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Title A STUDY OF RELATIONSHIPS OF FOUR INSECTS TO HEATING IN STORED GRAIN

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This study was conducted to determine the effects of insect infestation on areas of heating in stored grain, and to demonstrate the ability of four species of insects to initiate or promote the spread of these heating areas. The four insects used were the granary weevil *Sitophilus granarius* (L.), the lesser grain borer *Rhizopertha dominica* (F.), the saw-toothed grain beetle *Oryzaephilus surinamensis* (L.), and the red flour beetle *Tribolium castaneum* (Hbst.). All four of these insects are common pests of stored grain.

Heating was initiated by adding moisture to a small portion of a confined mass of wheat. The term hot spot was used in reference to areas of the grain mass that showed a rise in temperature above that of the surrounding grain. Hot spots due to the growth of fungi on the moistened grain were referred to as fungus hot spots.

A device was designed and constructed in which a small hot spot could be started and observed visually and electronically. It

consisted of a wooden box of about one cubic foot capacity with two glass sides and an internal system of thermocouples and humidity indicators. Ten of these boxes were in operation during a period of two years in 18 laboratory experiments. A larger system of thermocouples and humidity indicators was installed in a Butler bin at the Oregon State University Entomology Farm in which 600 bushels of wheat were utilized in four different experiments. Hard white wheat was used in all experiments, and test insects were obtained from laboratory cultures.

It was observed that fungus hot spots reached a peak of heating at room temperature about two weeks after moisture was added. Heating was confined to the small mass of grain that was moistened by the addition of water when no insects were present, and did not spread to the surrounding grain mass. The temperature declined rapidly unless additional moisture was forced into adjacent areas of the grain mass to start a second area of heating.

Effects of insects on fungus hot spots varied according to the species of insect present. The granary weevil demonstrated the greatest ability, of the four insects tested, to promote the spread of a fungus hot spot. Hot spots involving the granary weevil, either by itself or in combination with other insects, expanded until most of the wheat in the laboratory boxes was involved. The lesser grain borer demonstrated an ability to promote the spread of a fungus hot spot almost equal to that of the granary weevil, but required a longer period of time. The red flour beetle and the saw-toothed grain beetle failed to promote the spread of a fungus hot spot, and heating declined as rapidly in their presence as without them. Field experiments on a larger scale likewise showed the granary weevil to be superior to the saw-toothed grain beetle in promoting the spread of fungus hot spots. Higher temperatures were recorded in the field experiments than in the laboratory experiments but heating was confined to the small mass of moistened grain when granary weevils were not present.

A STUDY OF RELATIONSHIPS OF FOUR INSECTS TO HEATING IN STORED GRAIN

by

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A STUDY OF RELATIONSHIPS OF FOUR INSECTS TO HEATING IN STORED GRAIN

I. INTRODUCTION

This study was concerned with the activities of insects in connection with hot spots in stored grain. Its purpose was to determine the effects of insect infestation on areas of heating in stored grain and to demonstrate the ability of insects either to initiate or to promote the spread of these areas. This involved the introduction of four insect species into stored wheat under conditions which permitted observations of the physical and biological changes that took place in the substrate.

The four species of beetles that were chosen for the purpose of this study are commonly found as pests of stored grain. They were as follows:

1. The granary weevil, _Sitophilus granarius_ (L.) is one of the two most common true weevils that attack grain in the United States (the rice weevil, _S. oryzae_ is similar in habit). The granary weevil has no wings and is found only in stored products, but it is cosmopolitan in distribution. It is a voracious feeder in both the larval and adult stages. The adults may live as long as eight months, the females laying from 50 - 250 eggs, each one placed within a small hole chewed in the kernel and then covered with a gelatinous fluid.

The legless larvae burrow within the kernels and transform to pupal and adult stages there (Cotton 1962).

2. The lesser grain borer, Rhizopertha dominica (F.) is a small bostrichid beetle which is native to the tropics, but it has been spread throughout the world by commerce. The adults chew rapidly through whole or damaged kernels of grain. The larvae feed initially on the fine frass produced by the adults, but soon enter the damaged kernels to complete their life cycle. The females lay from 300 - 500 eggs, dropping them singly or in clusters in the grain (Cotton 1962).

3. The saw-toothed grain beetle, Oryzaephilus surinamensis (L.) is a small flat beetle which is cosmopolitan in distribution and attacks a wide variety of stored products. It feeds mainly on broken kernels and dust in stored grain. Adults are long-lived, averaging six to ten months, and have been known to live as long as three years. The females lay from 43 - 285 eggs and the larvae crawl actively about, feeding over a wide area (Cotton 1962).

4. The red flour beetle, Tribolium castaneum (Hbst.) is generally distributed throughout the world, particularly in flour mills. This small beetle feeds mainly on grain dust and broken kernels in stored wheat. The adults frequently live as long as one year and have been known to live longer than three years. The females lay about 450 eggs during their lifetime. The larvae feed widely on

grain dust and broken particles of wheat (Cotton 1962).

Two species of mites, Acarus siro L. and Tyrophagus putrescentiae (Schrank), were involved in parts of this study. Both species commonly are found in stored grains. Two other mites that were observed occasionally were Melichares keegani (Fox) and Raphignathus sp. Other insects found in the field experiments were the rusty grain beetle, Cryptolestes ferrugineus (Steph.), a fungus beetle, Cryptophagus sp., the grain psocid, Liposcelis divinitorius (Muller), and two parasites of grain beetles, Cephalonomia tarsalis (Ashm.): Bethylidae and Anisopteromalus calandrae (How.): Pteromalidae.

Two of the insects used in this study--the granary weevil and the lesser grain borer--are capable of penetrating undamaged kernels of grain and may therefore be considered as primary invaders. The remaining two species--the saw-toothed grain beetle and the red flour beetle--consume only fractured grain or grain dust, and may be considered as secondary invaders. The four insects were utilized singly and in various combinations in an attempt to discover either interrelationships between them, or total combined effects. Two groups of experiments were conducted in this study. One group was conducted in the laboratory on a small scale and at environmental temperatures near 70 degrees F. The second group of experiments was conducted on a larger scale in an attempt to simulate field storage conditions. Insects were maintained in culture in the laboratory to be used for infesting the experimental grain masses. Observations and conclusions from these experiments were based upon data recorded during the entire series of two groups of experiments.

As this study progressed the term hot spot took on a specific meaning, referring to limited areas of heating in the grain mass where the factor which caused heating was concentrated, causing the temperature in that limited area to rise above the temperatures of the surrounding grain. For the purpose of this study the term hot spot has been limited to those situations where a specific area within the grain mass showed a rise in temperature above that of the surrounding grain mass.

II. LITERATURE REVIEW

The potential of insect-produced heat in stored products by the accumulation of large, concentrated populations of insects has been pointed out by previous investigators (Howe 1962; Oxley and Howe 1944; Robertson 1948). It has long been known that excessive moisture in stored products also may lead to heating, even to extemes such as to trigger the combustion of hay stacks containing damp hay. The growth of fungi also may produce heating (Wallace and Sinha 1962).

Most of the studies on hot spots in stored grain have been made on mature hot spots in order to discover the insects, mites and fungi associated with these areas of heating. However, very little has been done to demonstrate the initiation and spread of hot spots by these factors, either singly or in combinations. Studies in England (Howe 1962) have established the fact that insect-initiated hot spots were produced by metabolic heat from the insects, which accumulates more rapidly than it can escape from the immediate environment of the insect population.

Howe (1943) studied a large bin of stored wheat in England and observed that heating tends to occur around the infested regions. The thermal center of the mass heats first since wheat has a low thermal conductivity. The amount of heating depends on the number of fourth stage weevil larvae present, and the distance of the heating spot from a cool surface. Convection currents tend to maintain a balance between carbon dioxide and oxygen and also produce a warming of regions directly above the heating center.

Oxley and Howe (1944) stated that Calandra [Sitophilus] spp. appear to be most effective in causing "spontaneous" heating of grain due to the development of insect populations. They observed the highest temperatures for insect-caused hot spots to be 100-108 degrees F. The maximum temperatures for oviposition and development of Calandra are about 90 and 95 degrees F. These high temperature hot spots are unfavorable to the development of Calandra, but its larvae, like those of Rhizopertha, are enclosed within the kernels so they cannot move away from the extreme temperatures and must perish. Oxley and Howe also found that, at temperatures below 68 degrees F and at a relative humidity of 60 percent, the development of Calandra may take as long as 120 days, but at higher humidities it may be shortened by as much as one-half. The winter survival of Calandra in cooler climates is usually limited to adults. It was demonstrated that temperature gradients result in movement of moisture within the grain mass to the point that hot grain becomes drier and cool grain becomes damper. This frequently leads to an accumulation of moisture at the surface and has led to the assumption that the dampness is the cause rather than the consequence of insect infestation.

Oxley and Howe further stated that the role of metabolic water in most insect infestations is insignificant because a relatively heavy infestation would require one year to raise the water content of the grain by one percent, if no water is lost. However, they also stated that extreme densities of insects (such as are found in culture jars) can raise the moisture content by several percent in one generation due to an accumulation of metabolic water.

