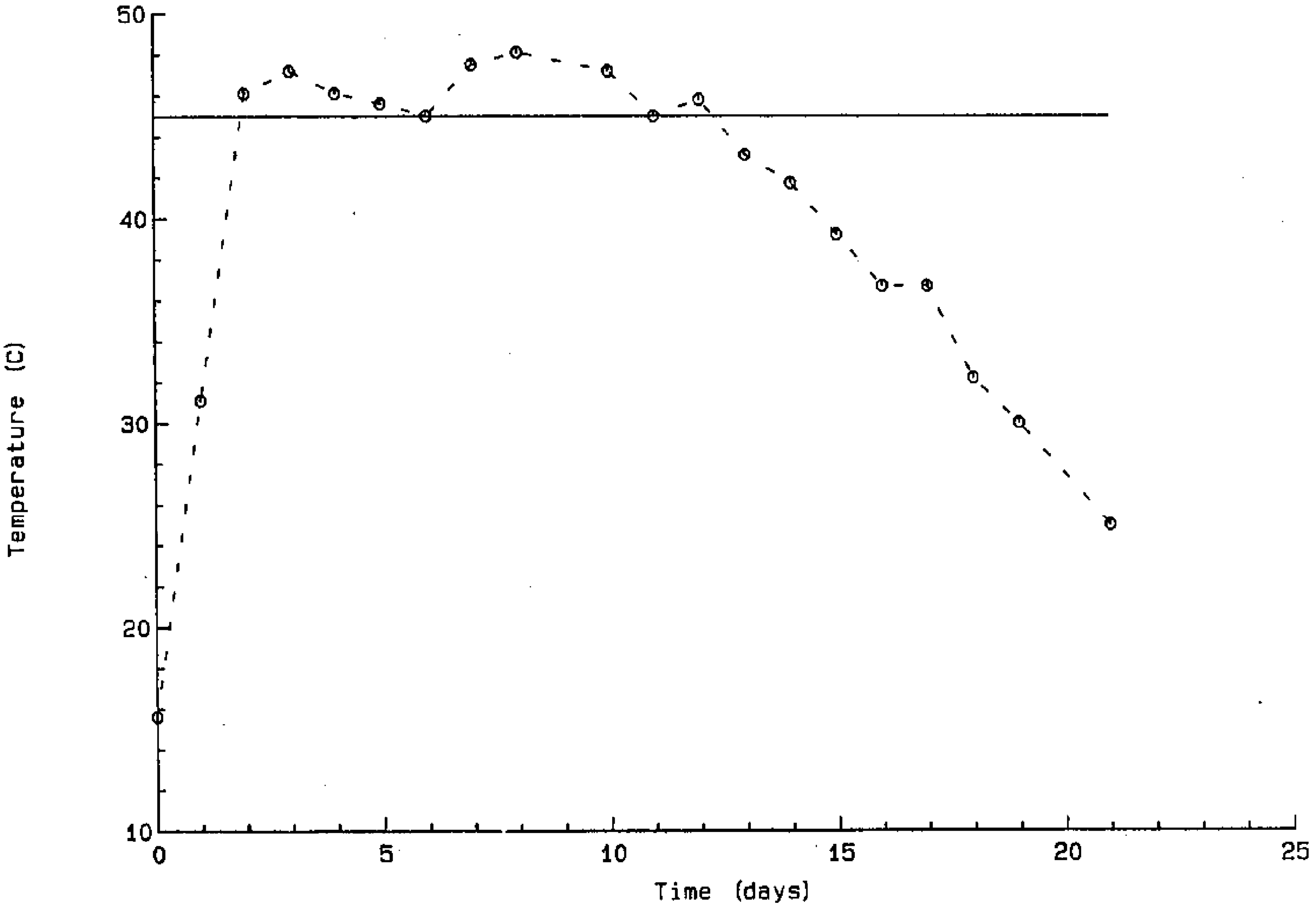

Figure B-4. Temperature record of test 4. The carbon-nitrogen ratio was 13.6:1 and the moisture content was 63% (wet basis).

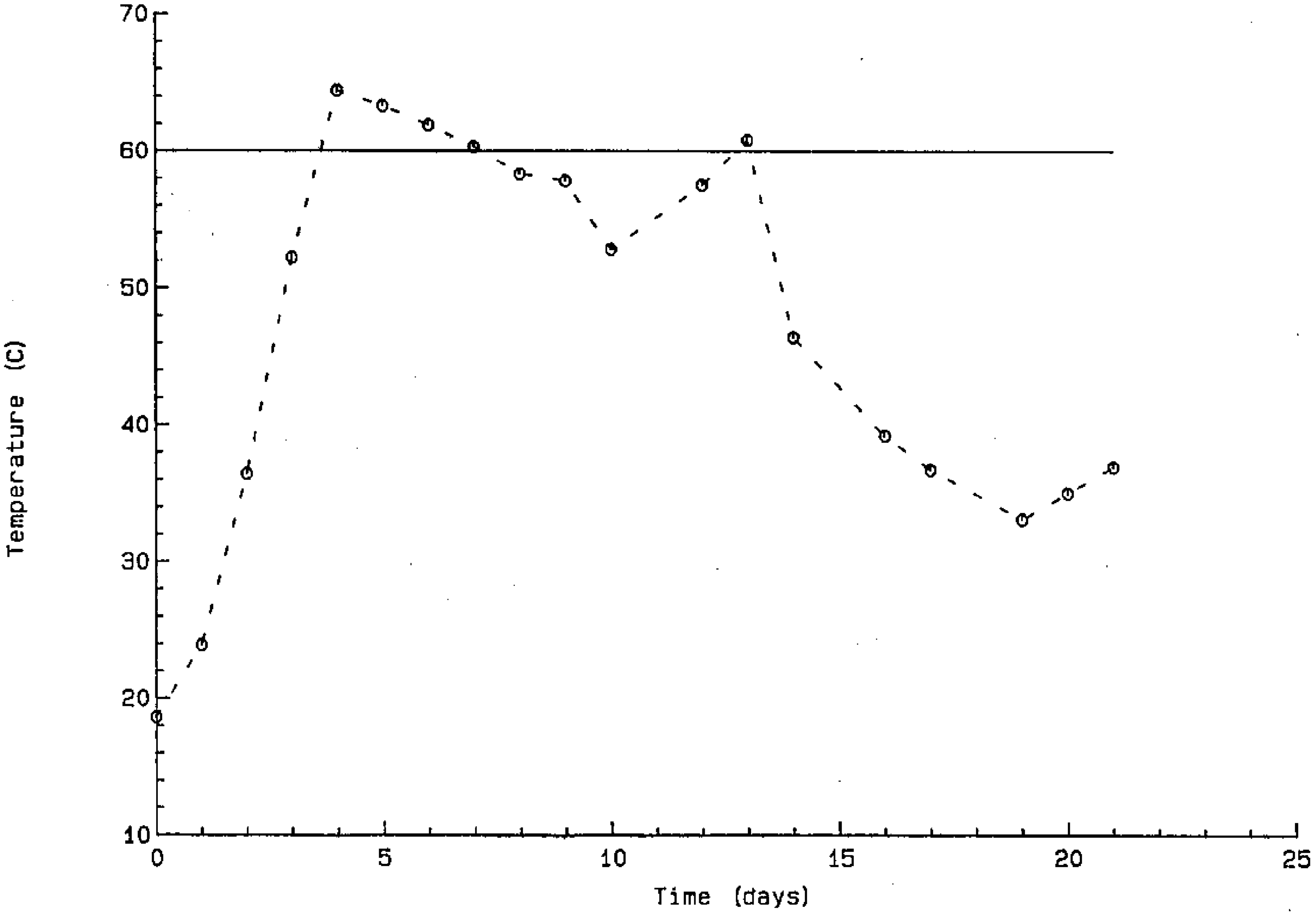

Figure B-5. Temperature record of test 5. The carbon-nitrogen ratio was 13.6:1 and the moisture content was 62% (wet basis).

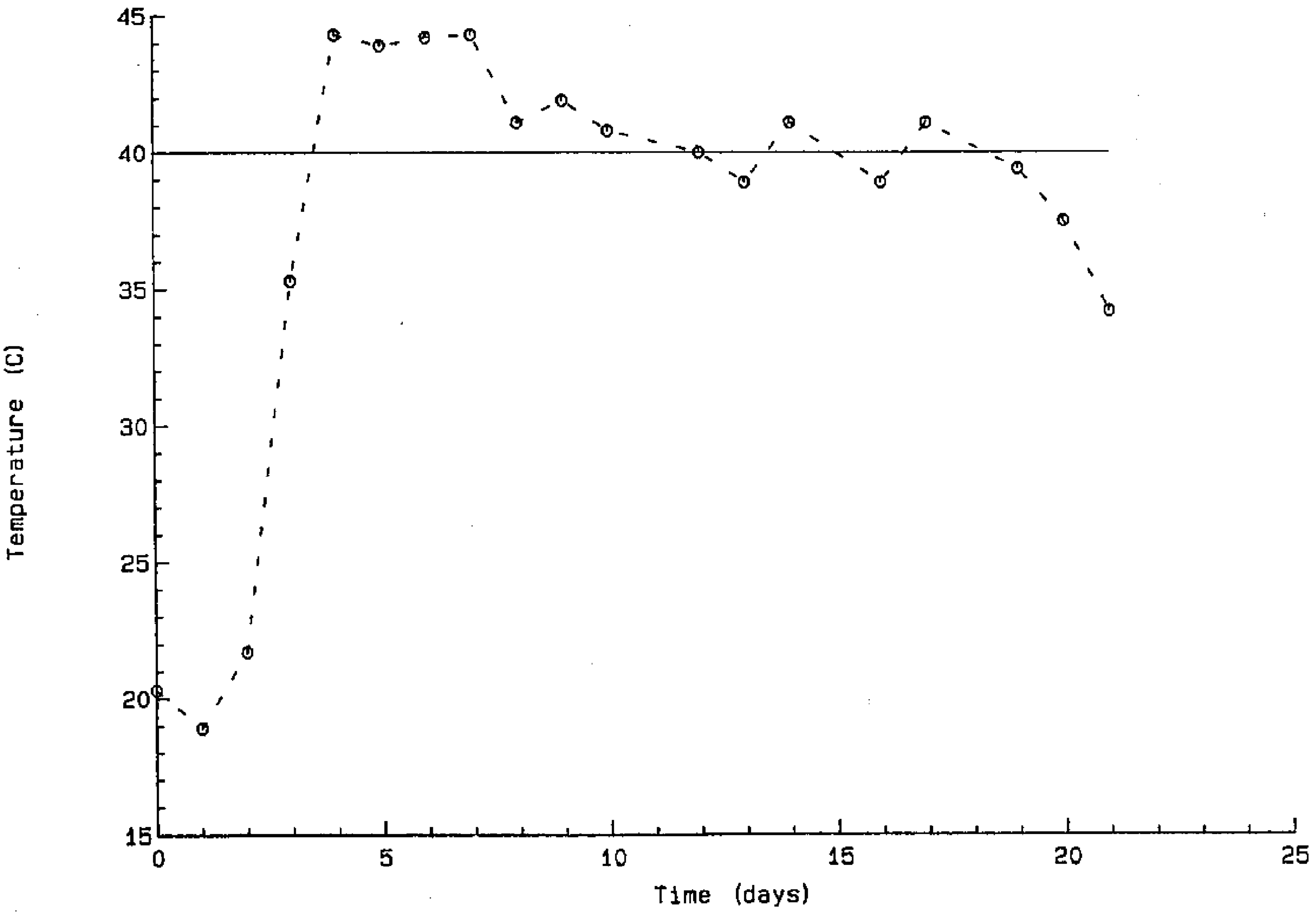

Figure B-6. Temperature record of test 6. The carbon-nitrogen ratio was 18.5:1 and the moisture content was 53% (wet basis).

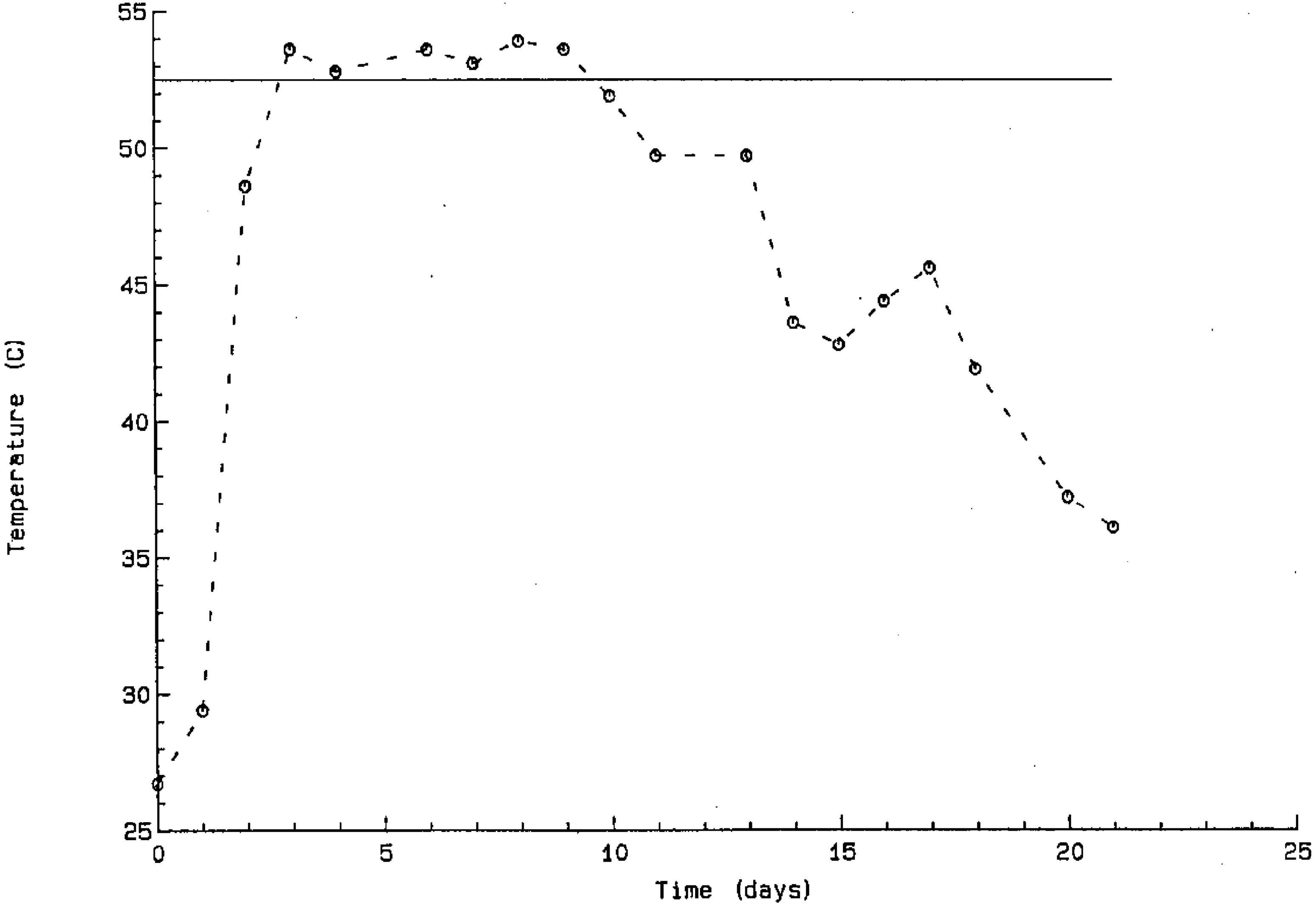

Figure B-7. Temperature record of test 7. The carbon-nitrogen ratio was 19.5:1 and the moisture content was 52% (wet basis).