Christensen and Hodson (1960) showed that moisture produced by weevils in wheat can raise the moisture content sufficiently to encourage the growth of storage fungi. When moisture vapor was not allowed to escape rapidly from the grain mass, areas some distance from the weevils showed an increase in moisture content with a corresponding increase in fungus growth accompanied by heat production.

A study of the physical aspects of heating and heat conduction in wheat was made by Robertson (1948) in Australia. He observed that dry wheat does not heat above 75 degrees F by itself and that heat produced by normal respiration of wheat does not explain the higher temperatures of stored wheat. He suggested that the temperature of an entire mass of grain is raised significantly by a light, but even, insect infestation. Where extreme temperatures (104 degrees F) were reached, the insects were forced to the surface where an equilibrium with the environment produced a temperature more favorable to insect development. Robertson also recognized that moisture due to insect respiration may account for higher temperatures than can be accounted for by insects alone.

Heating in stored grain was further investigated by Howe (1962), who reported on experiments conducted to determine the pattern of heat conduction in stored grain. He found that, at one meter from a heating area, the rise in temperature was less than one-half of the rise in the area itself, and only 15 percent of this rise was achieved in four weeks. He proposed the idea that hot spots increase in size because of the insect activity involved rather than the spread of heat by conduction, since grain is a poor conductor and the heat tends to move upward rather than outward. From information obtained earlier at the Pest Infestation Laboratory in England, (Howe 1943; Oxley and Howe 1944), he formulated the following hypothesis to explain how insects cause hot spots:

> ...insects are able...to induce hot spots by producing metabolic heat faster than it can escape from their immediate environment. The consequent small local rise of temperature accelerates both the metabolism of each insect and the rate of multiplication of the insect population and so continuously increases the amount of metabolic heat produced. This autocatalytic reaction causes a continuous acceleration of the rate of temperature increase until the level reached becomes unfavorable to insects. (Howe 1962. p. 138).

Howe also stated that, in early stages of heating, heat does not escape from the mass of grain, but is redistributed. He found that the most favorable conditions for production of hot spots is at 72 degrees F and 14 percent or more moisture content. He observed that damp grain heating usually is short-lived because the grain is dried as a result of high temperatures, and fungi are killed by heat.

The effects of temperature and humidity on the biology of various grain insects was studied by Howe (1956) and others. Tribolium castaneum laid eggs readily at humidities as low as 20 percent, but 68 degrees F seemed to be approximately the lowest temperature limit for oviposition (Howe 1962). Eggs did not hatch at temperatures below 64 degrees F and developed most rapidly at 100 degrees F. Humidity did not affect the duration of the egg period. The rate of larval development was higher at the highest humidity used (100 percent) and the optimum temperature was 95 degrees F. The pupal period was not affected by humidity and was shortest at 100 degrees F. It also was shown that the saw-toothed grain beetle required a high temperature to multiply rapidly. The minimum temperature at which it could complete a life cycle was about 64 degrees F and the probability of increase rapid enough to cause a population outbreak was unlikely if the initial temperature was much below 77 degrees F (Howe 1956).

Birch (1946) found that the multiplication of Calandra oryzae and Rhizopertha dominica was greatly increased by a slight increase in moisture content. The rate of multiplication of these two insects was three times as great in wheat of 12 percent moisture content as in wheat of 11 percent moisture content when the temperature was 73 degrees F.

Armstrong and Howe (1963) found examples of heating in grain storage where the saw-toothed grain beetle was the dominant species, but attributed the initial rise in temperature to some source other than the beetle. Further heating was considered by them to be due to increasing saw-toothed grain beetle populations. Any increase in moisture, whether through a leak in the roof of the storage structure or through the introduction of damp grain, apparently may increase the danger of rapid population growth. Active mold growth occurred at 70 percent relative humidity which was produced by 14 percent moisture content at 68 degrees F. The same grain at 14 percent moisture content produced a relative humidity of 73 percent at 80 degrees F. Therefore, higher temperatures produced conditions which favored the rapid development of molds and insects. Insects heated the grain to 104-113 degrees F, but if fungi were the main source of heat, the temperature often exceeded 122 degrees F. The heat produced by damp grain and fungal growth in large bulks was dissipated very slowly, (the time required for a given amount of cooling increased approximately as the square of the distance from a cooling surface), giving such insects as the saw-toothed grain beetle up to two or three months of favorable conditions for rapid increase, to the point where more heat was produced than was lost. They estimated that an initial population of 500 saw-toothed grain beetles, started at 95 degrees F and remaining above 77 degrees F, could multiply to five million individuals during a period of three months. This population was considered to be sufficiently large to prevent cooling and to initiate heating by subsequent multiplications.

Foster and Mayer (1962) studied the physical aspects of heat movement in a bulk of shelled corn by implanting an artificial hot spot in the corn. They found that convection played an important part in heat transfer, resulting in increases extending only half as far laterally from the hot spot as would be expected by conduction only. The surface layer of grain above the hot spot increased three percent in moisture content during a 165 day test.

Sinha (1961) made a study of insects and mites associated with hot spots in Canada and found the rusty grain beetle, Cryptolestes ferrugineus and the long, hairy mite, Glycyphagus destructor (Schrank) to be the most common insect and mite species associated with hot spots. He found no granary weevils in the hot spots observed in Manitoba and Saskatchewan.

A study of storage fungi was made by Christensen (1957) in which he recognized the influence of insects and mites on the development and growth of fungi in stored grain.

Wallace and Sinha (1962) found species of _Penicillium_ to be the most abundant fungi associated with hot spots, but several species of _Aspergillus_ frequently were encountered, the most common being _Aspergillus flavus_ Link.

Sinha (1958) reported on damage due to heating in stored grain that passed through Winnepeg, Canada during the crop year of 1957-58. He stated that the economic loss resulting from heating was modestly estimated at nearly one million dollars. Sinha noted that the insect seemingly most involved in heating was the rusty grain beetle, _Cryptolestes ferrugineus_, and that the most common fungus found in connection with hot spots was _Aspergillus flavus_.

Wheat from storage of seven years duration in Yorkton, Saskatchewan, was studied during the spring of 1961 by Sinha, Liscombe and Wallace (1962). More than 24 species of microorganisms, ten species of mites and four species of insects were found to be distributed through areas of the grain that showed various degrees of reduction in viability. The greatest concentrations of microorganisms, mites and insects were found in the areas of grain showing the lowest rates of viability.

Sikorowski (1964) confirmed the attractiveness of moldy wheat in hot spots to insects in a study of food relationships between three insects and a series of storage fungi. He found that red flour beetles, flat grain beetles and saw-toothed grain beetles would complete all life stages on a diet of *Aspergillus versicolor* (Vuill.) only. He also observed that *A. candidus* Link and *A. chevalieri* (Mangin) Thom and Church were utilized to a lesser extent as food, and that *A. repens* (Cda.) DeBary and *A. parasiticus* Speare actually were detrimental to both mature and immature stages of the three insects tested.

Howe (personal correspondence 1964) recognized problems of sampling and testing with probes and used permanent thermocouples for temperature records as far as possible.

III. METHODS

The initiation of hot spots under controlled conditions was deemed essential to this study. A laboratory device was designed and constructed in which a small hot spot could be started and observed visually and electronically (Eighme 1964). It consisted, essentially, of a wooden box with two glass sides and an internal system of thermocouples and humidity indicators. Twelve copper-constantan thermocouples were placed three inches apart on both a vertical and horizontal axis through the center of the box. Solid constantan wire[1] was arranged as a framework through the center of the box (Figure 1, page 15), and solid copper wire[2] with plastic insulation was used to make the thermocouple connections. The copper wires were connected to a 12 pole rotary switch[3] which was mounted on the end of the box. An extension of the constantan wire and a copper wire from the switch were connected to a temperature potentiometer[4], the 12-pole switch provided a rapid means of taking temperature readings from the 12 thermocouples throughout the box (Figure 2, page 16).

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[1] 20 gauge, bare. Leeds and Northrup Co., Philadelphia.

[2] 22 AWG. Belden.

[3] Mallory shorting switch 31112J.

[4] Leeds-Northrup temperature potentiometer 8693.