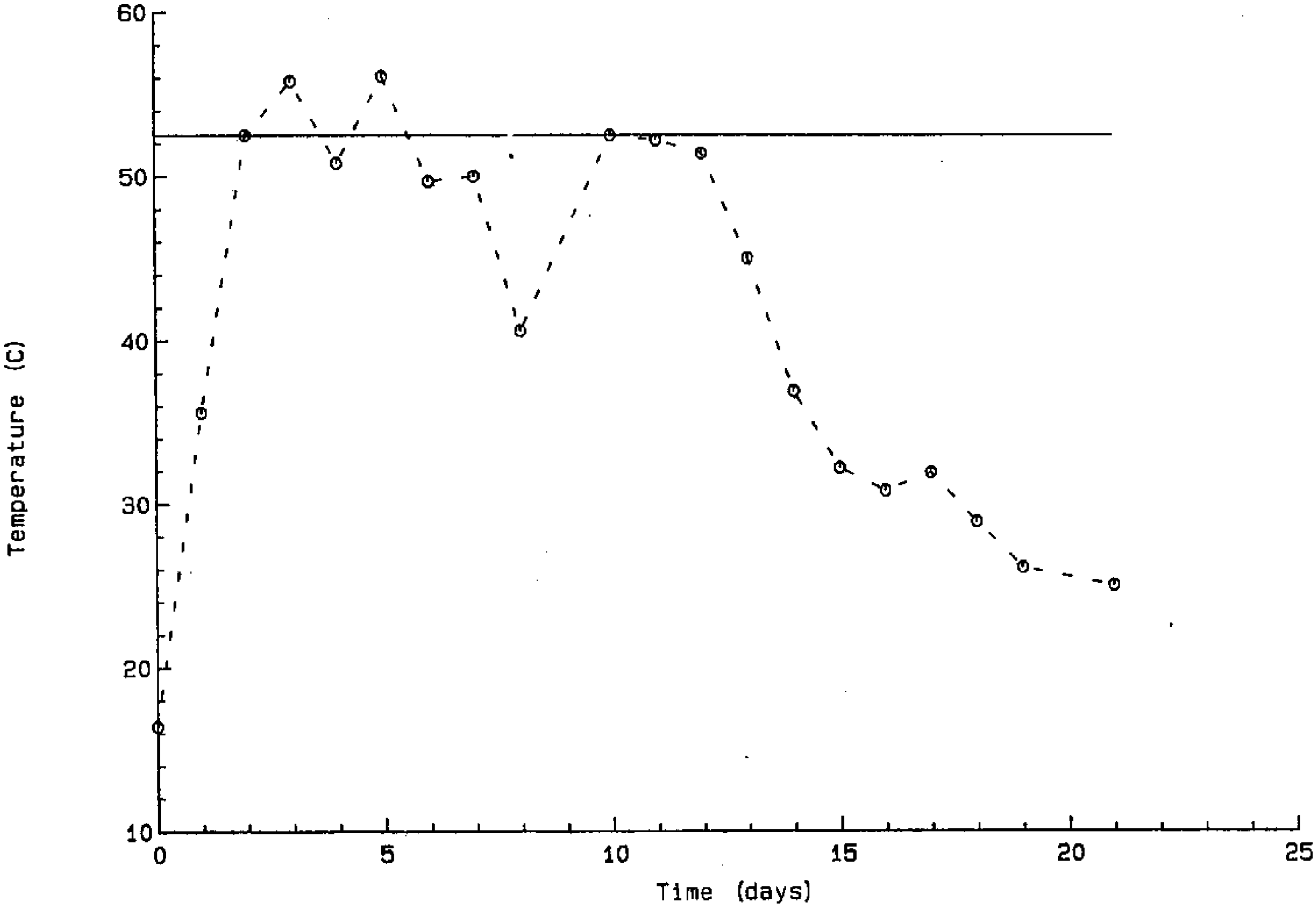

Figure B-8. Temperature record of test 8. The carbon-nitrogen ratio was 18.5:1 and the moisture content was 57% (wet basis).

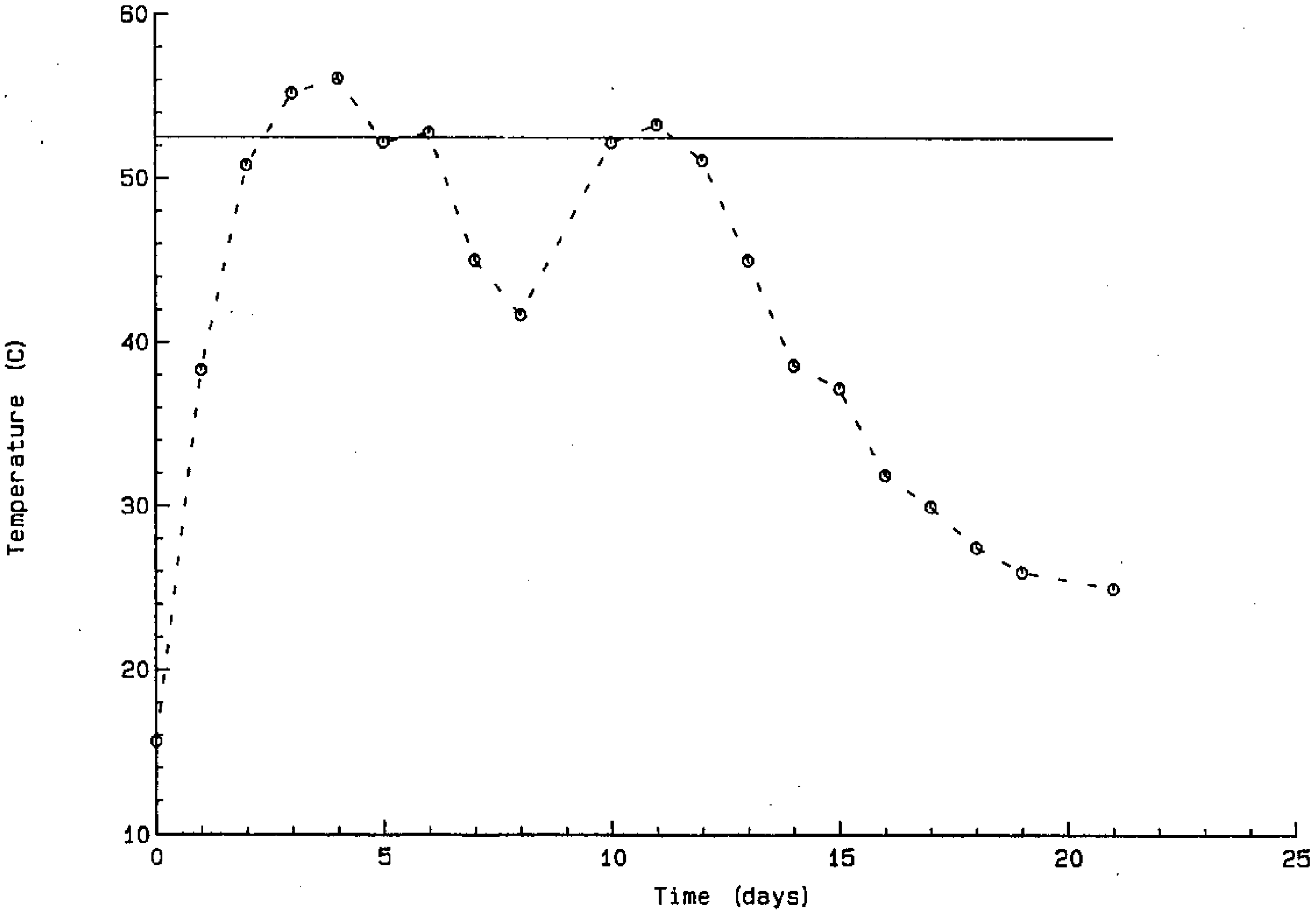

Figure B-9. Temperature record of test 9. The carbon-nitrogen ratio was 18.5:1 and the moisture content was 56% (wet basis).

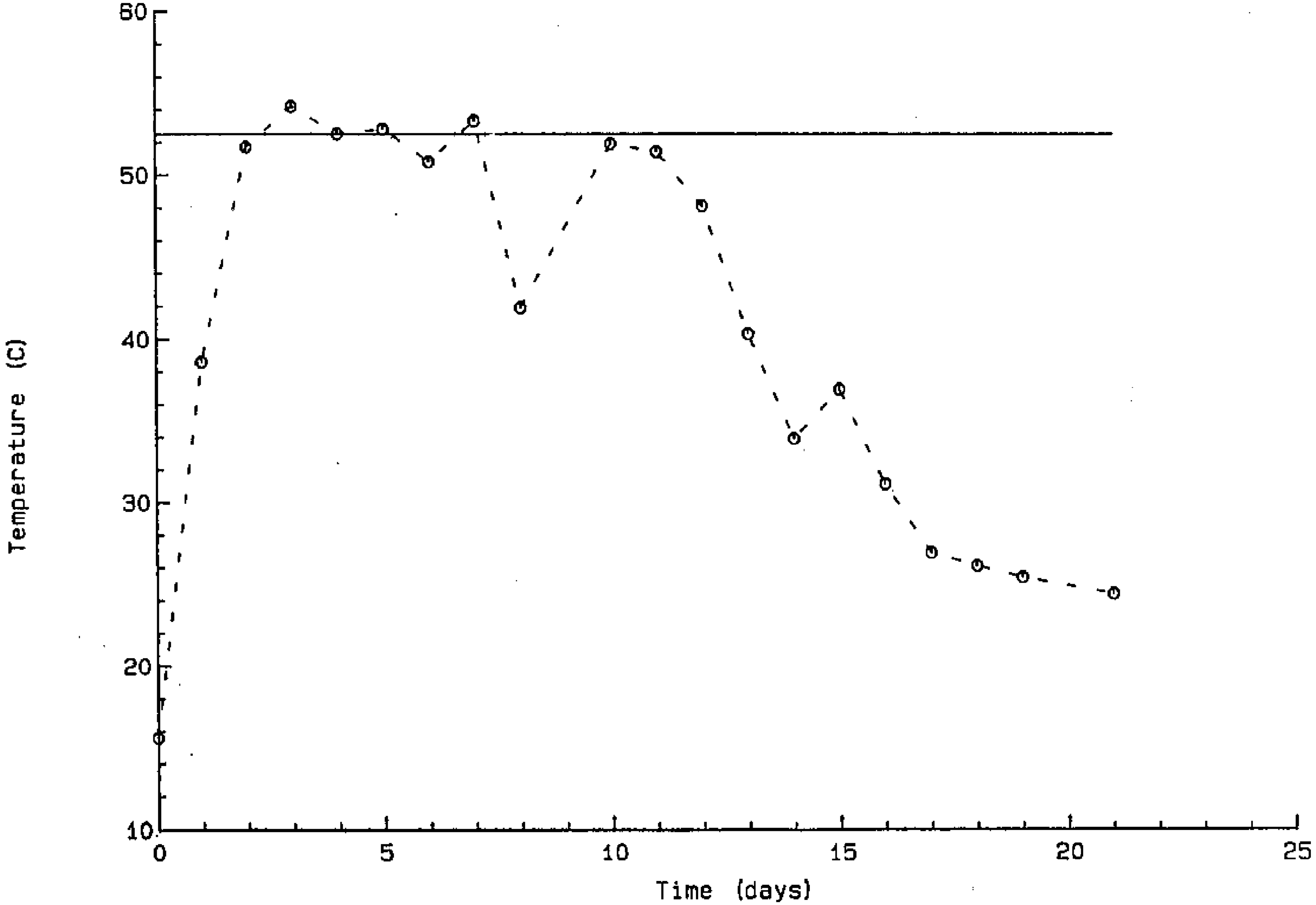

Figure B-10. Temperature record of test 10. The carbon-nitrogen ratio was 18.5:1 and the moisture content was 53% (wet basis).

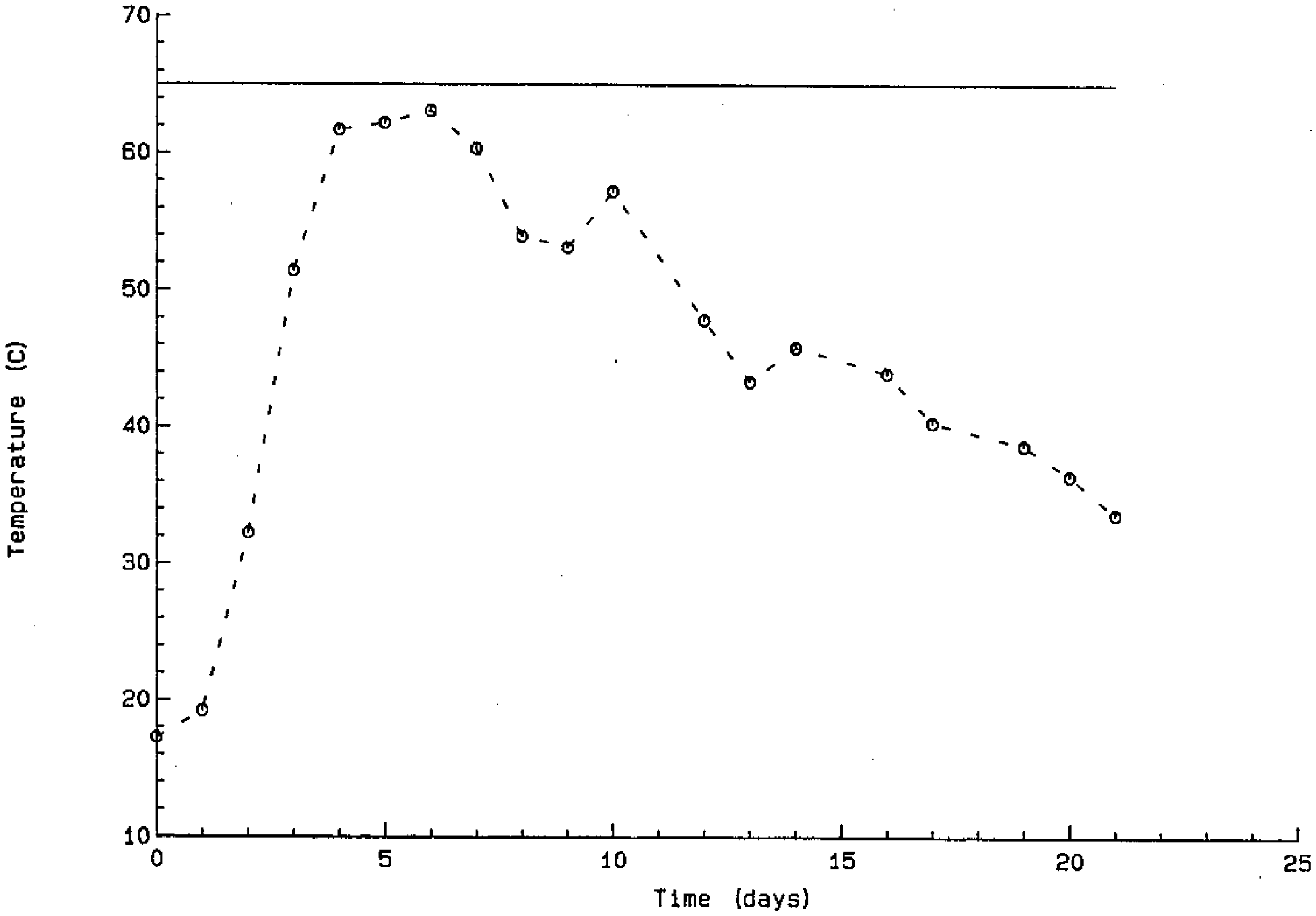

Figure B-11. Temperature record of test 11. The carbon-nitrogen ratio was 18.5:1 and the moisture content was 53% (wet basis).