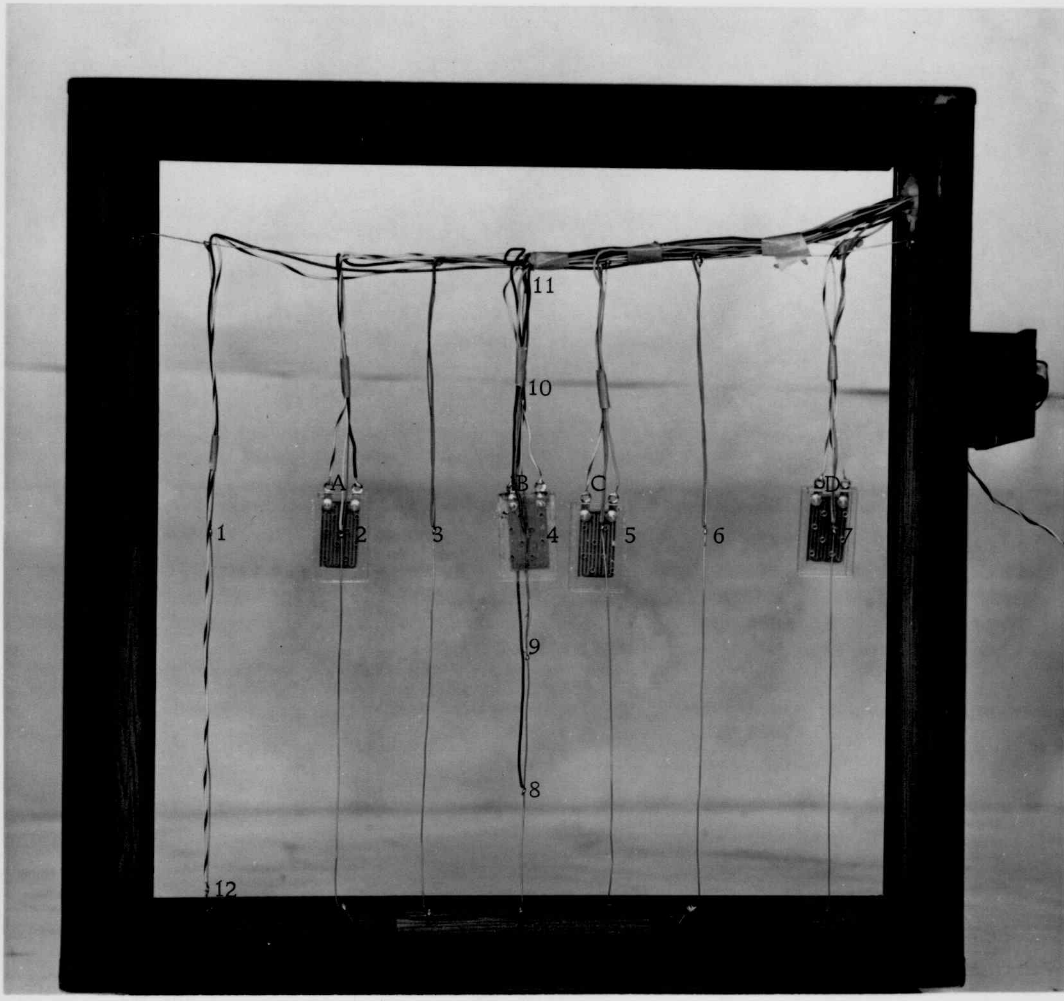

Figure 1. An empty laboratory box showing the thermocouple positions (1-12) and the relative humidity indicators (A-D).

A B

Figure 2. Part of the series of ten boxes showing the switch plates, the hygrometer (A), and the potentiometer (B).

A series of four relative humidity sensing elements[5] was installed to trace the accumulation and movement of moisture, using the framework of the thermocouple system as a basis of support (Figure 1, page 15). These were wired to a second rotary switch mounted on the switch plate at the end of the box. A common ground wire from the elements and the wire from the switch were connected to a miniature phone jack mounted on the switch plate. The use of a phone plug connection simplified the hooking of the humidity sensing elements to the direct reading hygrometer[6] (Figure 2, page 16).

Ventilation holes were cut in the top and bottom of the box to allow for escape of carbon dioxide and excess moisture. The holes were covered with plastic screen to prevent escape or ingress of insects. Moisture was added to the grain in the box by means of a glass tube installed through a hole in the top, which led to a piece of cellulose sponge in the center of the grain mass.

It was found that a hot spot could be started with fungi, insects or both, and its spread could be observed visually through the glass sides. The thermocouple system provided for a record of temperature changes throughout the box without disturbing the hot spot with a probe, and the humidity indicators provided records of moisture movement throughout the grain mass.

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[5]El-Tronics, Inc., Warren Components Div., Warren, Pennsylvania.

[6]*Ibid.*

Ten boxes were constructed during the summer and fall of 1963 and all were put into operation during the remainder of 1963 and 1964. Several boxes were re-used for subsequent experiments and replicates of former experiments. The top and glass sides were removed for cleaning and the entire assembly was fumigated and aired before refilling.

Due to the small mass of grain involved in the laboratory hot spots, heat was dissipated more rapidly than under conditions of normal grain storage. Consequently a field study was conducted with a similar arrangement in a 1000 bushel Butler bin (Figure 3, page 19) involving 600 bushels of wheat. A four foot cube frame bearing a grid of 539 thermocouples spaced at four inches by six inches by six inches and 64 relative humidity elements spaced at nine inches by 12 inches by 12 inches was buried in the grain mass (Figures 5 and 6, pages 21 and 22). The Butler bin was partitioned so as to provide a control room where switch panels were mounted, bearing rotary switches for the 539 thermocouples and the 64 relative humidity elements (Figure 4, page 20). Temperature readings were taken with a temperature potentiometer and relative humidity was measured with a hygrometer.

The thermocouples were numbered according to the column and row in the grid, there being seven rows of seven columns, and each column bearing 11 thermocouples. One 12-position rotary switch

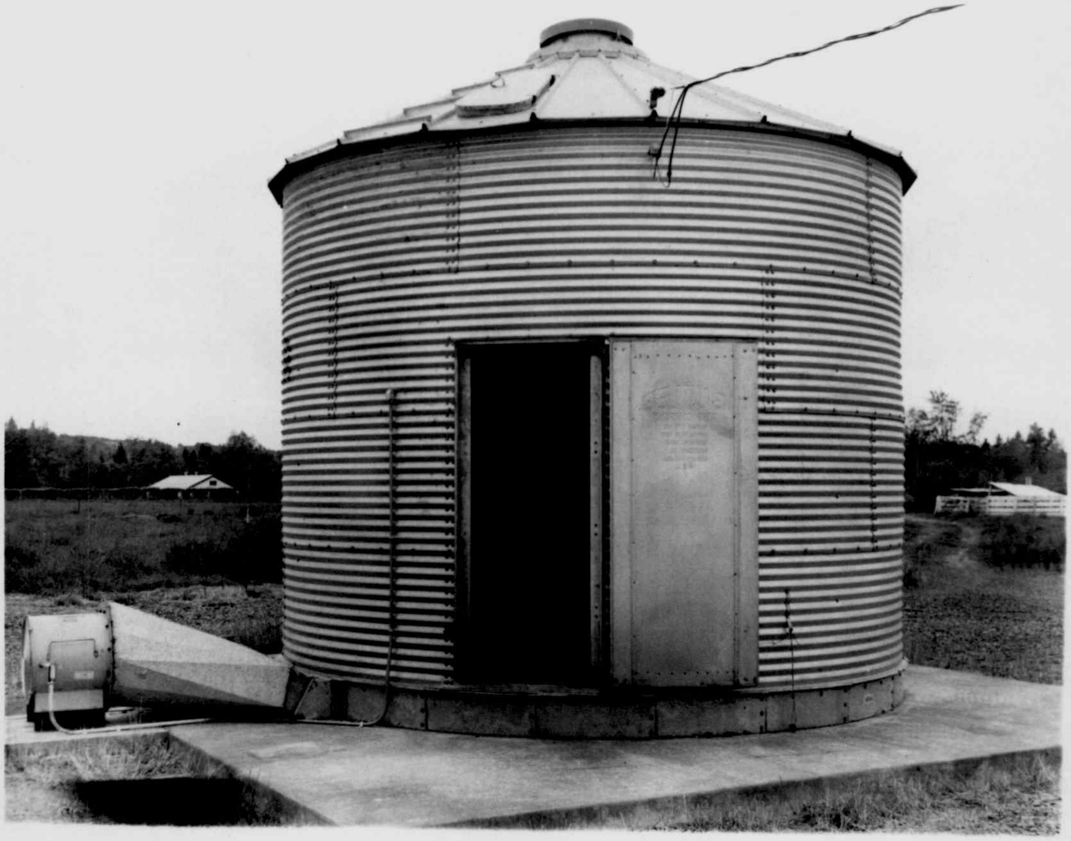

Figure 3. The Butler bin in which field experiments were conducted.