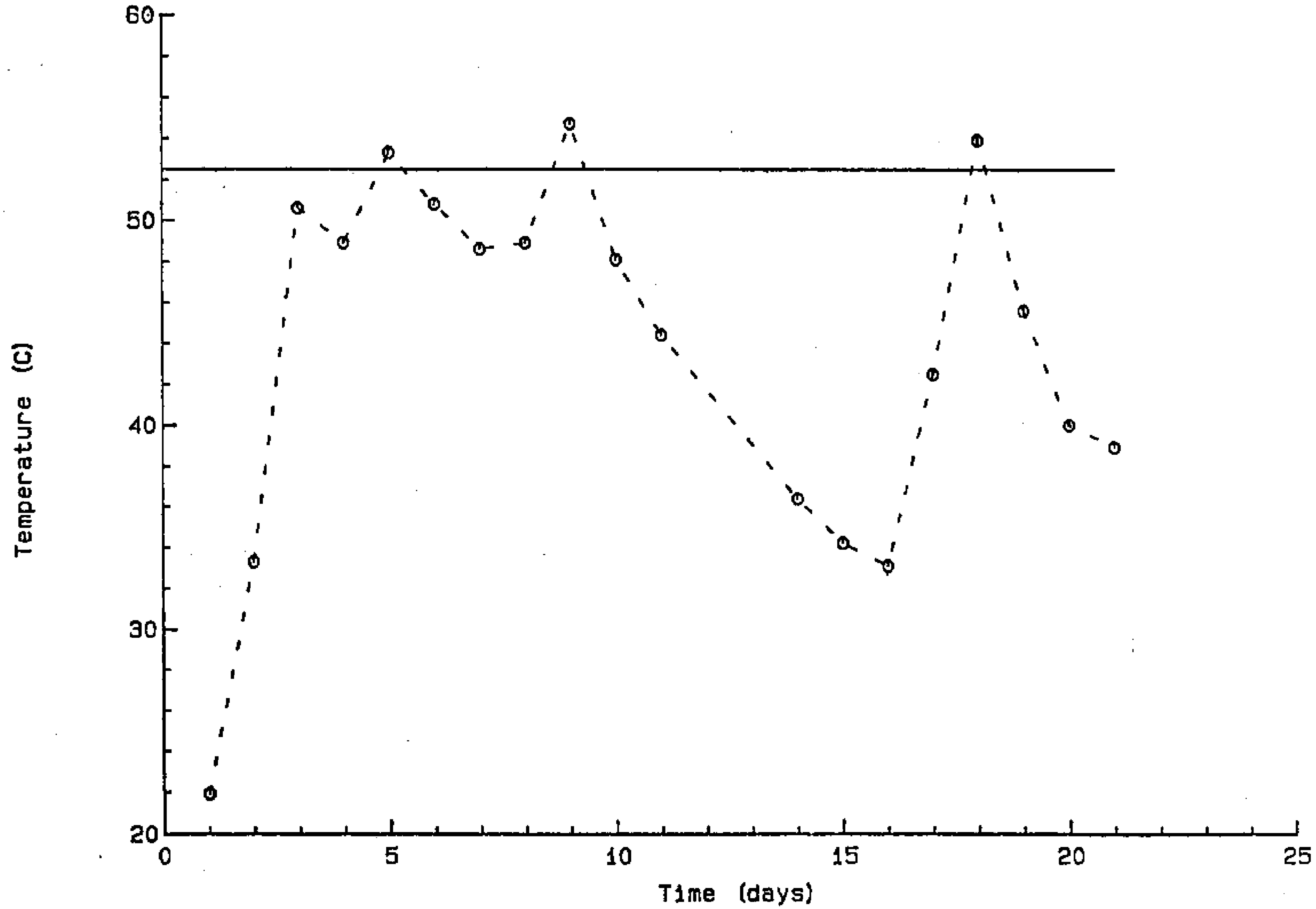

Figure B-12. Temperature record of test 12. The carbon-nitrogen ratio was 20:1 and the moisture content was 43% (wet basis).

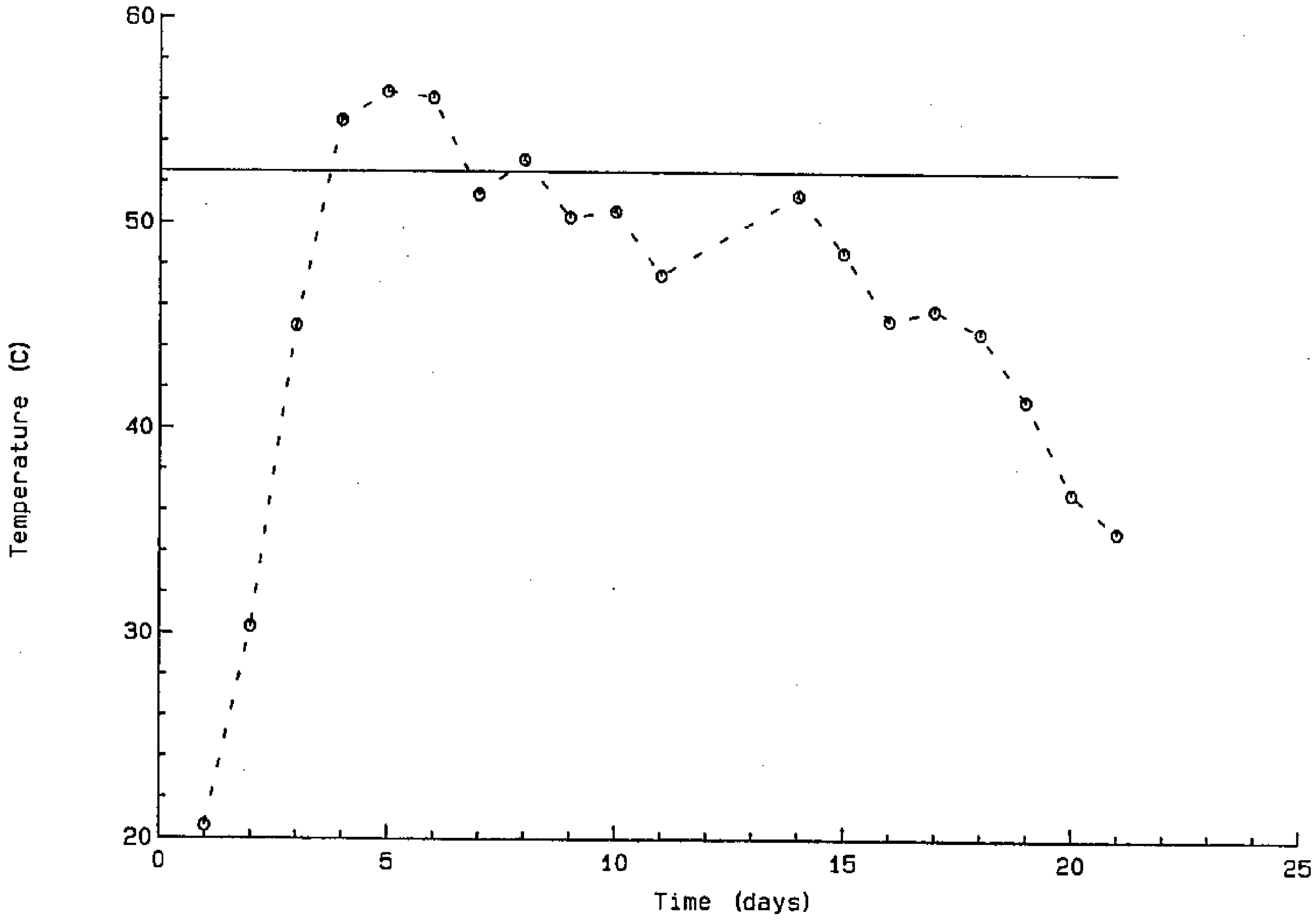

Figure B-13. Temperature record of test 13. The carbon-nitrogen ratio was 20:1 and the moisture content was 67% (wet basis).

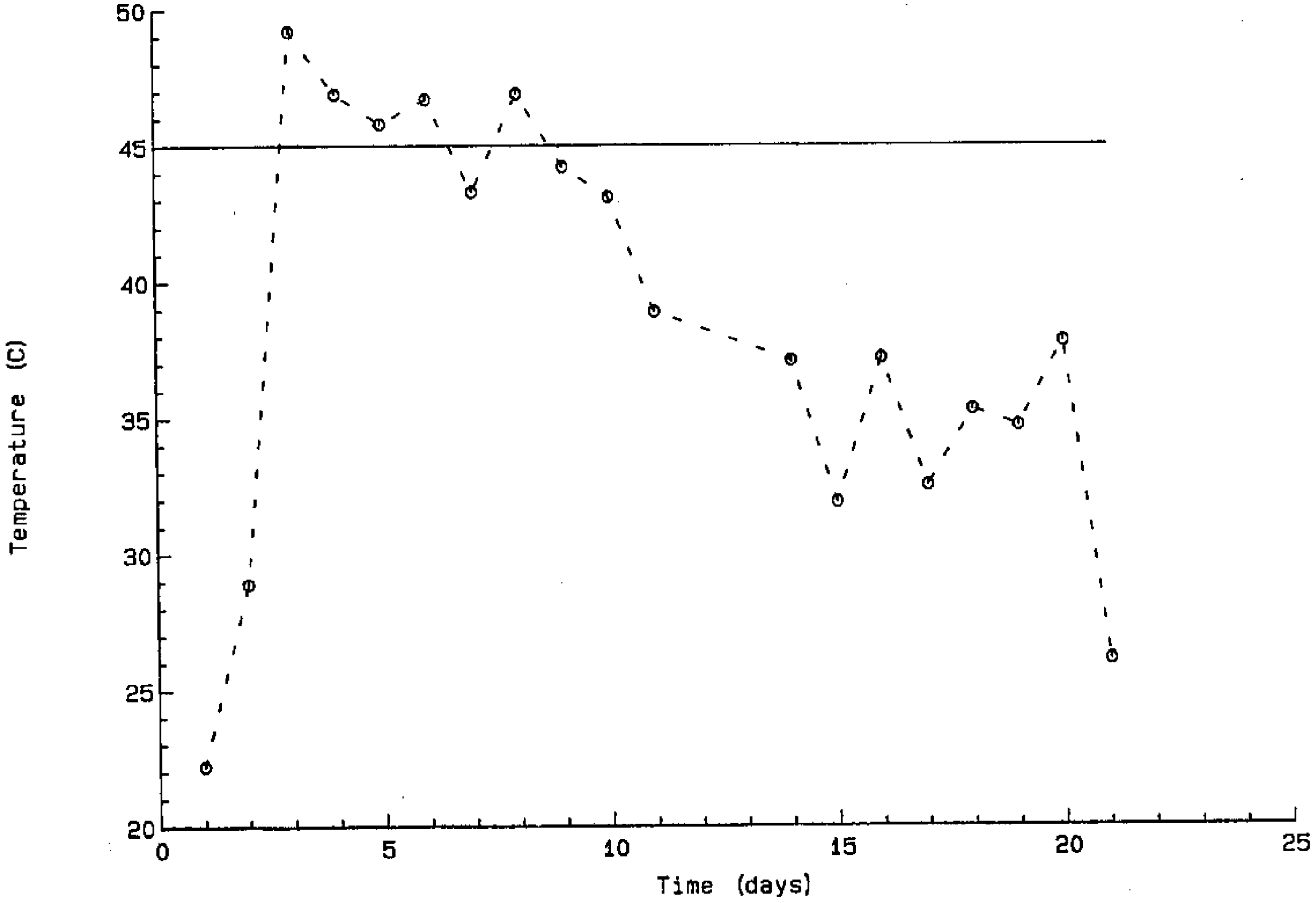

Figure B-14. Temperature record of test 14. The carbon-nitrogen ratio was 25:1 and the moisture content was 46% (wet basis).

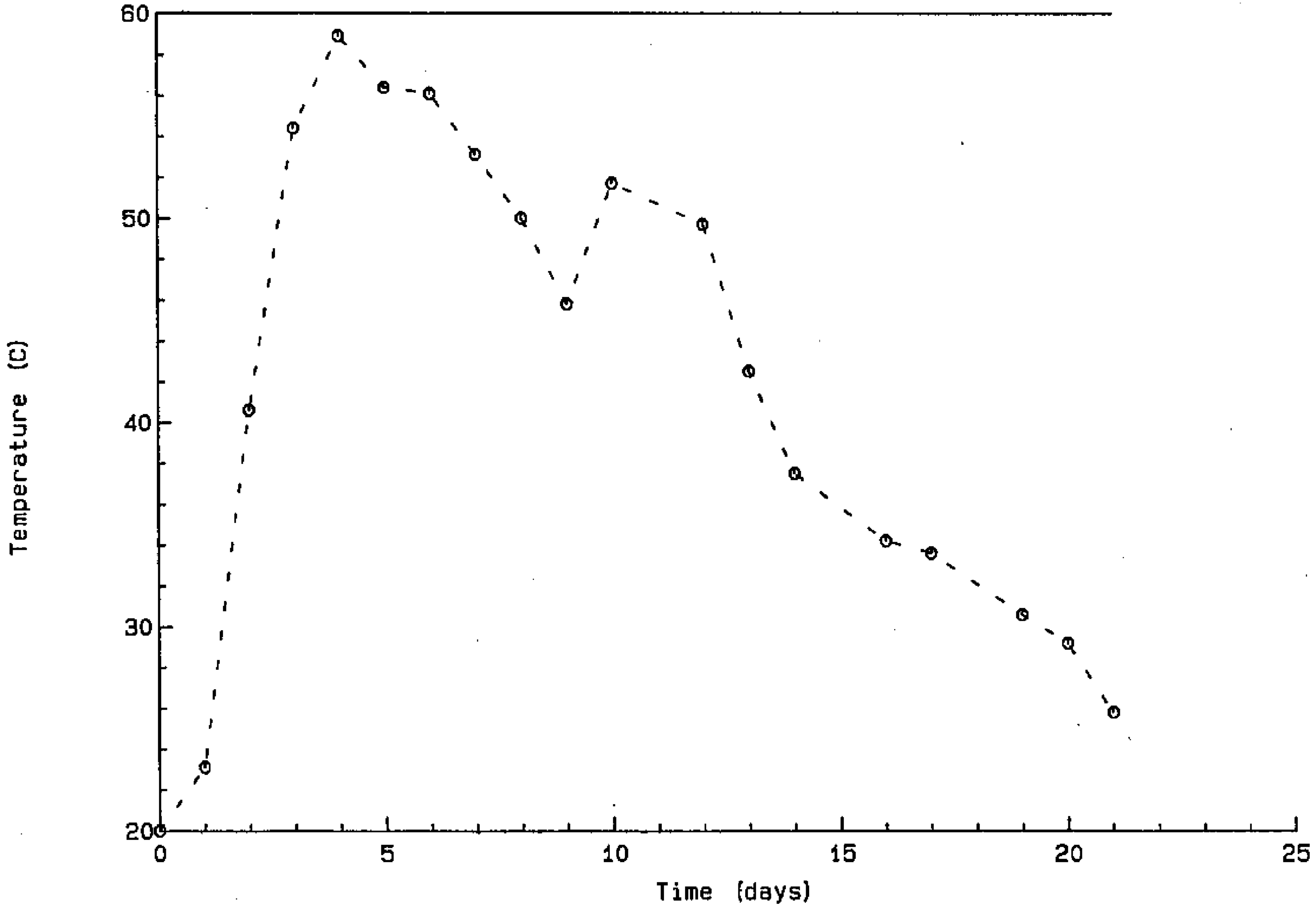

Figure B-15. Temperature record of test 15. The carbon-nitrogen ratio was 23.4:1 and the moisture content was 46% (wet basis).

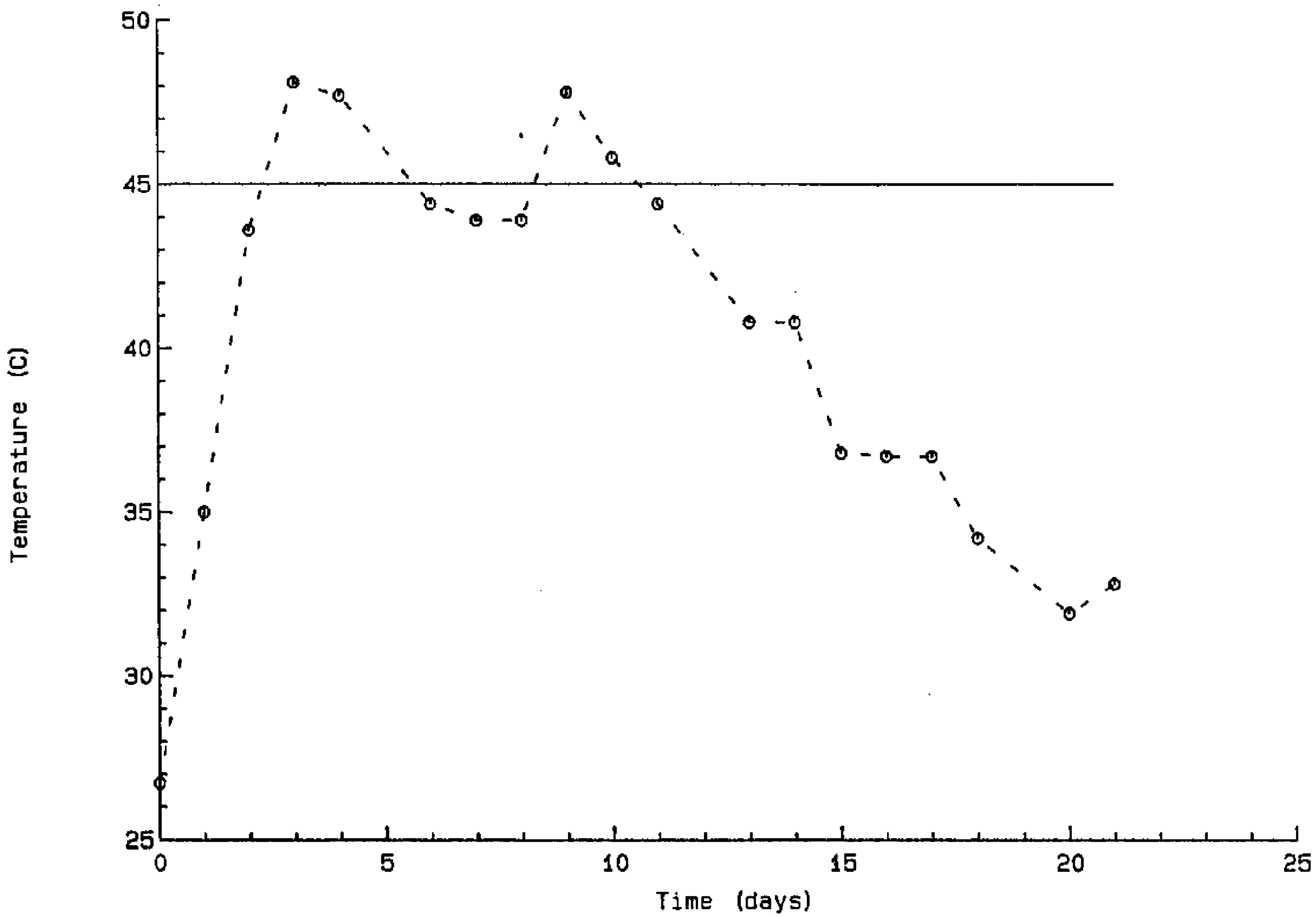

Figure B-16. Temperature record of test 16. The carbon-nitrogen ratio was 24.5:1 and the moisture content was 65% (wet basis).

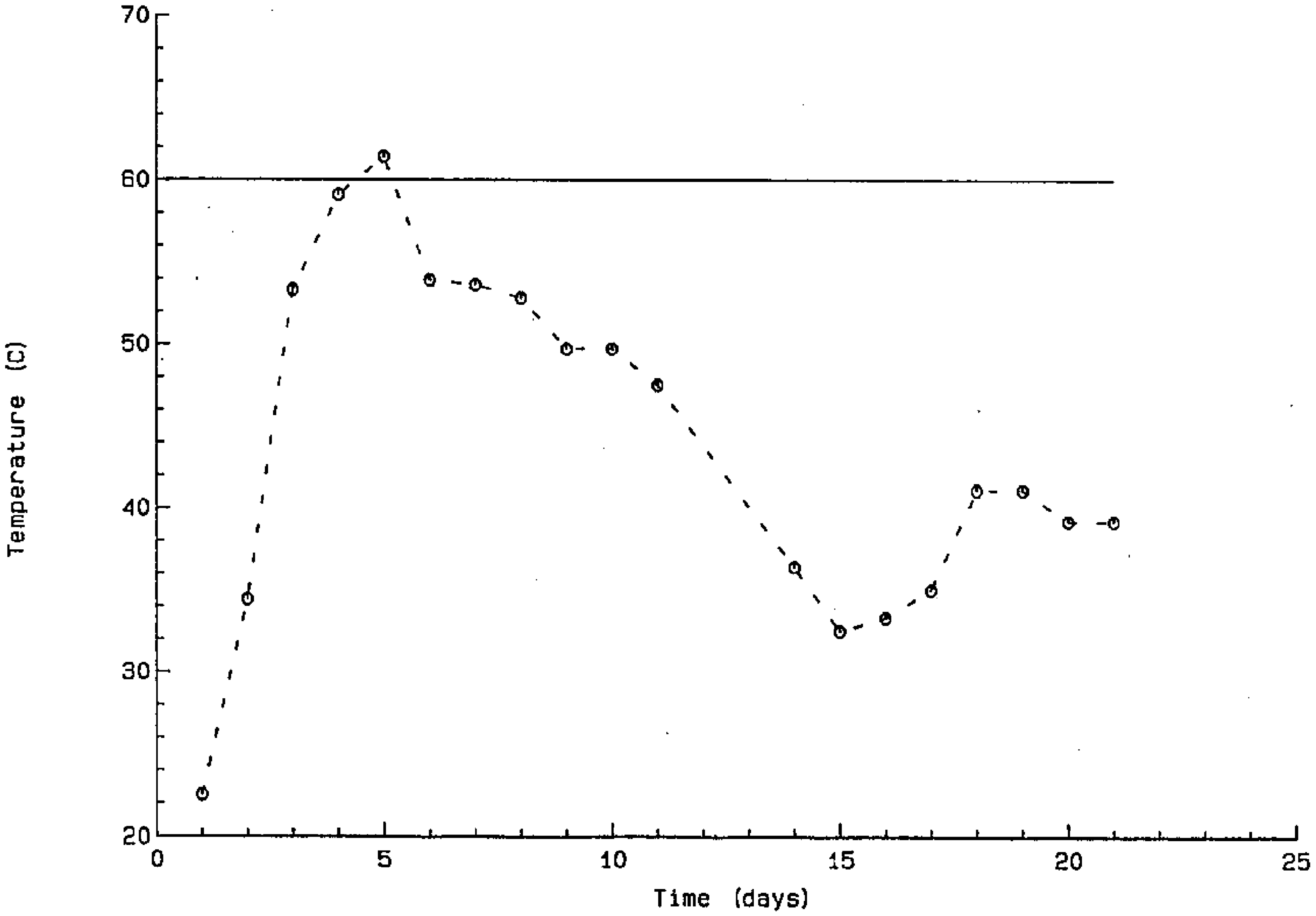

Figure B-17. Temperature record of test 17. The carbon-nitrogen ratio was 25:1 and the moisture content was 61% (wet basis).

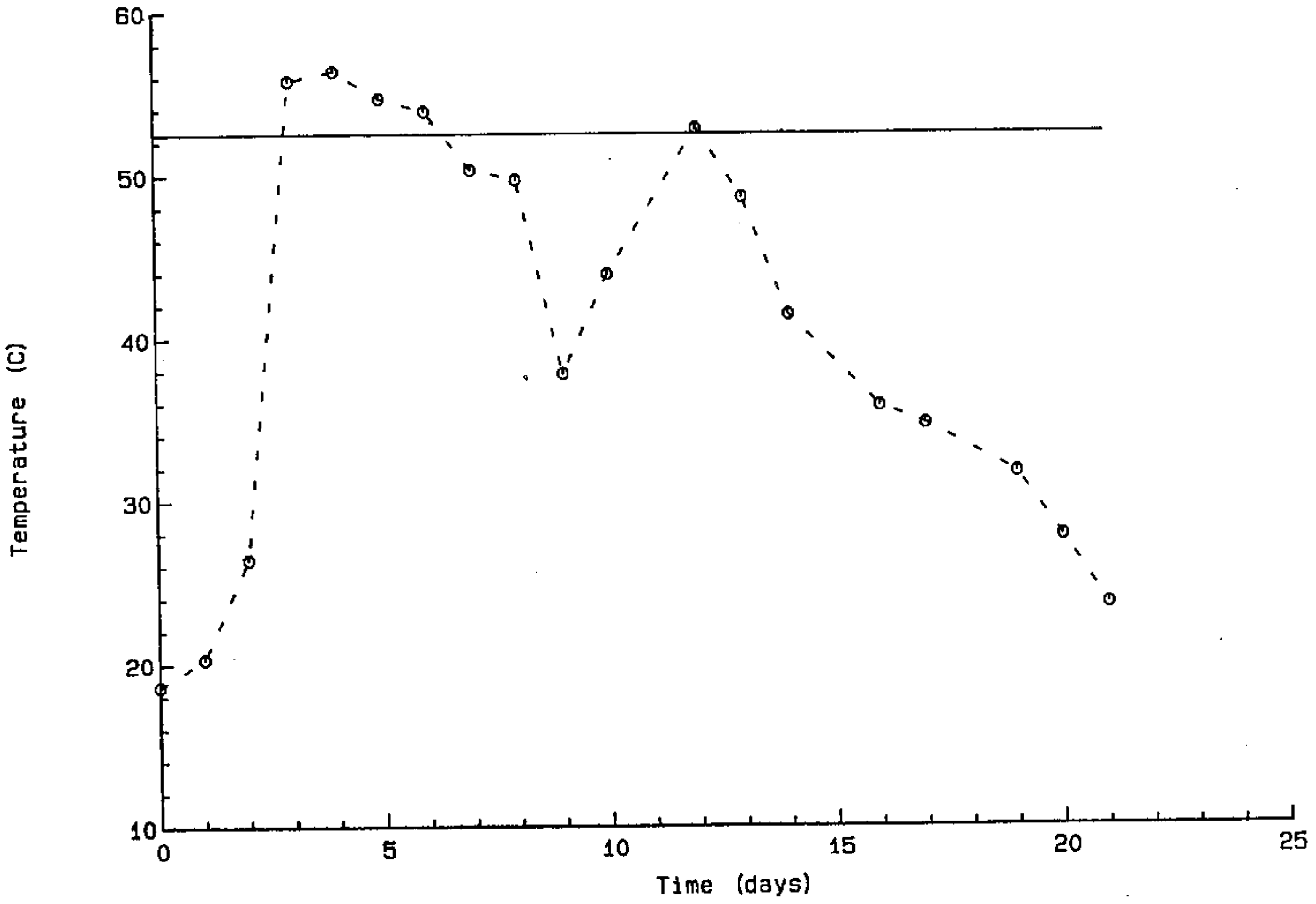

Figure B-18. Temperature record of test 18. The carbon-nitrogen ratio was 26.7:1 and the moisture content was 58% (wet basis).

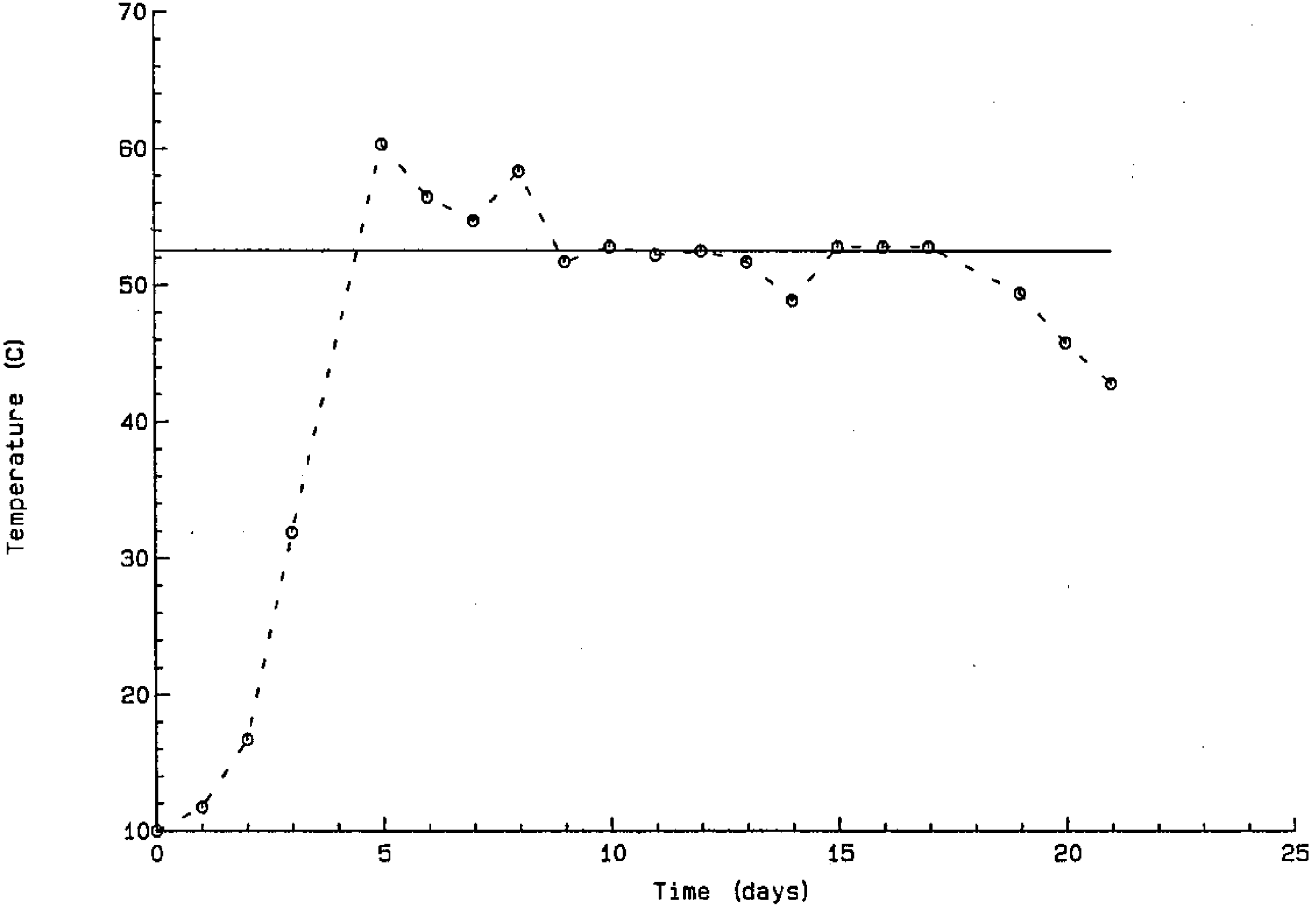

Figure B-19. Temperature record of test 19. The carbon-nitrogen ratio was 10.4:1 and the moisture content was 57% (wet basis).

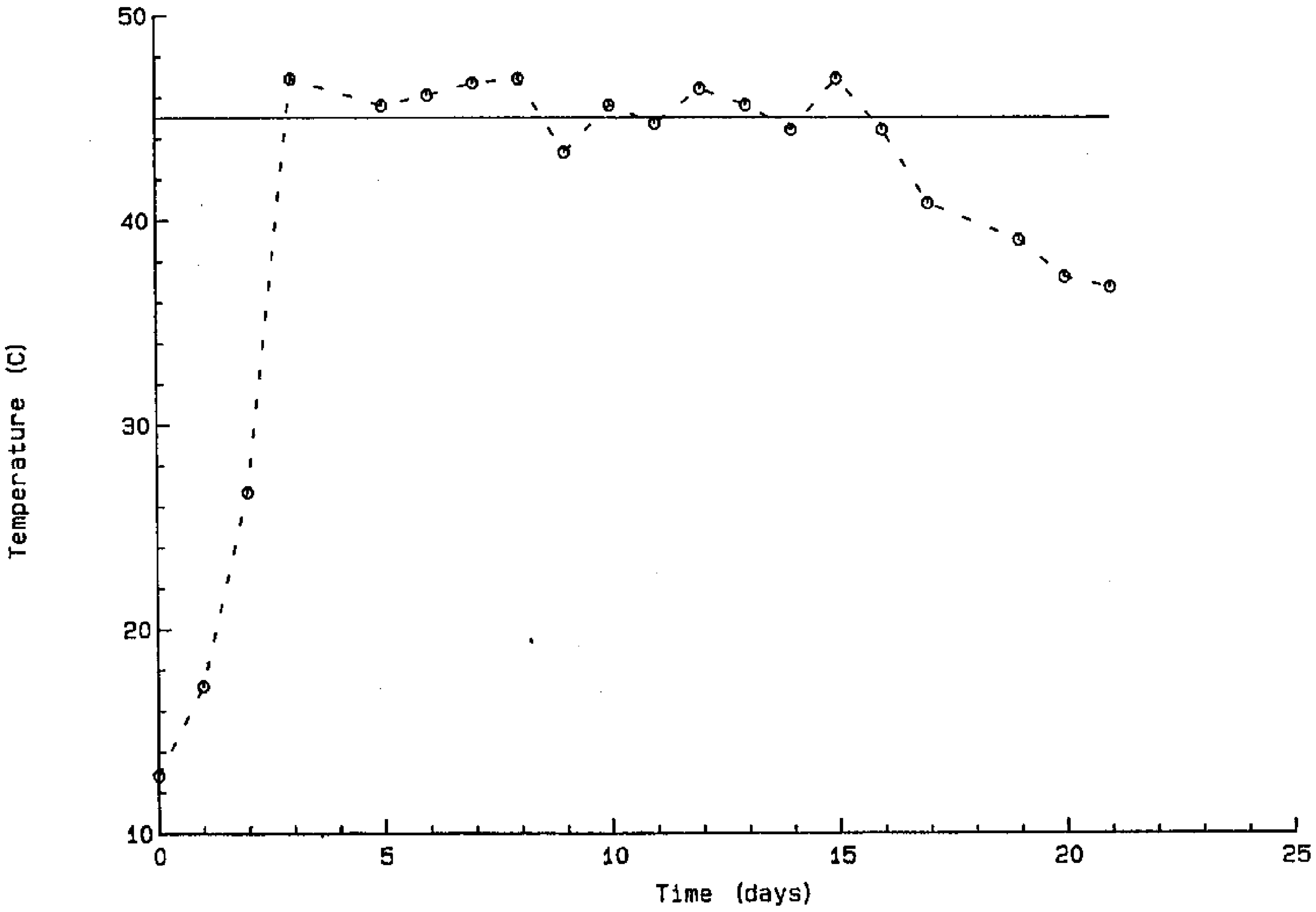

Figure B-20. Temperature record of test 20. The carbon-nitrogen ratio was 13.6:1 and the moisture content was 47% (wet basis).