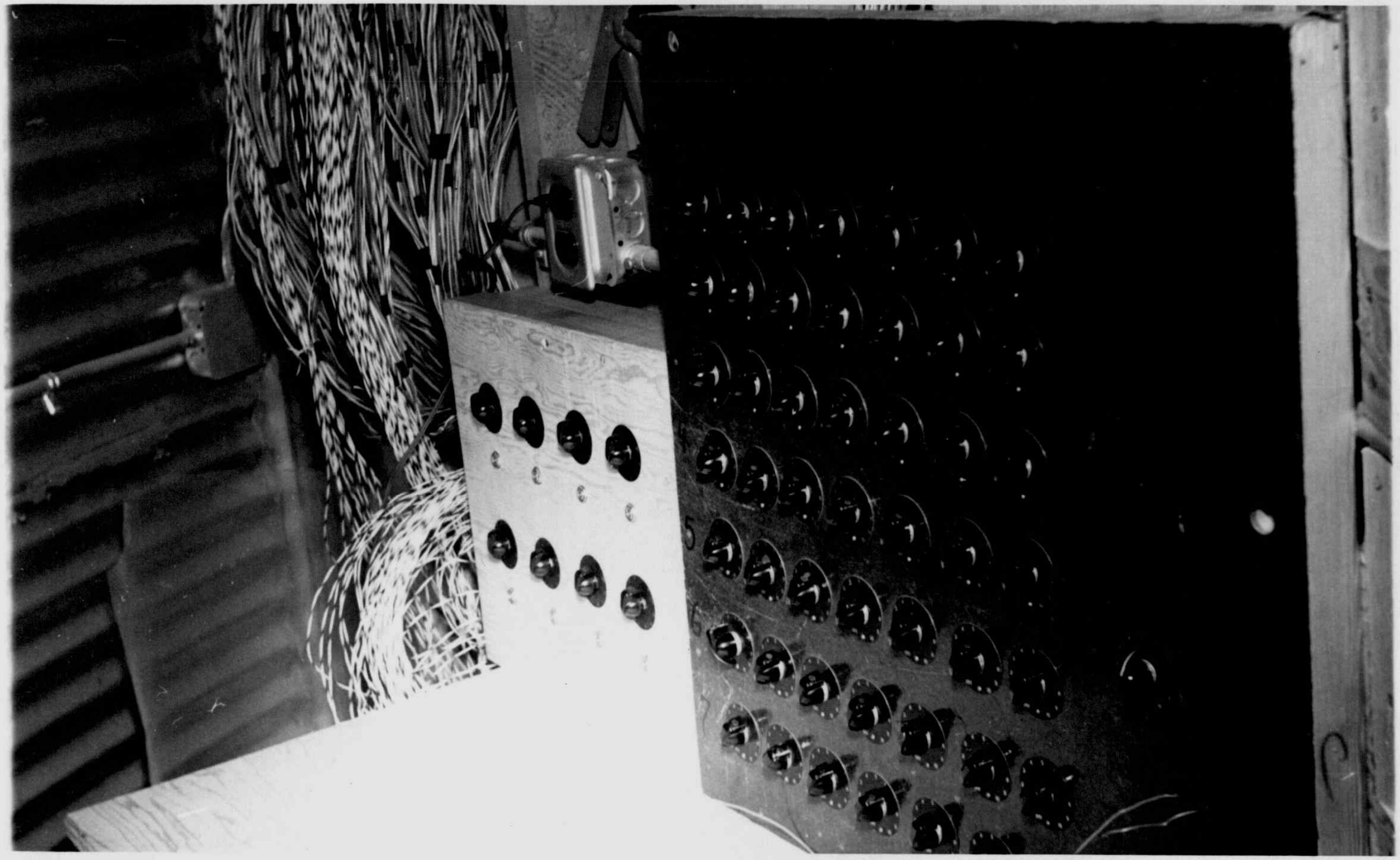

Figure 4. The Butler bin switchboards for 539 thermocouples and 64 relative humidity indicators.

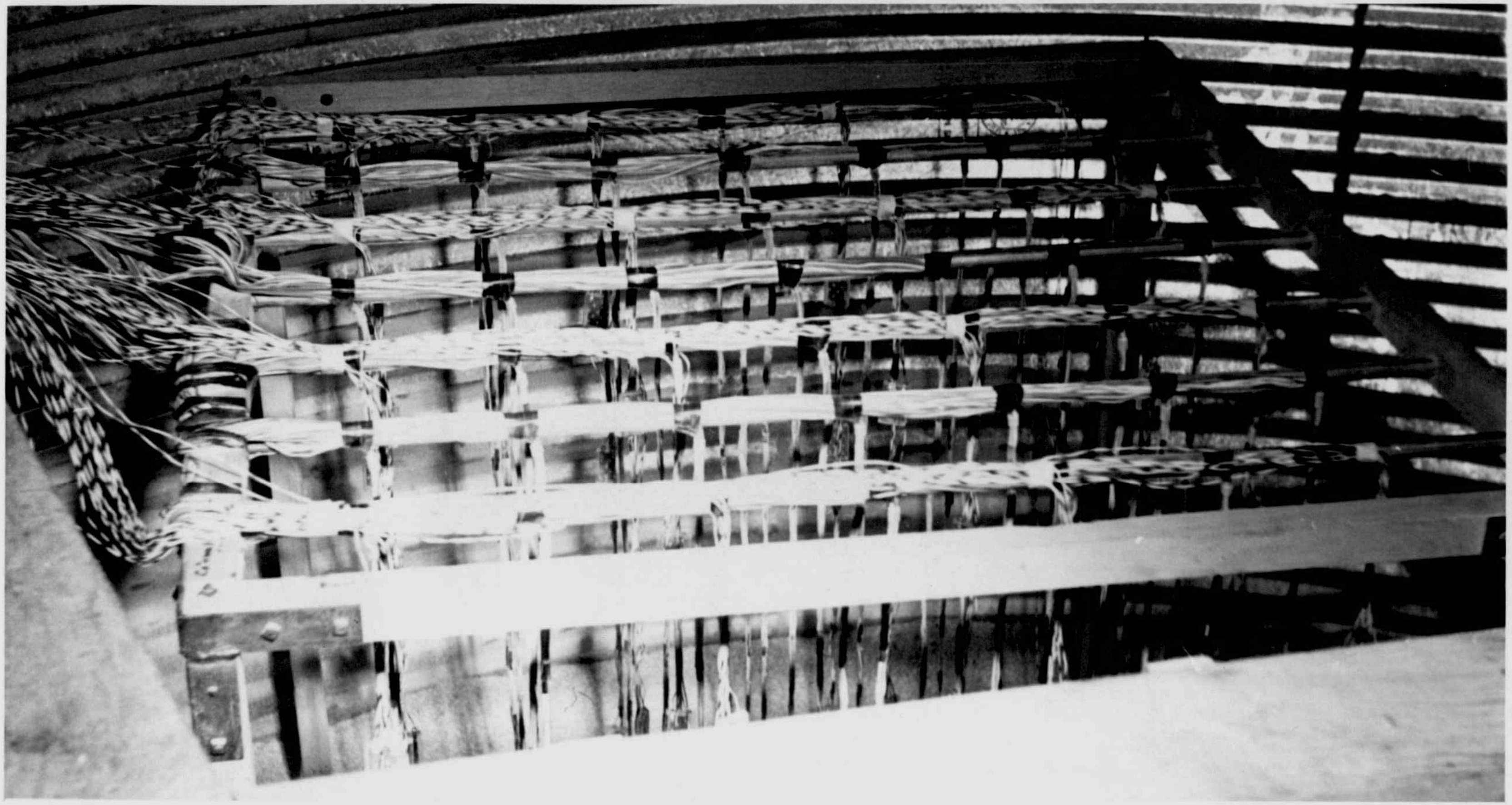

Figure 5. The thermocouple-relative humidity system in the Butler bin before being covered with wheat.