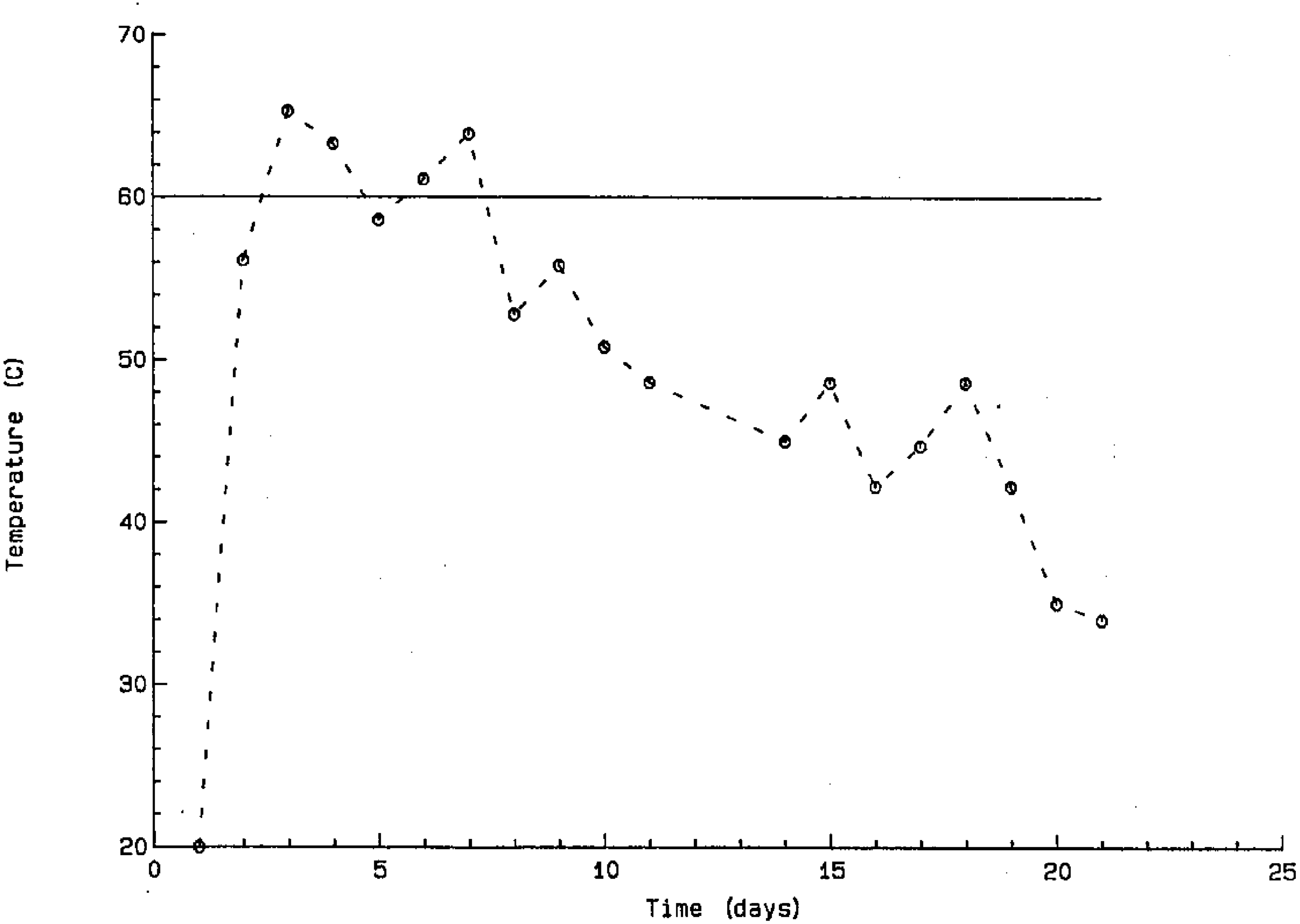

Figure B-21. Temperature record of test 21. The carbon-nitrogen ratio was 15:1 and the moisture content was 49% (wet basis).

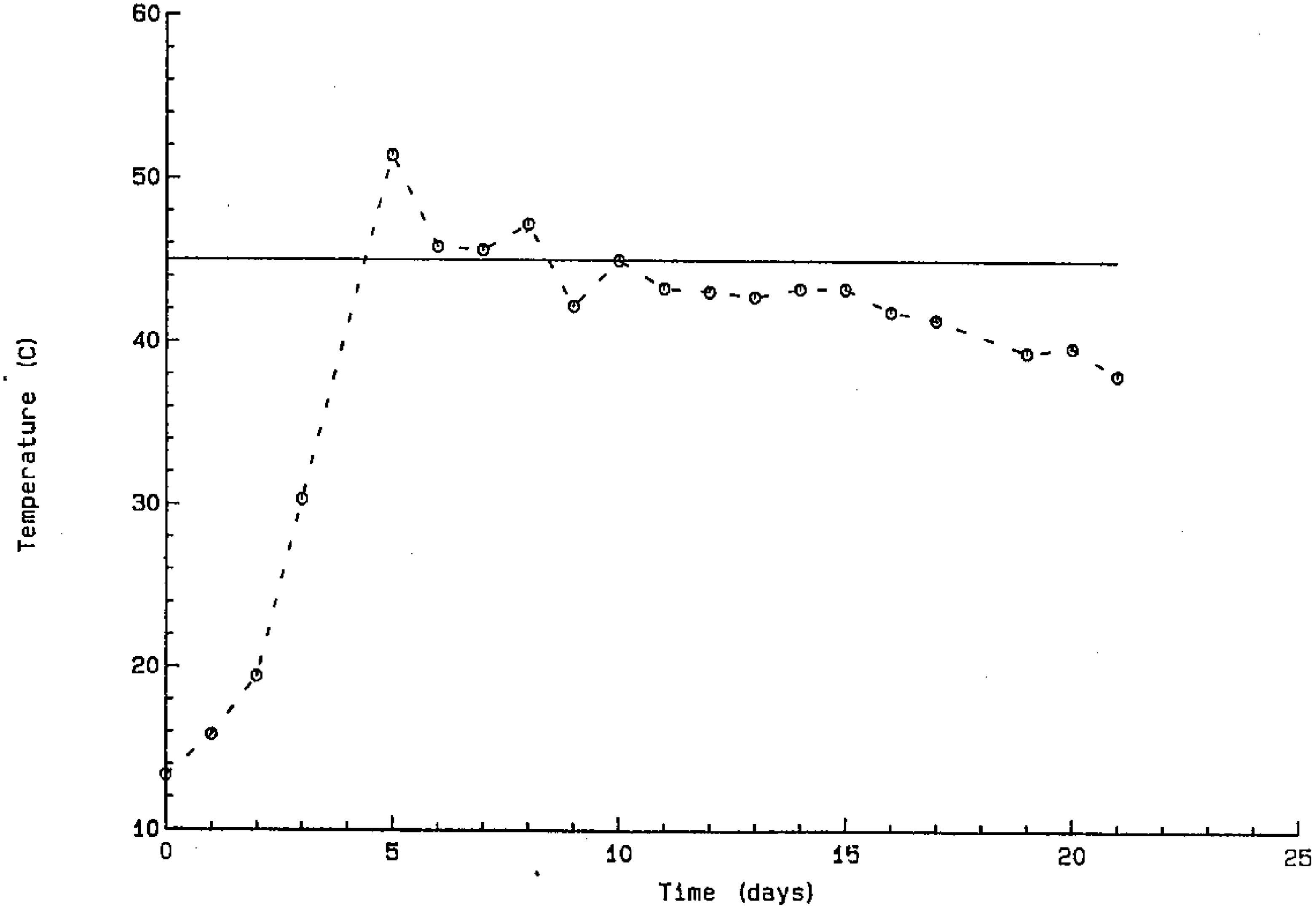

Figure B-22. Temperature record of test 22. The carbon-nitrogen ratio was 13.6:1 and the moisture content was 64% (wet basis).

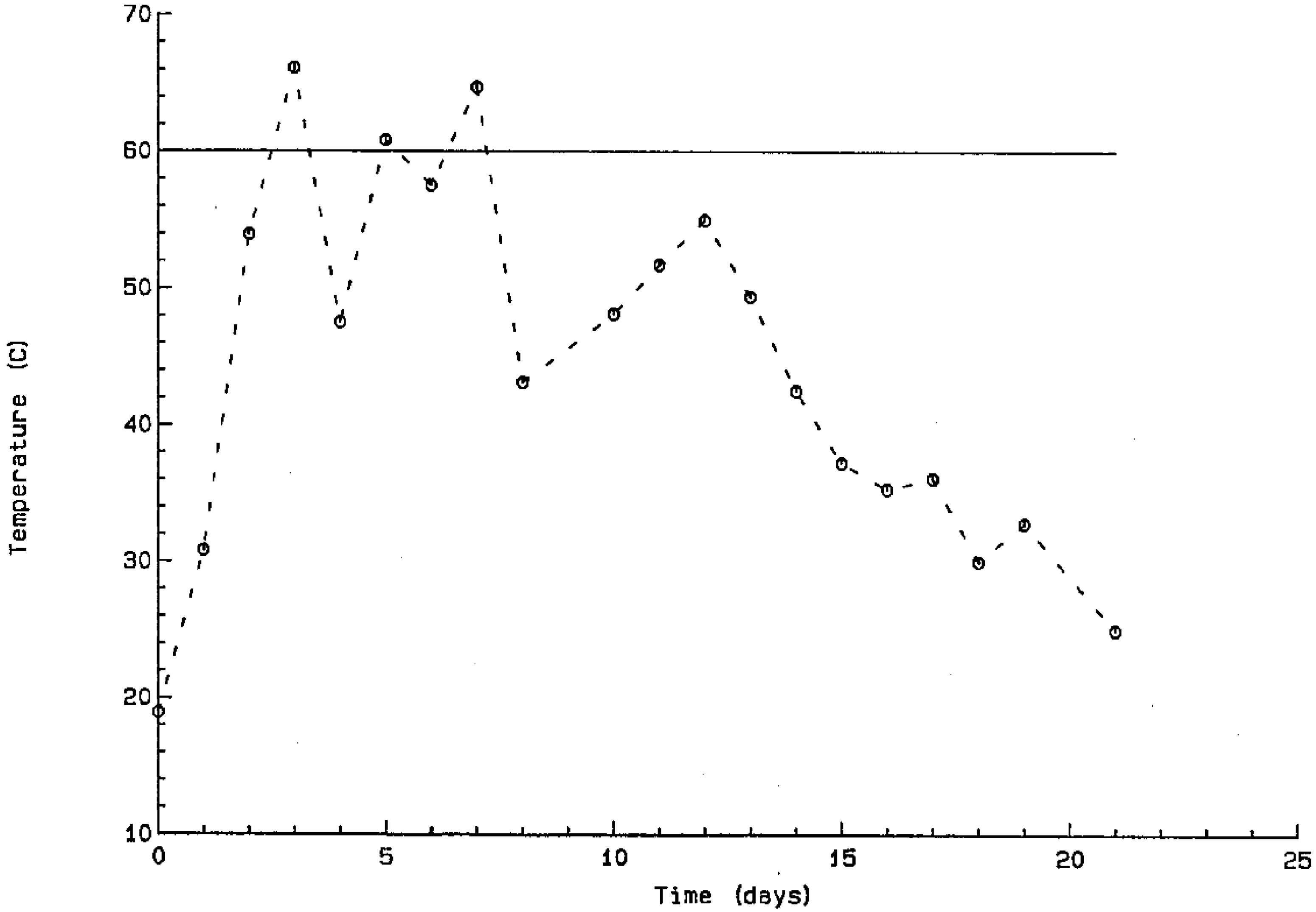

Figure B-23. Temperature record of test 23. The carbon-nitrogen ratio was 13.6:1 and the moisture content was 65% (wet basis).

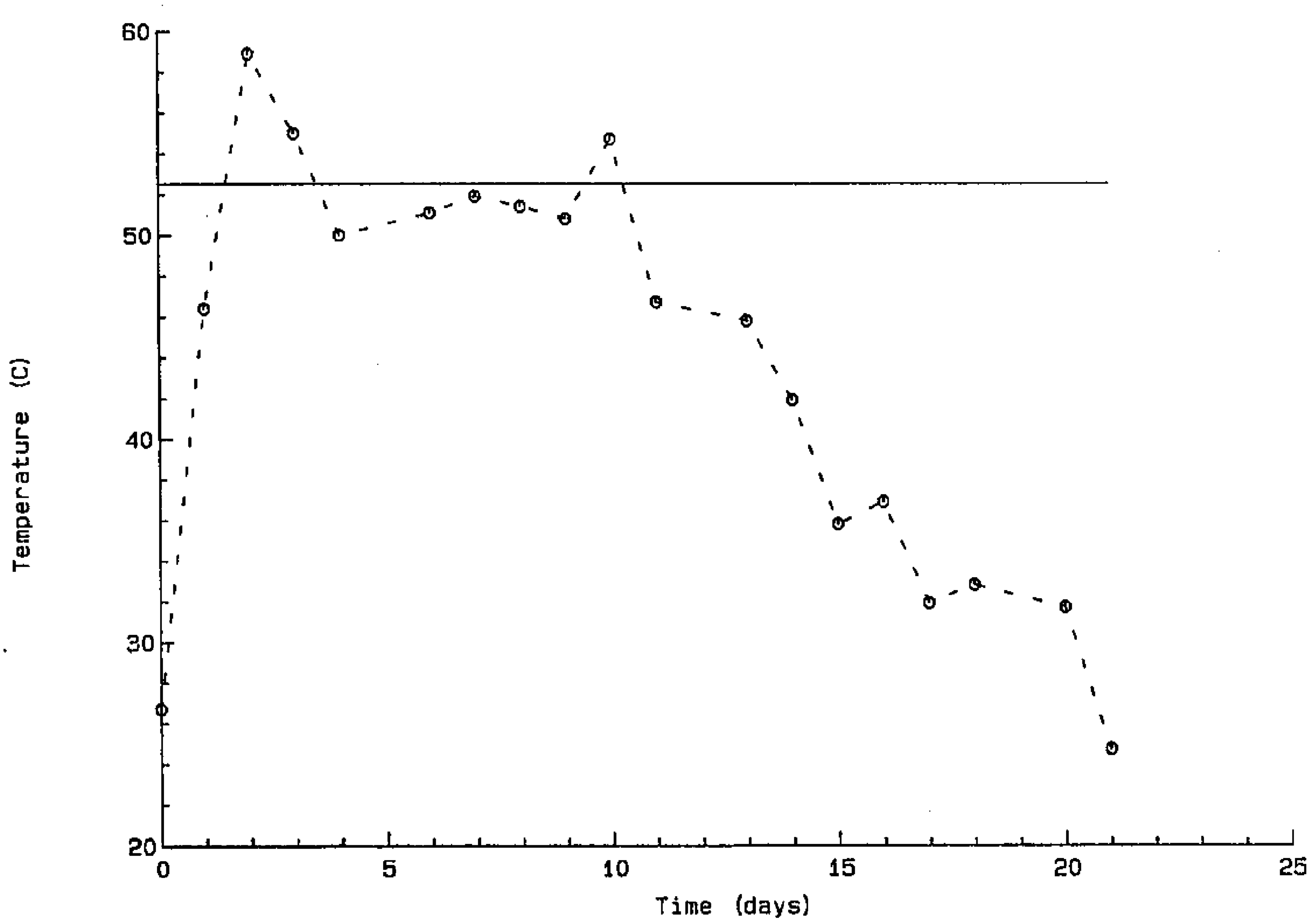

Figure B-24. Temperature record of test 24. The carbon-nitrogen ratio was 19.5:1 and the moisture content was 40% (wet basis).

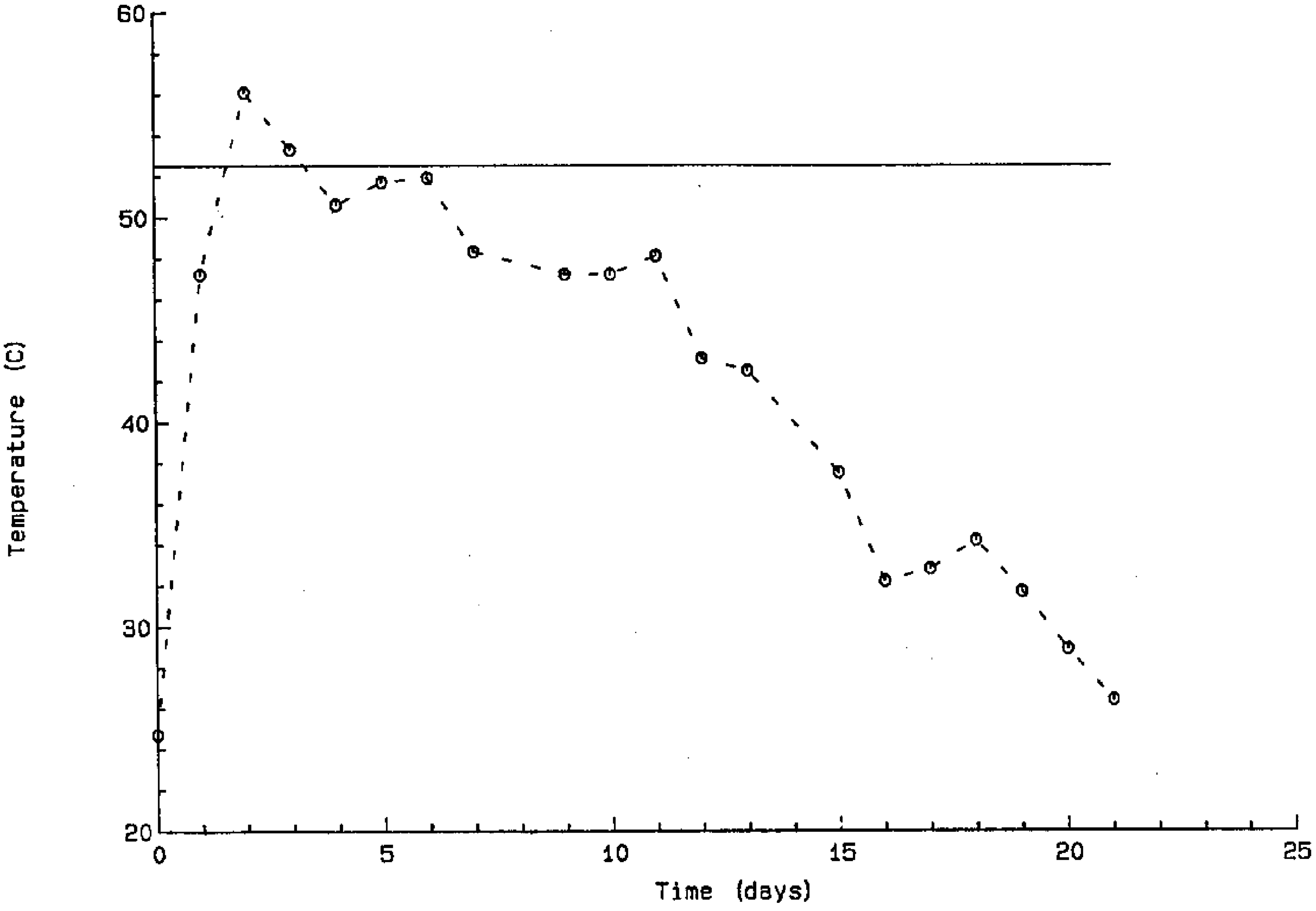

Figure B-25. Temperature record of test 25. The carbon-nitrogen ratio was 18.8:1 and the moisture content was 58% (wet basis).

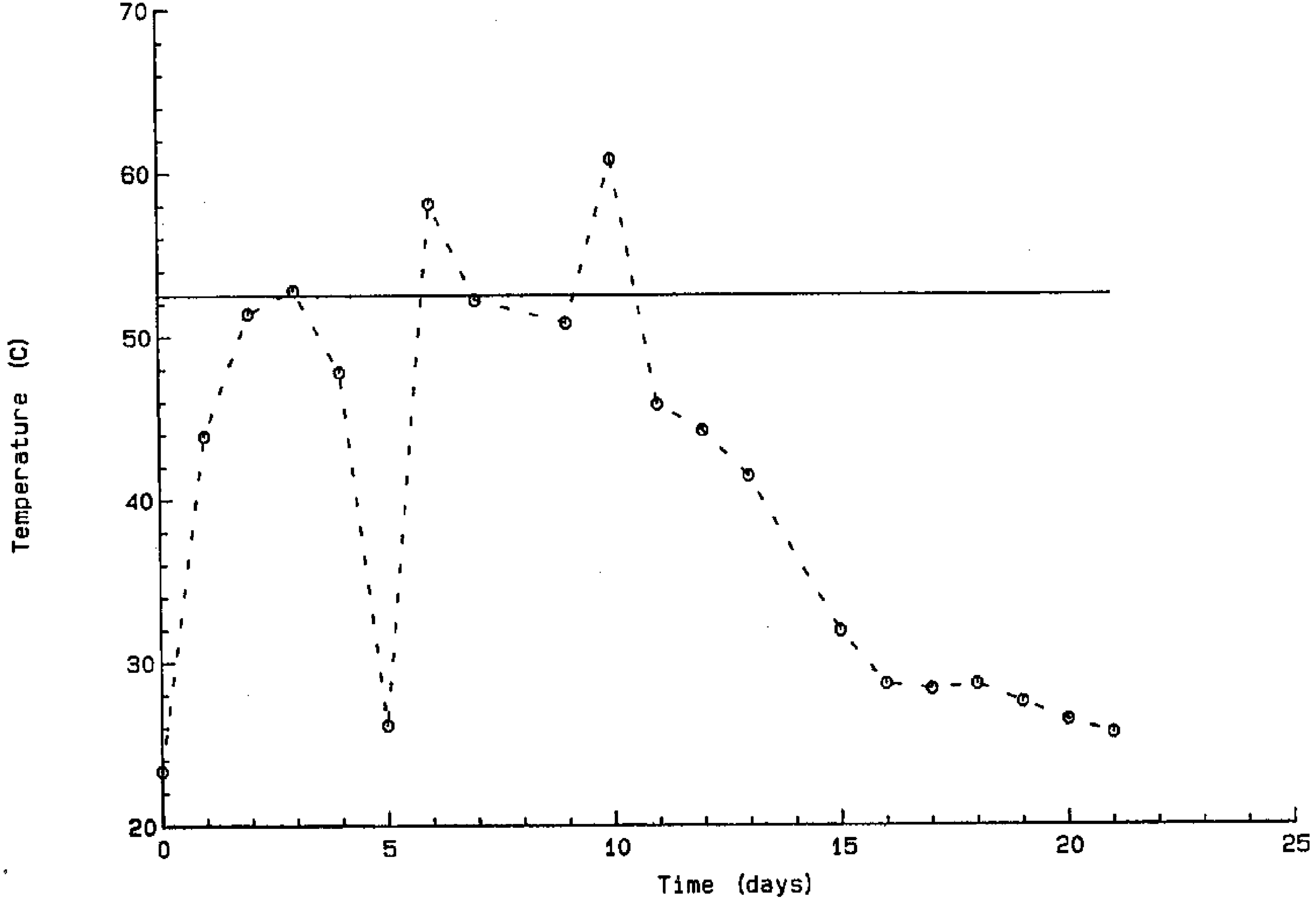

Figure B-26. Temperature record of test 26. The carbon-nitrogen ratio was 18.8:1 and the moisture content was 56% (wet basis).

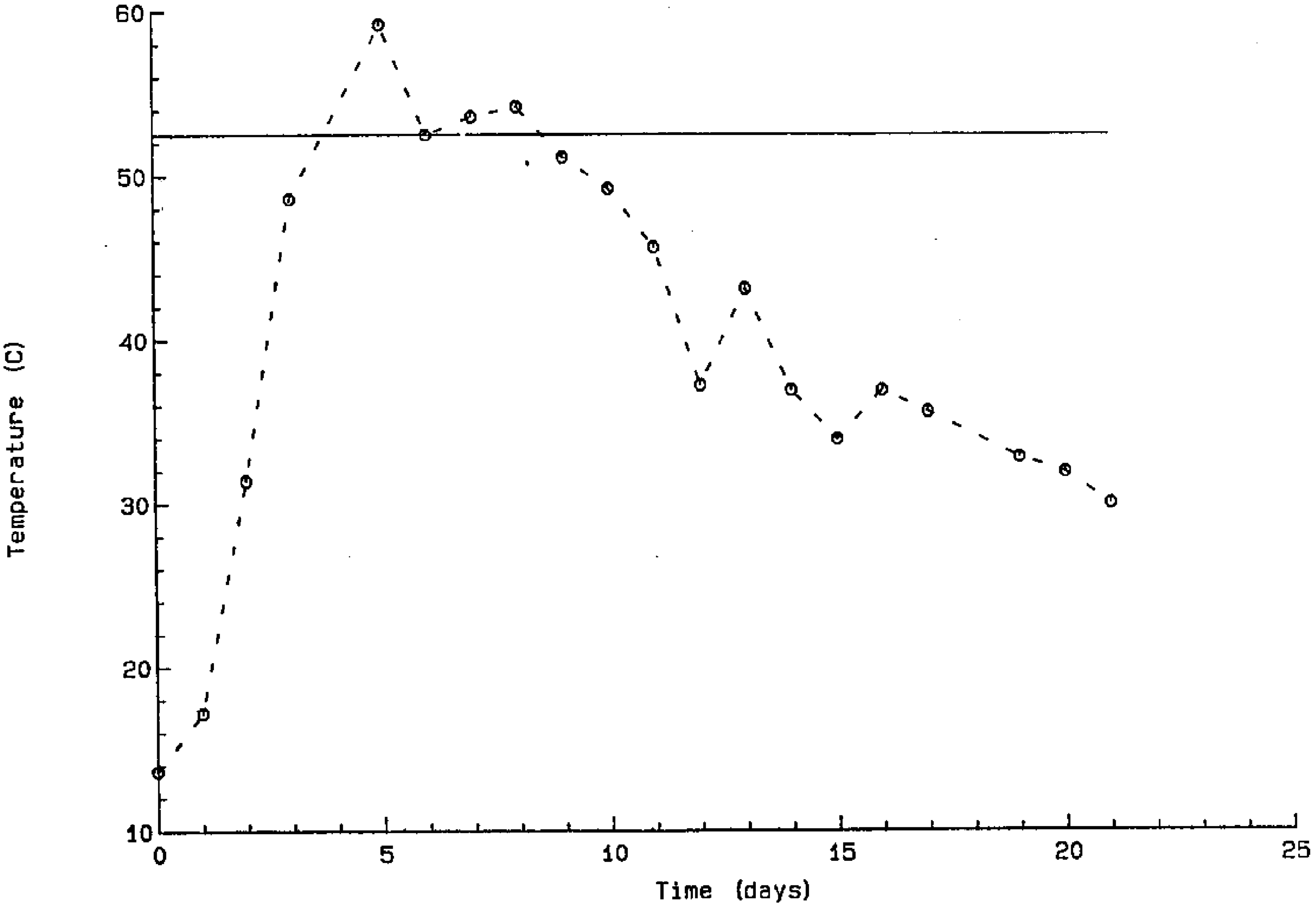

Figure B-27. Temperature record of test 27. The carbon-nitrogen ratio was 18.5:1 and the moisture content was 59% (wet basis).

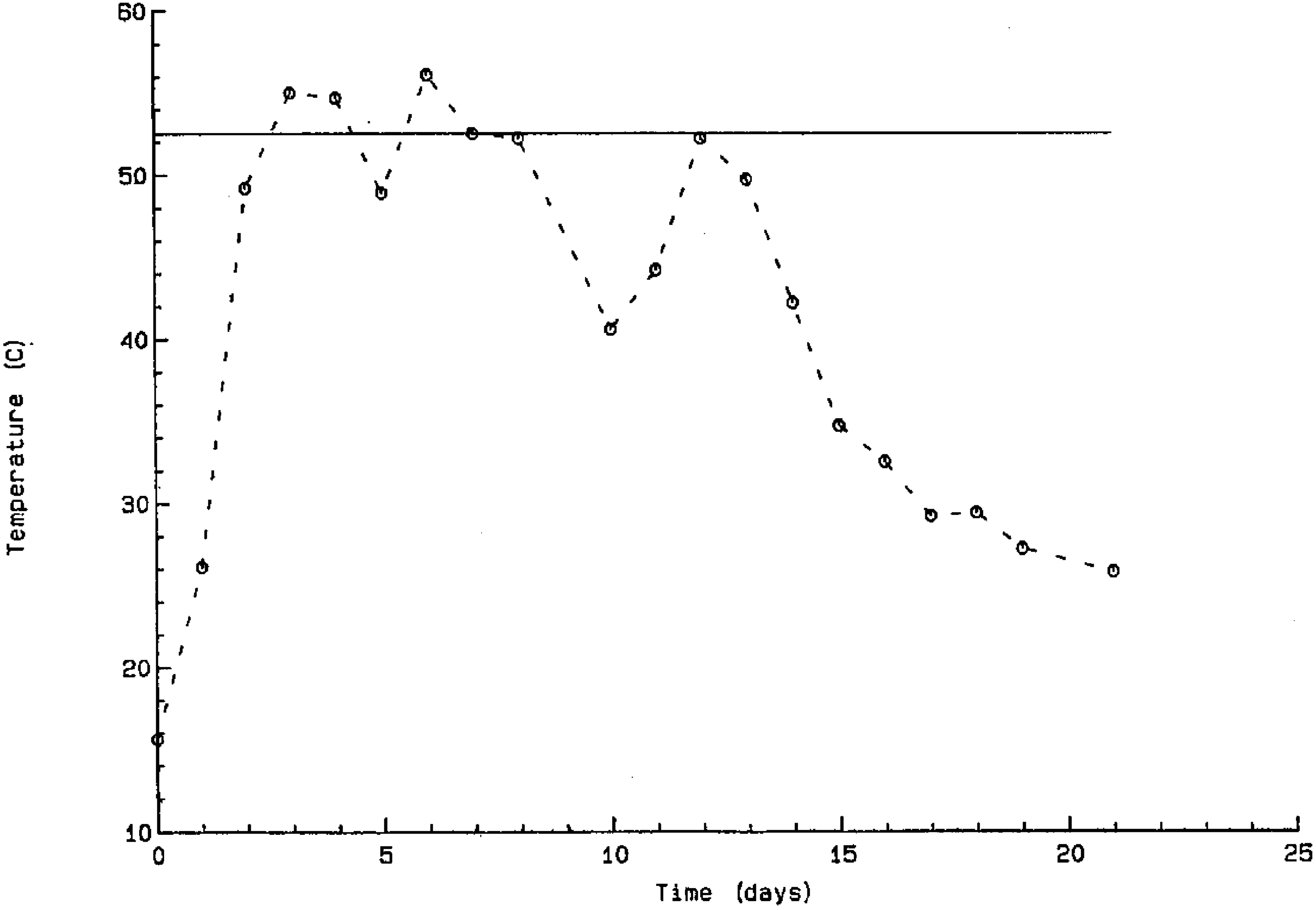

Figure B-28. Temperature record of test 28. The carbon-nitrogen ratio was 18.5:1 and the moisture content was 56% (wet basis).