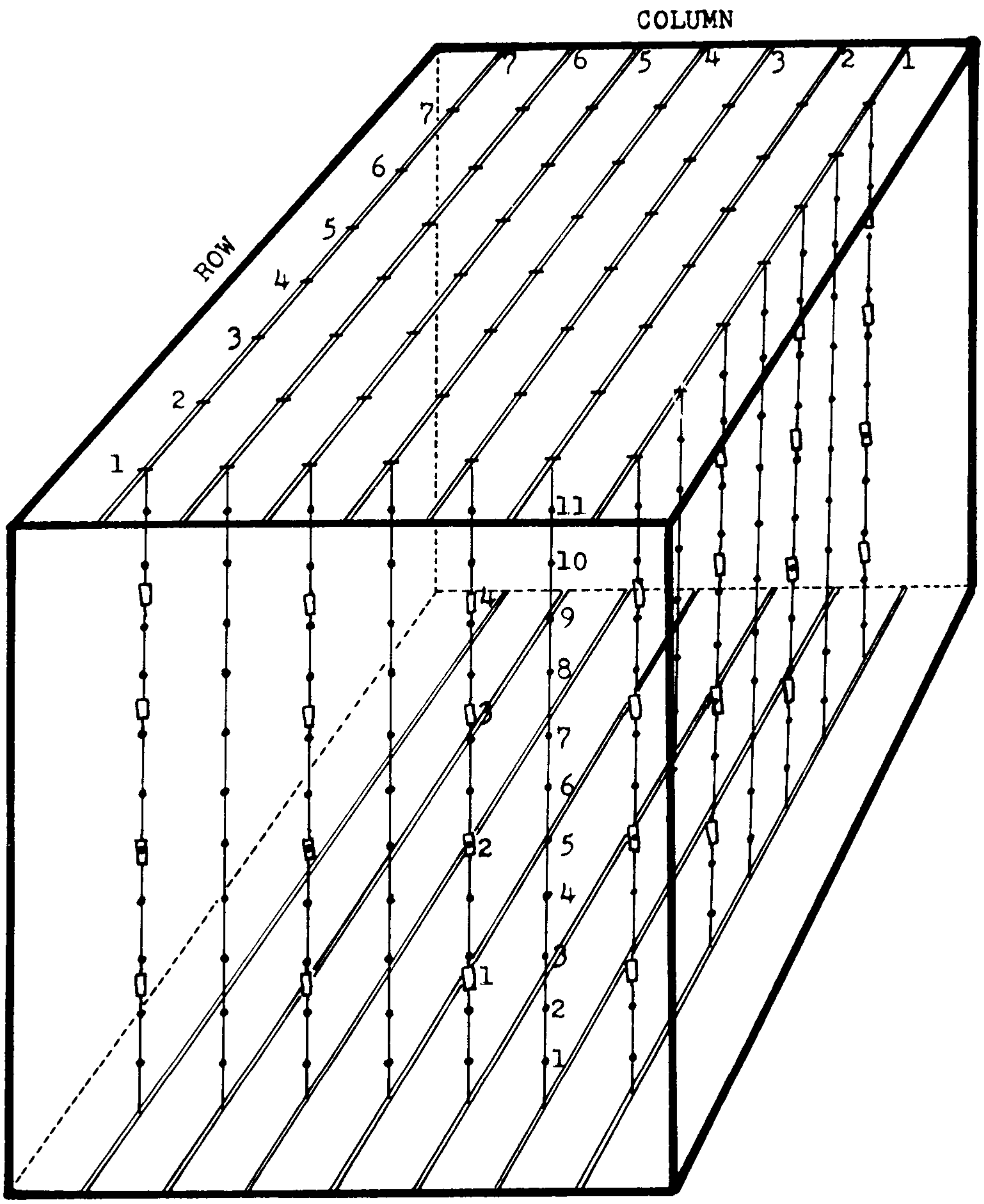

Figure 6. Diagram of the Butler bin system showing placement and numbering of thermocouples (dots) and humidity indicators (rectangles).

was used for each column with 11 positions for thermocouples and an off position. A selector switch was used to connect to any given row, reading only the column that was switched on in that row. The constantan side of the thermocouples was used as a common ground throughout the system and the copper side was wired to the switches. It was possible with this arrangement to connect the copper wire from the selector switch and the constantan ground wire to the potentiometer, and then read any thermocouple in the system by manipulation of switches. This was a real aid when large numbers of readings were needed to determine the extent of a developing hot spot.

The thermocouple system served as a framework of support for the relative humidity system. The 64 relative humidity indicators were distributed evenly over the system (Figure 6, page 22) so as to trace as accurately as possible the movement of moisture. A separate switchboard was constructed for the relative humidity system and installed on the control panel next to the thermocouple switchboard (Figure 4, page 20). A separate rotary switch was used for each group of eight relative humidity elements. The latter were numbered according to column and row and the hygrometer was connected to one switch at a time by means of a phone jack.

The relative humidity elements were constructed in the form of printed circuit wafers and had to be protected from scarification due to the wheat grains by a capsule of one-eighth inch plexiglass acrylic plastic (Rohm and Haas) with the lower end open and the side perforated to allow for air movement. According to specifications[7] the relative humidity system had an accuracy of plus or minus three percent. In re-using the laboratory boxes it was discovered that the relative humidity elements from the center of active hot spots had deteriorated to the extent that readings were lowered by as much as five percent. These elements either were replaced or compensated for in subsequent experiments.

The purpose of the relative humidity readings in these experiments was to trace the accumulation and movement of moisture in the grain mass, so it was not deemed necessary to convert these readings to actual amounts of moisture in the interstitial air, but rather to use them as an indication of the moisture accumulations in the grain. An alternative method would have been to take probe samples, and to determine the actual moisture content of the grain at various spots. This would have resulted in a definite disturbance of insect activities, however, and could have altered appreciably the pattern of hot spot development.

The moisture content of wheat has been shown to bear a direct relation to the relative humidity of the interstitial air after equilibrium is reached. A relative humidity of 75 percent has been

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[7] Ibid.

demonstrated to produce a moisture content of about 15 percent (Agrawal 1957; Christensen 1957). Gay (1946) performed a series of experiments that showed the moisture content of wheat to vary with the relative humidity from a moisture content of eight percent at a relative humidity of 20 percent to a moisture content of 17 percent at a relative humidity of 80 percent. He performed these experiments at temperatures from 20 - 100 degrees F and found a slight drop in moisture content with an increase in temperature. The magnitude of this drop decreased with increases in relative humidity such that at 20 percent relative humidity the moisture content dropped about 0.25 percent for each ten degrees rise in temperature and at 80 percent relative humidity the moisture content dropped about 0.15 percent for each ten degrees rise in temperature.

A fluctuating line voltage at the site of operation of the Butler bin was observed to vary the readings of the hygrometer by three - four percent. This was remedied by placing a voltage regulator in the line leading to the hygrometer.

The metal walls of the Butler bin absorbed heat from the sun (particularly during the summer months) in sufficient quantities to gradually alter the temperature of the entire grain mass. A large blower was installed to force air through the grain during cool weather by way of the perforated metal floor. Since periods of warm weather are quite brief in western Oregon, it was possible to prevent the grain mass from being warmed to high temperatures by the sun. The blower also was planned as an aid to fumigating and drying the grain.

One of the greatest technical problems in these experiments was arriving at a suitable sampling technique. Sampling by probe is a common method in grain studies, but it invariably disturbs the insect population in, or in the vicinity of, a hot spot. No better technique was found in this study, however, so sampling was kept to a minimum in an effort to avoid ecological disturbances in the developing hot spot. The activity of the insects was observed visually as much as possible on the glass-sided laboratory boxes. A small probe was used occasionally to determine the general distribution of insects and fungi, but only as the nature of the experiment indicated its necessity.

A small initial hot spot was established in the Butler bin by adding moisture in a manner very similar to that used in the small laboratory experiments. A piece of cellulose sponge was buried in the center of the grain mass, and a glass tube was extended from the sponge to the surface so that water could be added to the sponge periodically. This provided a source of moisture sufficient to initiate a hot spot in dry grain.

Hard white wheat was used in all of the experiments described in this study. It contained 15 percent broken kernels and 4.5 percent chaff and weed seed by count. The grain was fumigated with commercial grain fumigant (carbon tetrachloride and ethylene dichloride) and then aired before using.

When samples were available in sufficient quantity, the moisture content was measured with a Steinlite Model 400G electronic moisture tester. Before adding moisture to the experimental bins, the grain showed a moisture content of 11.5 - 12.5 percent.

IV. EXPERIMENTS

Introduction

The purpose of the experiments in this study was to make a comparison of the effects of four insects, both singly and in combinations, on heating in stored grain. The introduction of insects into small masses of grain in the laboratory comprised the first series of 18 experiments. The second series of four experiments was performed in a larger mass of grain under field storage conditions.

The laboratory experiments involved 1.1 cubic feet of hard white wheat and were initiated with 1500 insects of one species, or up to 4000 insects of a mixture of two or more species. Heating was initiated, in most instances, by adding small amounts of moisture to the center of the grain mass. No moisture was added in some experiments and in one heat was supplied from an electrical source. One experiment was performed with no insects in order to determine the extent of heating resulting from the addition of moisture alone. Some laboratory experiments were repeated as replicates, and some were repeated with minor variations. The first ten experiments involved all of the four insects, and combinations of them, used in this study.

The four field experiments involved about 600 bushels of hard white wheat, and three were initiated with large numbers of insects.

One field experiment involved no insects. These tests extended over a longer period of time than the laboratory experiments and were conducted as a comparison and verification of the results obtained in the small scale laboratory experiments.

A summary of the results of the 18 laboratory experiments and the four field experiments may be seen on page 30.

Temperature and humidity readings were taken daily on each experiment during the active heating stage. Readings were taken at two or three day intervals or sometimes only weekly when the data showed no particular change over extended periods. The temperatures were recorded by thermocouple numbers (Tables 1-13) according to the numbering system as shown in Figure 1 (page 15). Thermocouples 1-7 were arranged horizontally from one end of the box to the other through the center of the grain mass and thermocouples 8-11 were arranged vertically through the center of the grain mass. The graphs in Figures 11-21 are based on thermocouples 1-4, thermocouple 4 at the center of the hot spot and thermocouples 3, 2 and 1 at 3, 6 and 9 inches respectively from the center (as indicated by distance in inches on the graphs). Figures 22 and 23 are likewise based on four thermocouples in the Butler bin system, located at the center and up to 18 inches to one side.

The room in which the laboratory experiments were conducted was not closely controlled for temperature and humidity, but records

SUMMARY OF RESULTS FROM LABORATORY AND FIELD HOT SPOT EXPERIMENTS

Experiment number	Insects involved	Number of insects added	Amount of water added	Number of days water added	Greatest increase in temperature (F) above ambient temperature	Number of days heating continued	Fungus hot spot	Expanded hot spot
			Laboratory experiments involving 1.1 cu. ft. of wheat					
2	none	--	65 ml.	10	6	14	yes	no
2a	none	--	265 ml.	67	10	40	yes	no
13	none	--	1200 ml.	48	12	50	yes	no
1	GW	1500	65 ml.	10	14	247	yes	yes
14	GW	1500	65 ml.	10	13	180	yes	yes
11	GW	750	1400 ml.	50	10	80	yes	no
3	GW	1500	none*	--	14	154	no	yes
16	GW	2000	none	--	none		no	no
6	LGB	1500	195 ml.	51	15	180	yes	yes
10	GW & LGB	3000	195 ml.	73	4	18	yes	no
15	GW & LGB	3000	155 ml.	35	14	70	yes	yes
18	GW & LGB	3000	65 ml.	10	14	30	yes	yes
7	GW & STGB	3000	195 ml.	73	11	175	yes	yes
8	GW & LGB & STGB & RFB	4000	195 ml.	73	19	180	yes	yes
4	RFB	1500	65 ml.	10	8	28	yes	no
5	STGB	1500	65 ml.	10	8	35	yes	no
17	STGB	1500	65 ml.	10	10	20	yes	no
9	RFB & STGB	3000	195 ml.	73	4	20	yes	no
12	mites	**	115 ml.	25	4	4	yes	no
			Field experiments involving about 600 bu. of wheat					
1	none	--	2200 ml.	35	42	21	yes	no
2	GW	4000	2200 ml.	35	30	60	yes	yes
3	GW & STGB	5000	4 gallons	2	69	70	yes	yes
4	GW & STGB	6000	4 gallons	4	84	120	yes	yes

* Insects concentrated by artificial heat source.

** A total of 9 ml. of a concentrated, mixed culture was added.

Abbreviations:
- GW - Granary weevil
- LGB - Lesser grain borer
- RFB - Red flour beetle
- STGB - Saw-toothed grain beetle

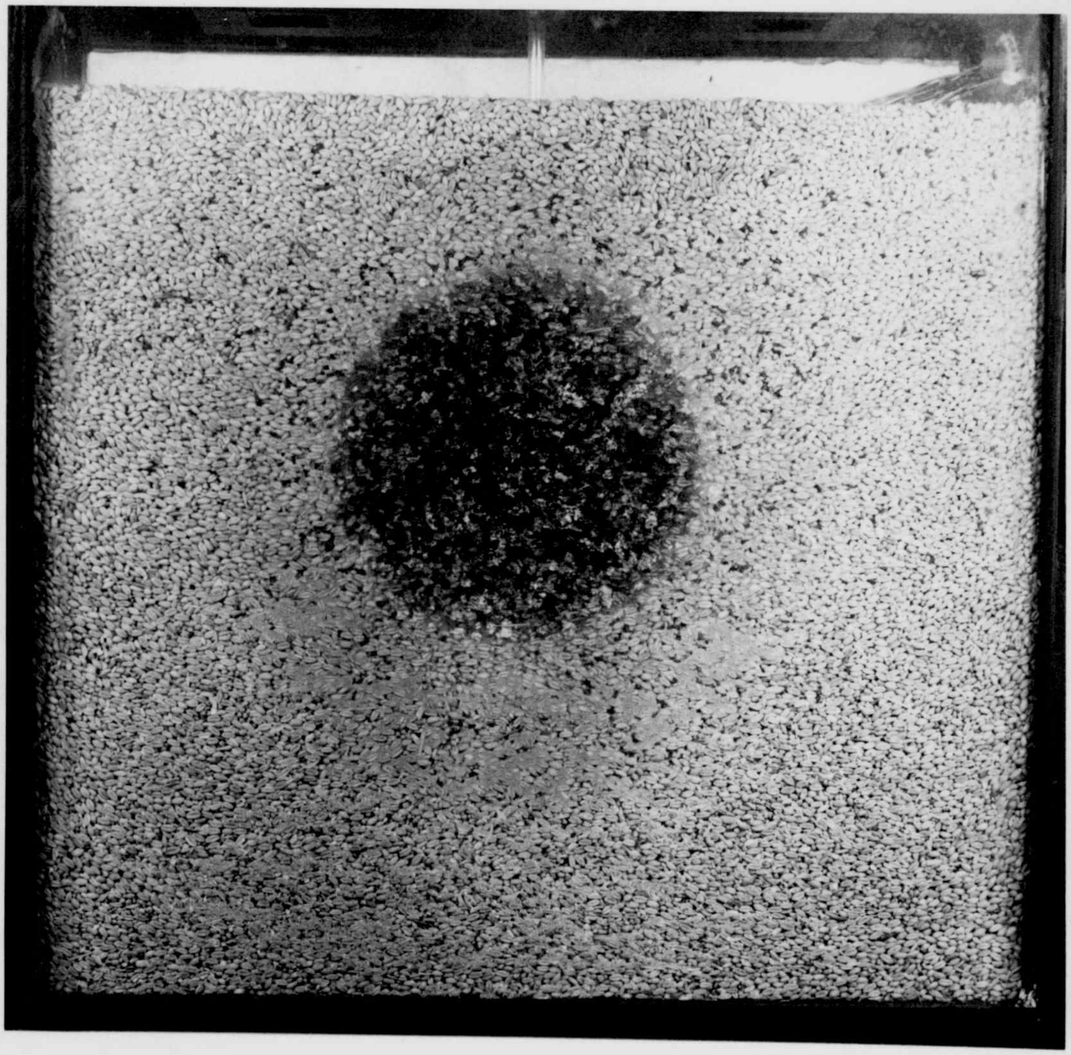

Figure 7. A laboratory moisture-insect-initiated hot spot involving the granary weevil in an early stage of development.

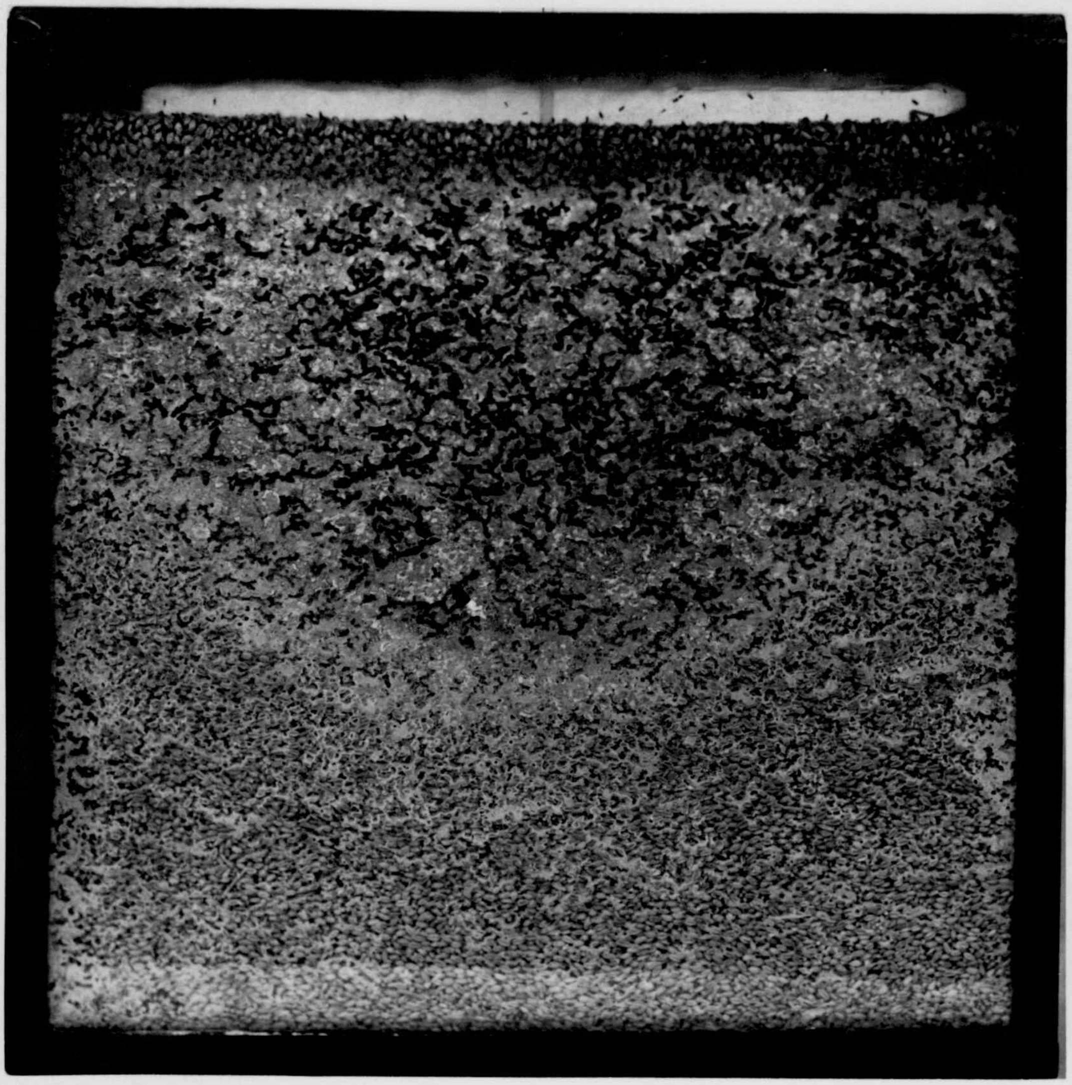

Figure 8. A laboratory moisture-insect-initiated hot spot involving the granary weevil in a late stage of development.