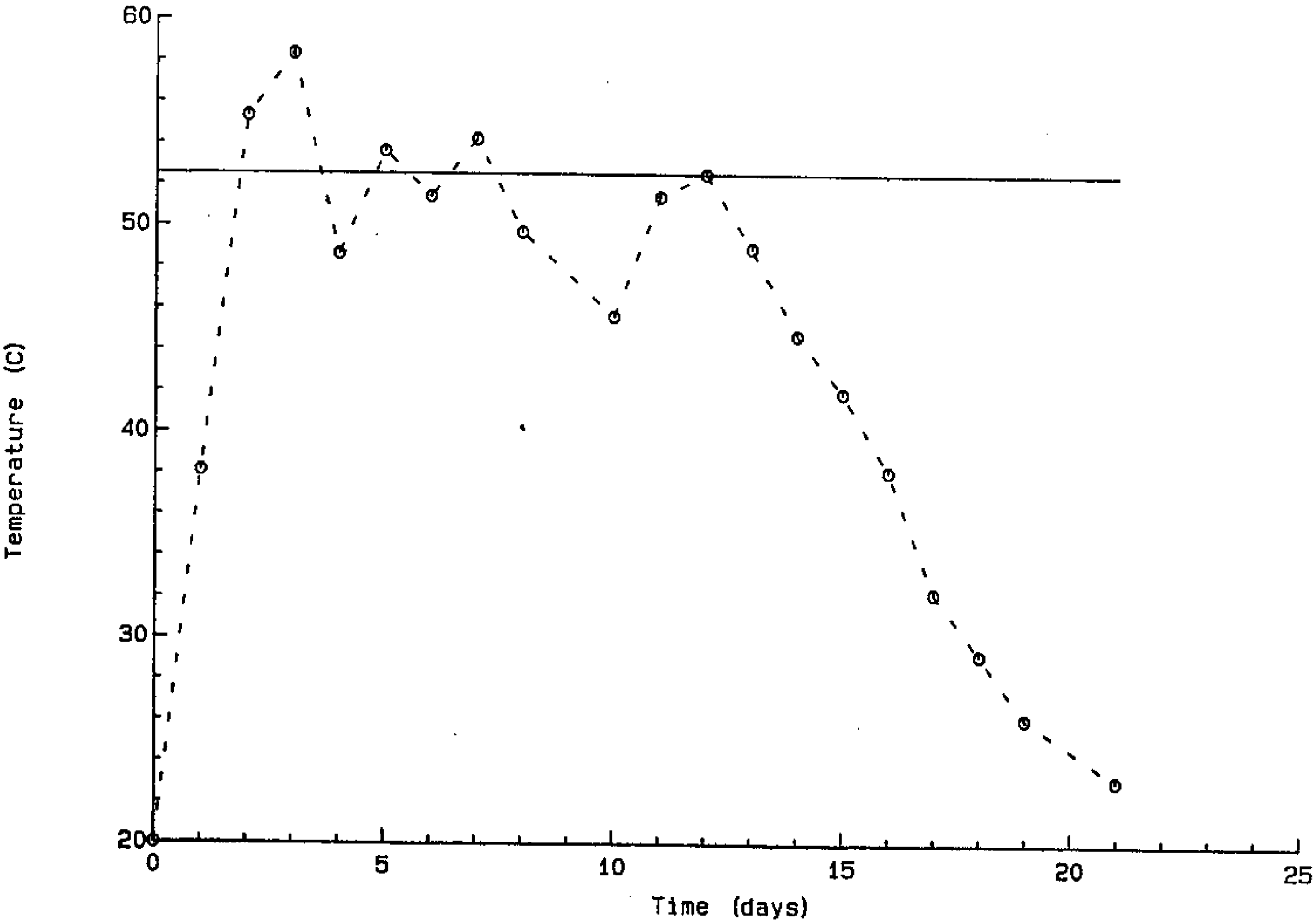

Figure B-29. Temperature record of test 29. The carbon-nitrogen ratio was 18.5:1 and the moisture content was 55% (wet basis).

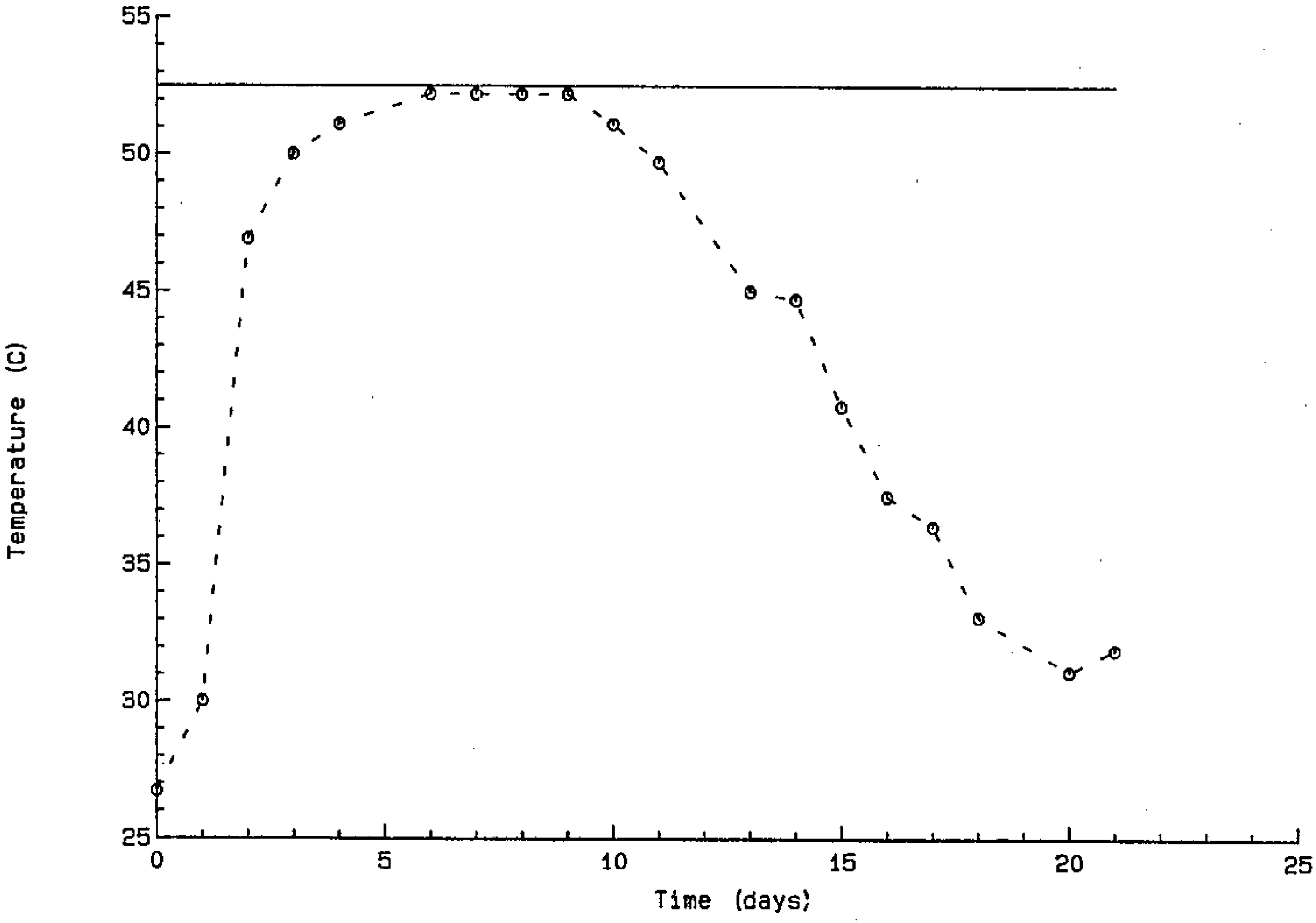

Figure B-30. Temperature record of test 30. The carbon-nitrogen ratio was 19.5:1 and the moisture content was 66% (wet basis).

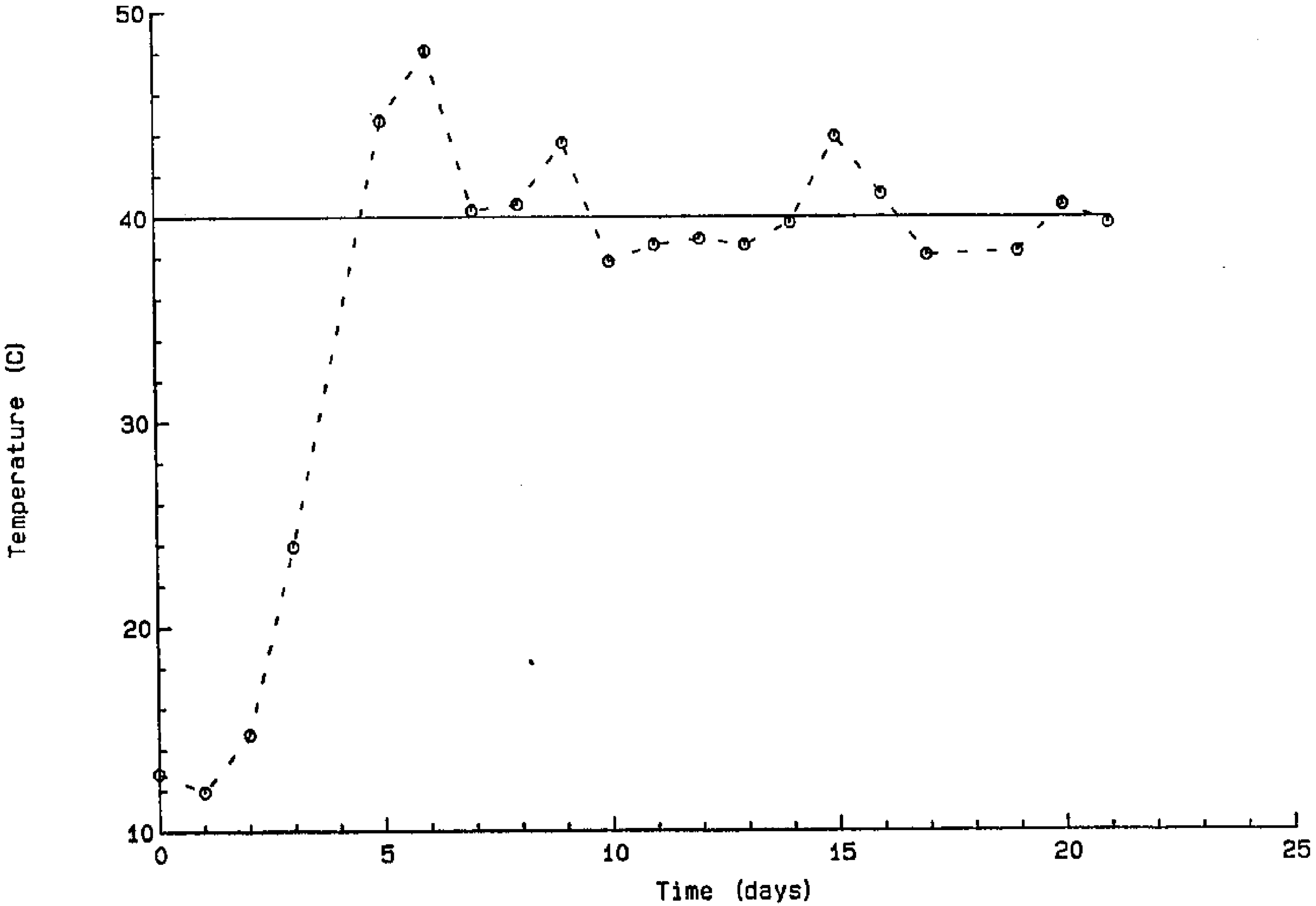

Figure B-31. Temperature record of test 31. The carbon-nitrogen ratio was 18.5:1 and the moisture content was 55% (wet basis).

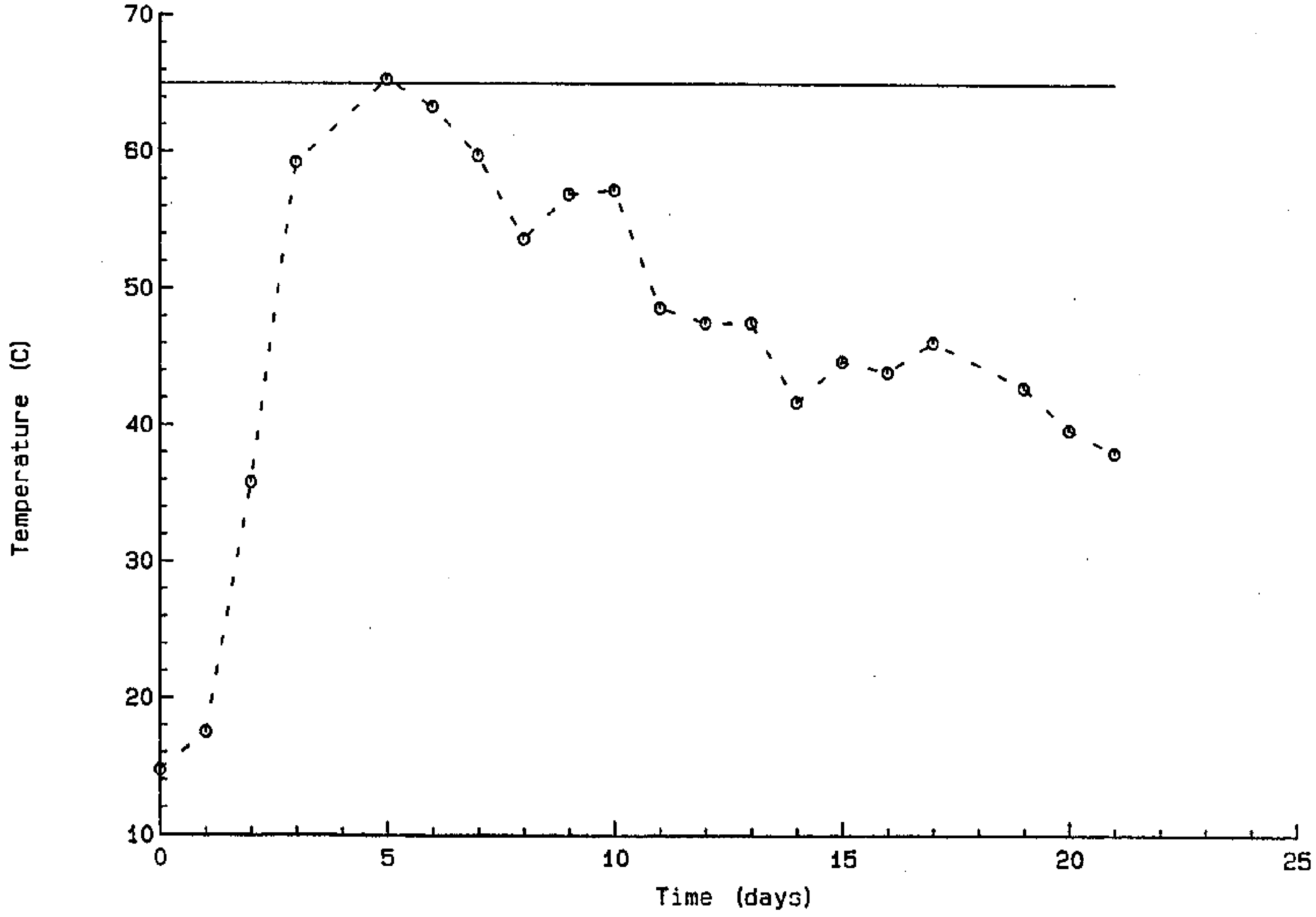

Figure B-32. Temperature record of test 32. The carbon-nitrogen ratio was 18.5:1 and the moisture content was 55% (wet basis).

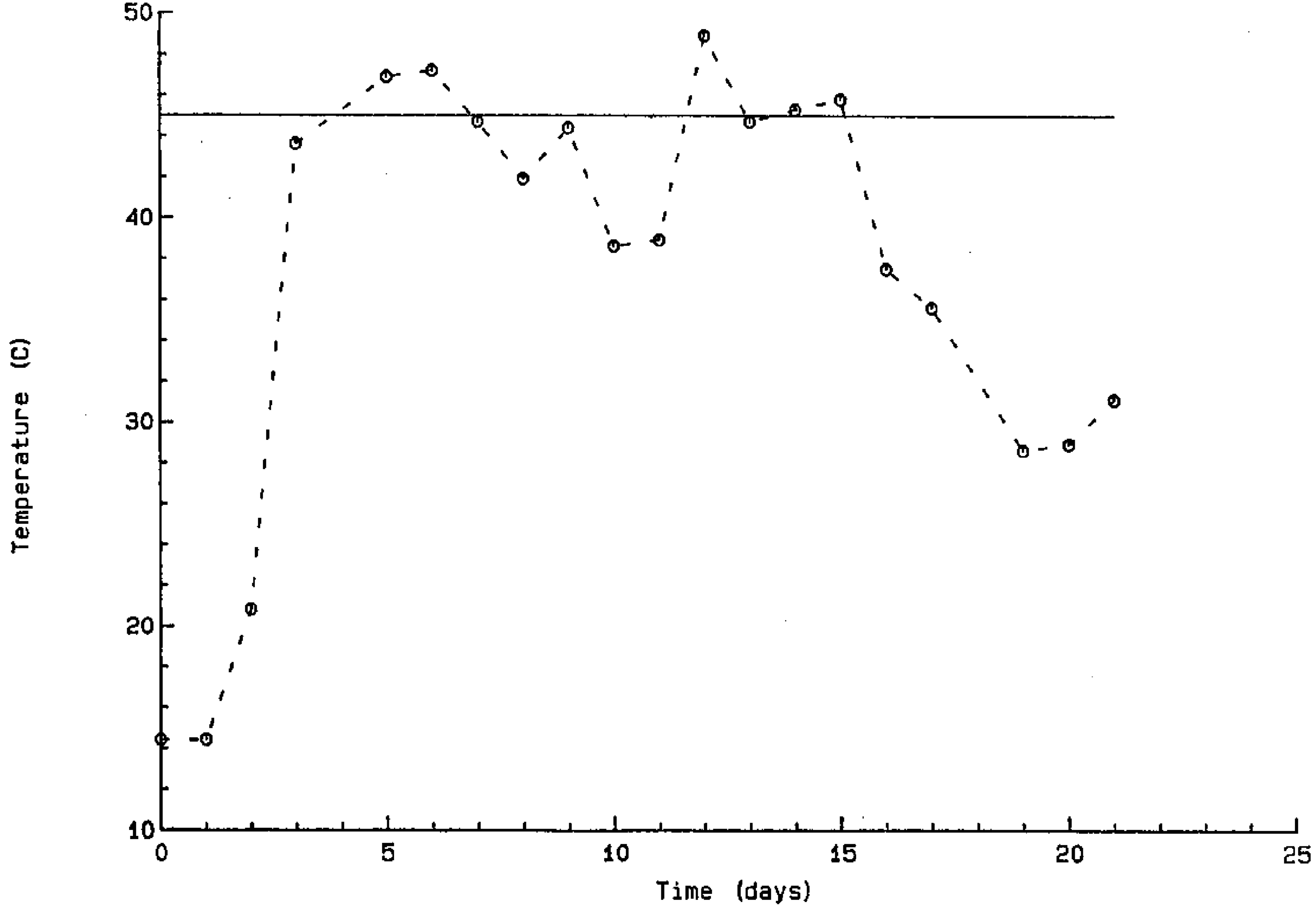

Figure B-33. Temperature record of test 33. The carbon-nitrogen ratio was 23.4:1 and the moisture content was 50% (wet basis).

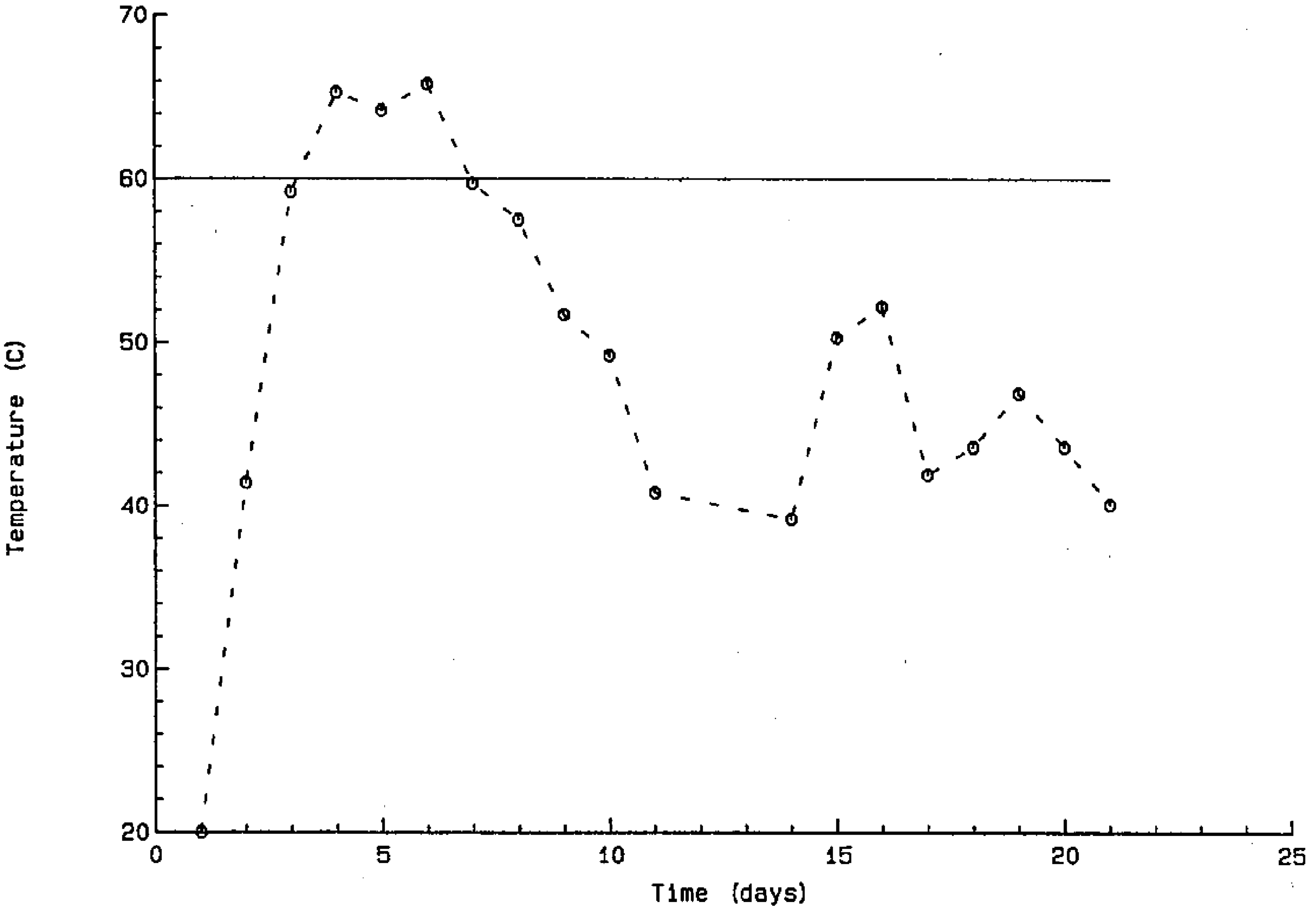

Figure B-34. Temperature record of test 34. The carbon-nitrogen ratio was 25:1 and the moisture content was 46% (wet basis).

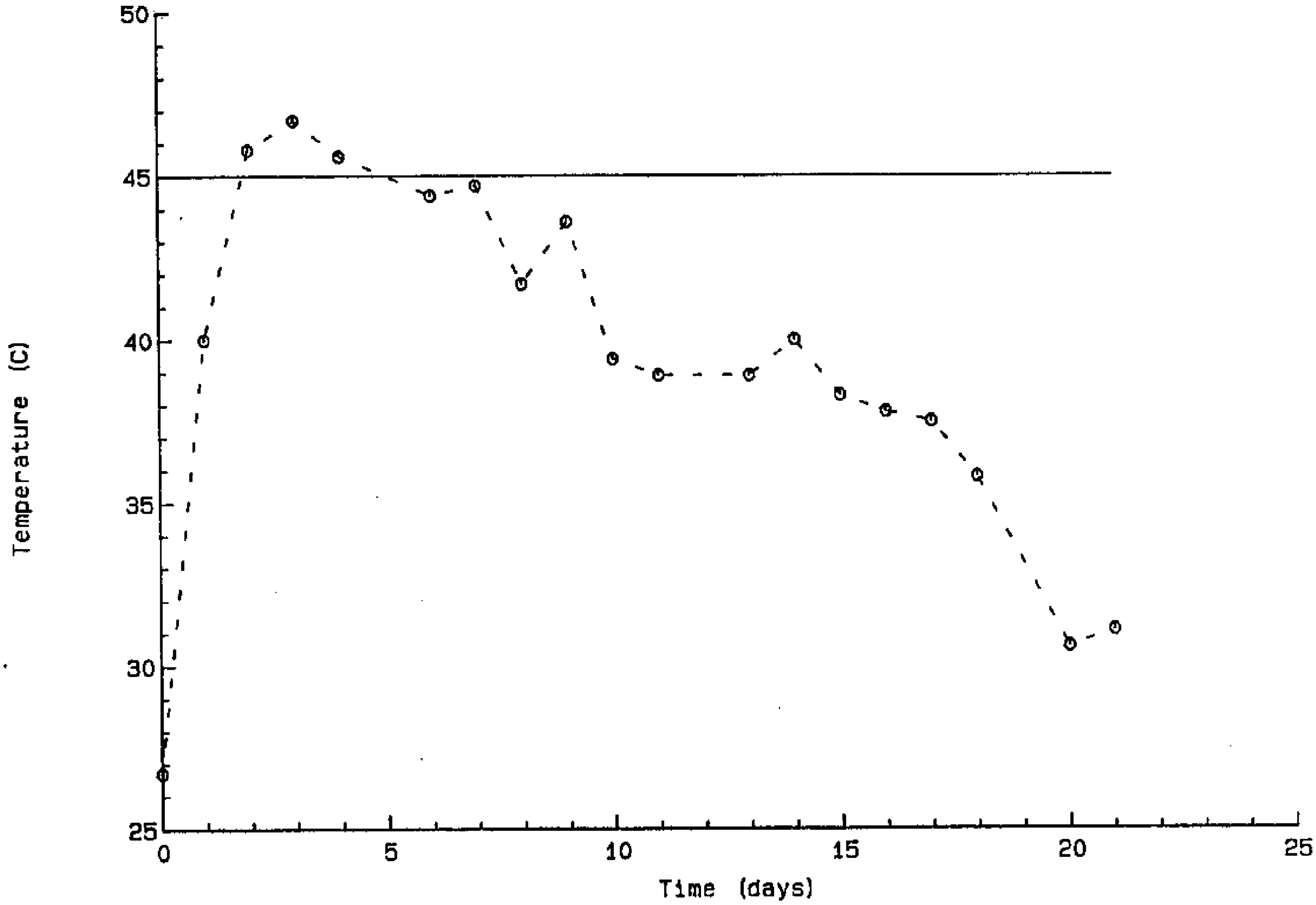

Figure B-35. Temperature record of test 35. The carbon-nitrogen ratio was 24.5:1 and the moisture content was 65% (wet basis).

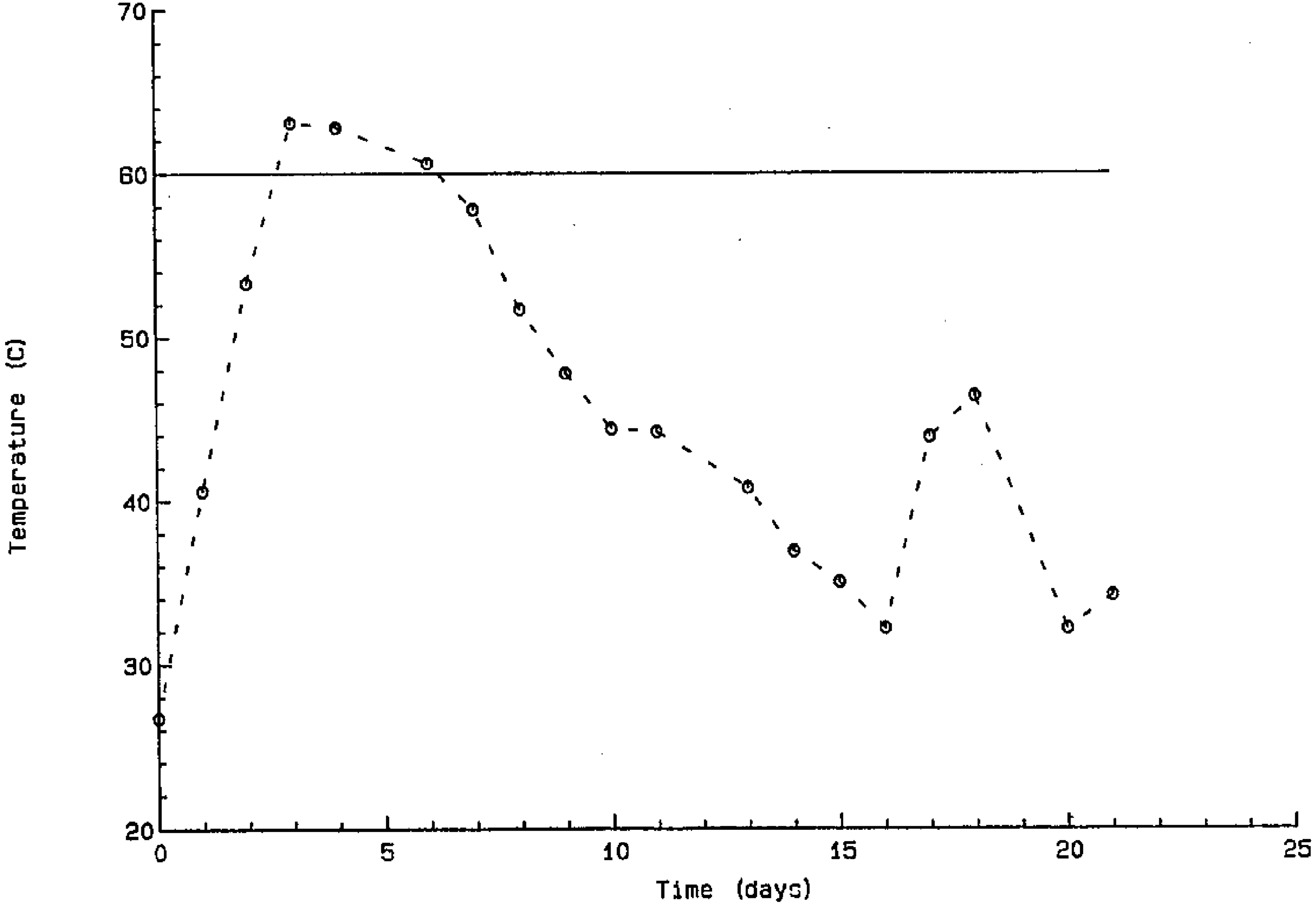

Figure B-36. Temperature record of test 36. The carbon-nitrogen ratio was 24.5:1 and the moisture content was 60% (wet basis).

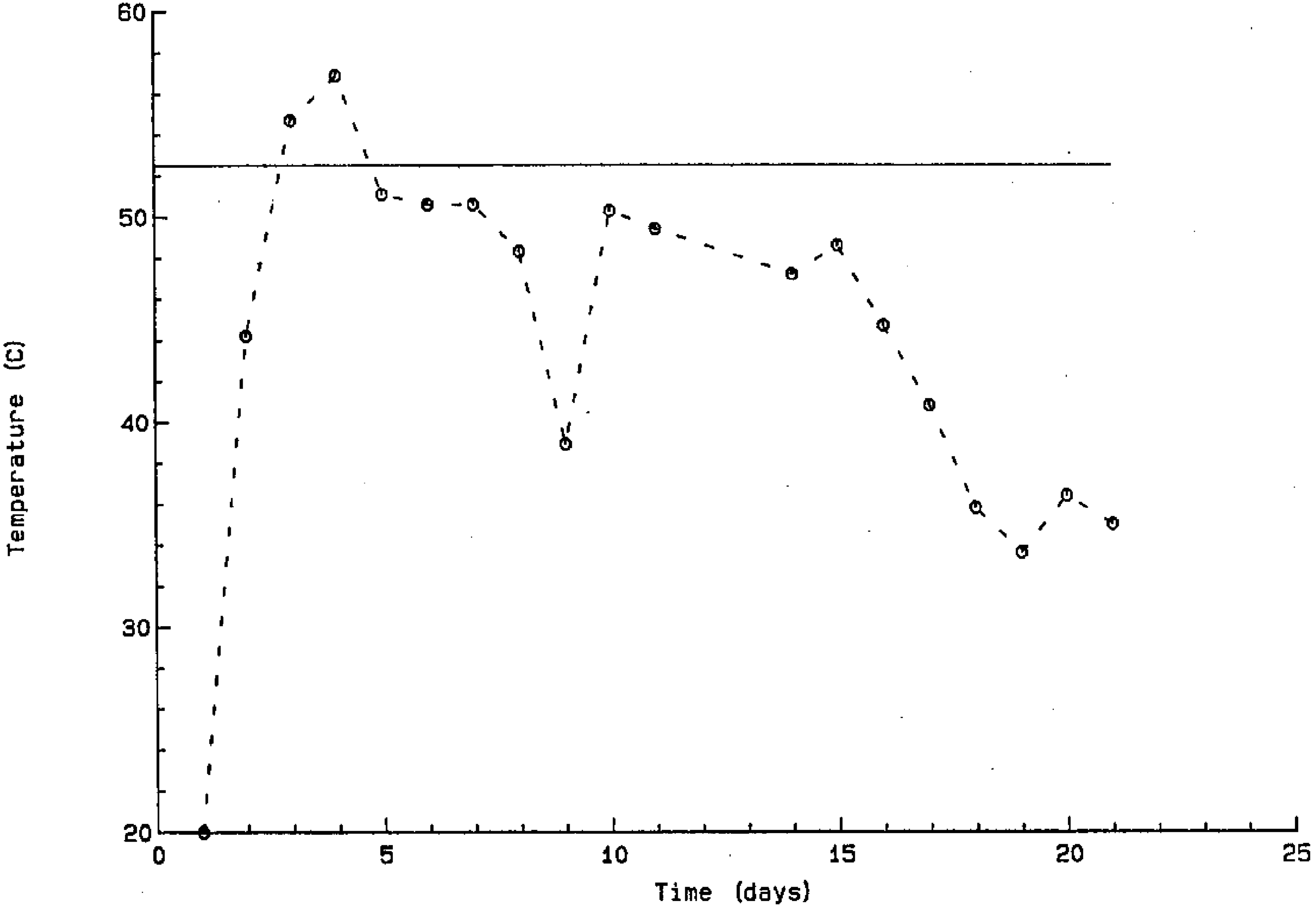

Figure B-37. Temperature record of test 37. The carbon-nitrogen ratio was 28:1 and the moisture content was 56% (wet basis).