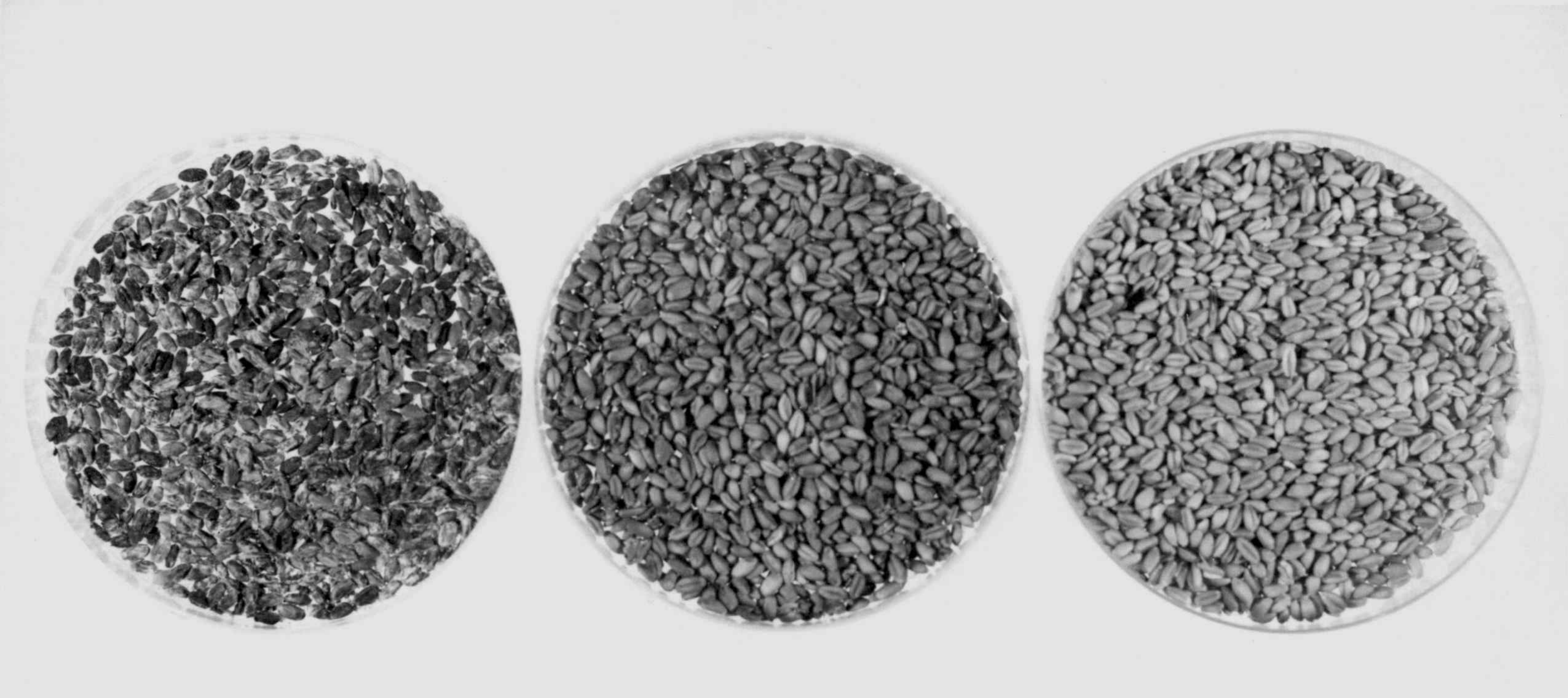

Figure 9. Probe samples from the Butler bin hot spot. Sample on the right from area outside of heating area, center sample from edges of hot spot and sample on the left from the center of hot spot.

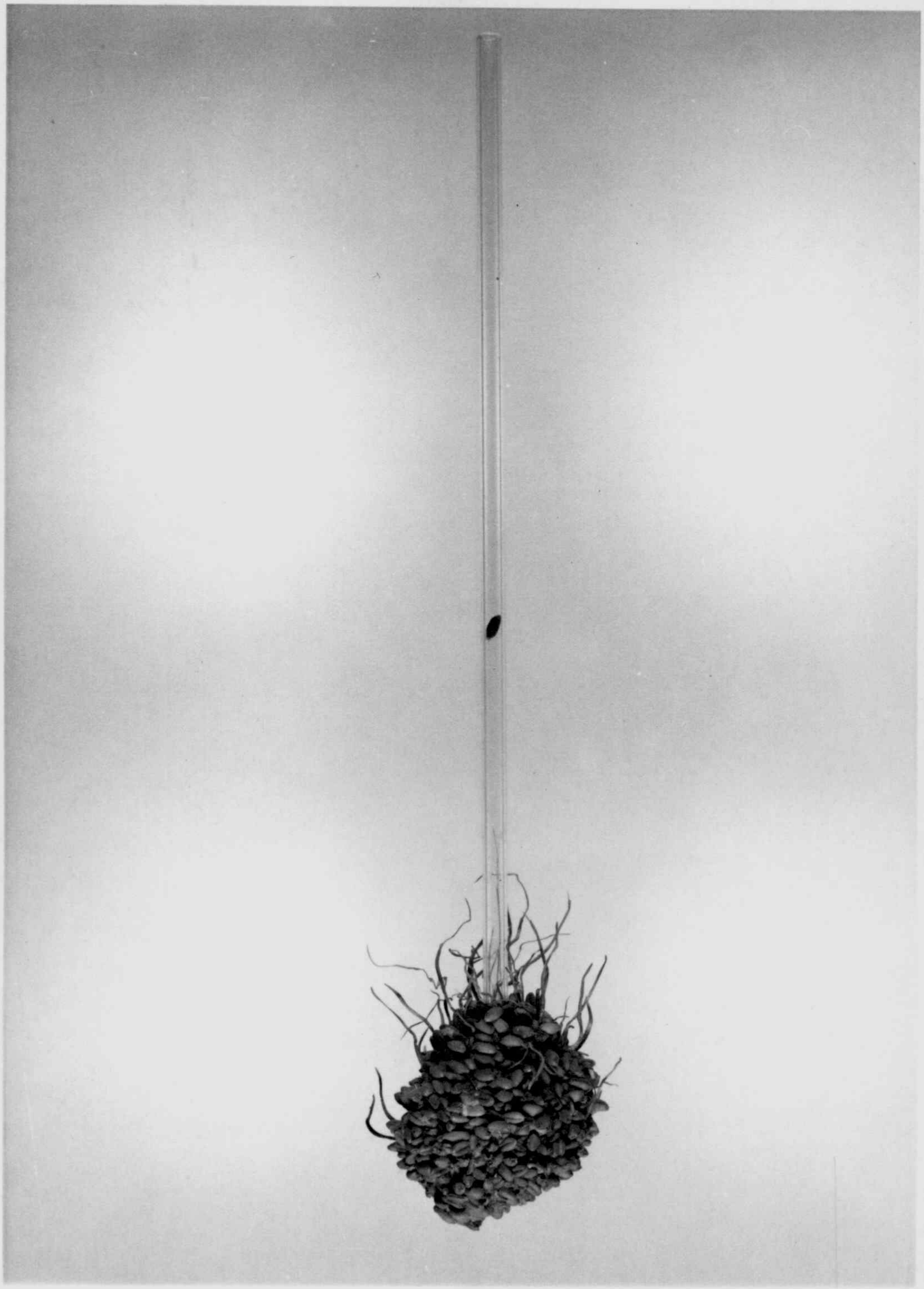

Figure 10. The ball of fungus infested grain from the center of laboratory Experiment Two, a fungus hot spot with no insects involved.

from a thermograph in the room showed that the temperature remained fairly constant throughout the winter months (68-70 degrees F). During the summer months, however, the room temperature fluctuated more according to the outdoor temperatures. Because of these fluctuations, the graphs which were constructed to show temperature changes in the hot spots were based on the differences between thermocouple readings in the center of the hot spot and readings from thermocouple 12 situated near the bottom corner of the box. The latter was as far from the center of the hot spot as possible but still within the grain. Temperature readings at thermocouple 12 were used as a base for computing the rise in temperature at the other thermocouples. This served to dampen the effects of rapid changes in room temperature.

Laboratory Experiments

Experiment One: Moisture-initiated hot spot with granary weevils

This experiment was conducted in one of the laboratory boxes wired with thermocouples and relative humidity elements as previously described. Hard white wheat with a moisture content of 12 percent was used to fill the box. A two inch cube of cellulose sponge was placed in the center of the mass at the lower end of a glass tube that extended through an opening in the top of the box. Moisture was added in five milliliter increments over a period of ten days until 65 milliliters of water had been added.

About 1500 granary weevils, Sitophilus granarius, from a laboratory culture were added near the moistened sponge at the center of the grain mass as the box was filled. The box was filled to within two inches of the top and the cover was secured in place with wood screws and sealed with grease.

Temperature and relative humidity readings were taken for eight months, commencing on April 17, 1963 and ending on December 27, 1963. Figure 11 (page 37) shows a summary of the temperature fluctuations at the center of the box, where a hot spot was initiated by adding moisture. The temperature began to rise during the first week and reached a peak of ten degrees at the end of the second week. This initial rise in temperature was restricted to the center of the grain mass, with the temperature rising only one degree at a distance of nine inches from the center (Figure 11, page 37). A second rise in temperature occurred during the third week and continued upward for six weeks until a peak of 14 degrees above ambient room temperatures was reached. The temperature at the center declined to nine degrees during the tenth week, but then rose rapidly to a peak of 13 degrees at the end of the 12th week. The heating area had spread sufficiently by that time to produce a similar peak up to six inches from the center, and by the 22nd week the

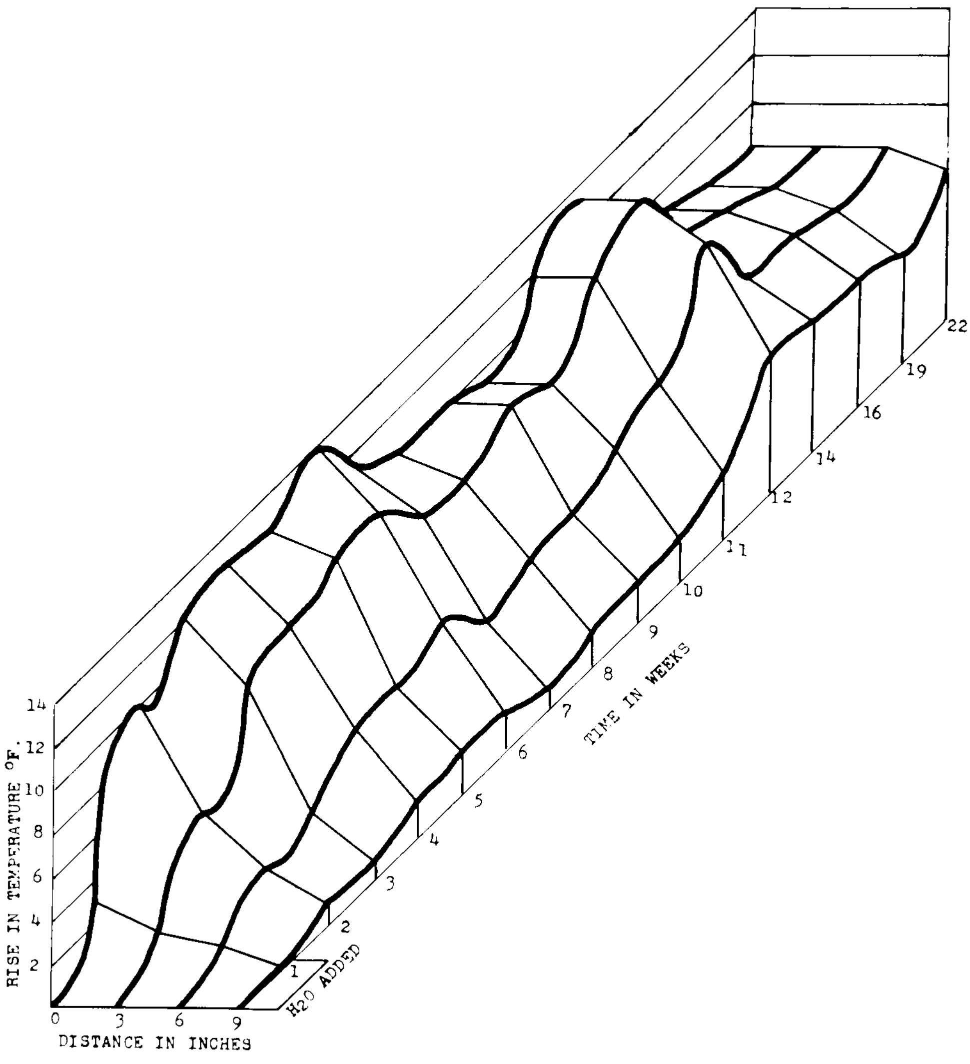

Figure 11. Experiment One. Moisture-initiated hot spot with granary weevil.

heating was almost uniform across the box. Temperature readings for all 12 thermocouples are recorded in Table 1 (pages 111 and 112).

This experiment involved a moisture-initiated hot spot with granary weevils and was performed to determine the effect of granary weevils on heating in wheat. It was compared subsequently with experiments that involved other insects, and with a control in which no insects were involved.

Experiment Two: Moisture-initiated hot spot with no insects involved

A box identical to the one used for Experiment One was constructed and wired as before. It was filled with clean (uninfested) wheat, and moisture was added in the same way and in the same amounts as in Experiment One.

A summary of the temperatures at the center of the box where moisture was added is shown in Figure 12 (page 39). The temperature readings from all of the thermocouples for a period of seven weeks is recorded in Tables 2 and 3 (pages 113 and 114). The rise in temperature at the center of the grain mass was quite similar to the initial rise of temperature seen in Experiment One but it was not maintained. The temperature began to drop rapidly after about ten days, descending to room temperature in about 20 days. The rise

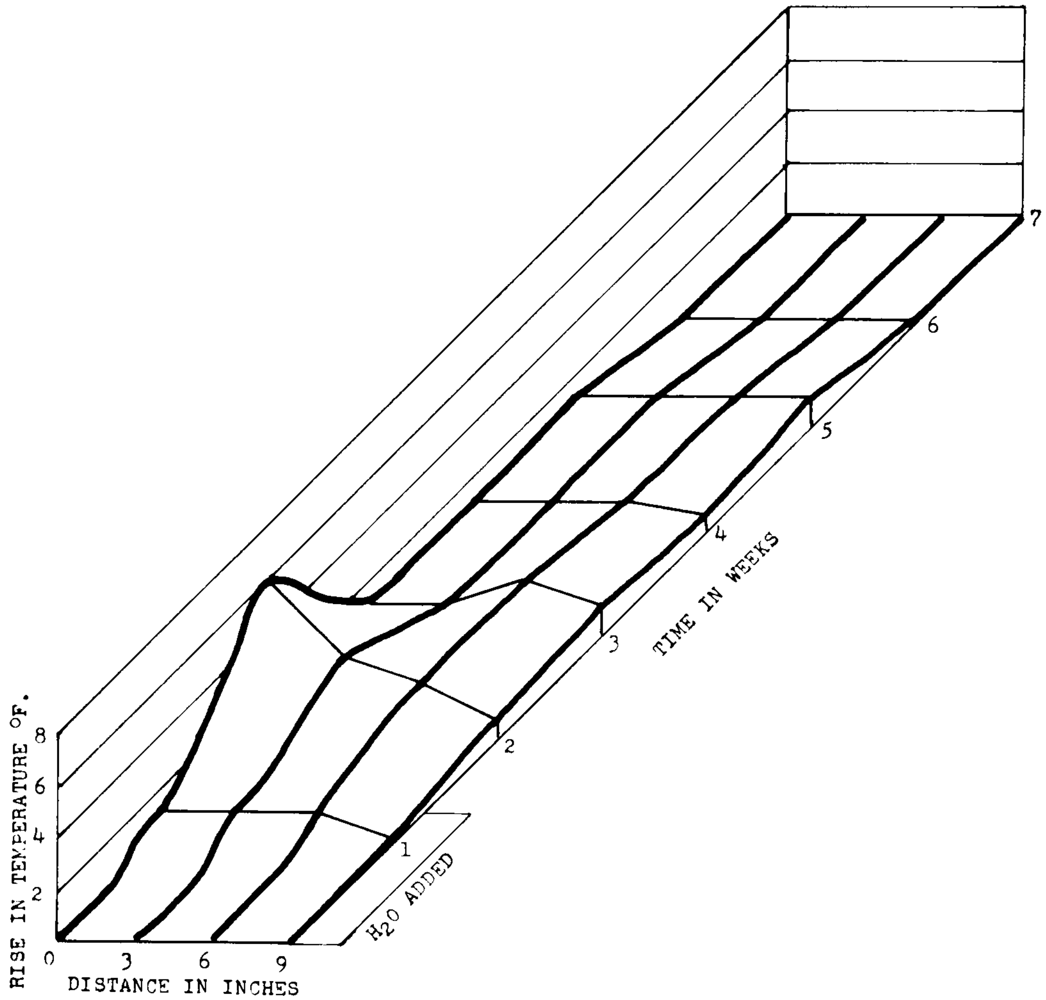

Figure 12. Experiment Two. Moisture-initiated hot spot with no insects involved.

in temperature did not occur until after moisture was no longer being added, and the highest temperature was not equal to that of Experiment One.

Another experiment was conducted which was identical to Experiment Two, except that moisture was added continuously throughout the experiment. There was a similar sudden rise in temperature but, instead of dropping after reaching a peak, it continued to rise to a maximum of eight degrees F above room temperature over a period of 20 days. It then gradually dropped over a period of 20 days until it had nearly descended to room temperature. There was no further indication of heating in this experiment.

The central core of the first hot spot formed in Experiment Two is shown in Figure 10 (page 34). The core of the second hot spot formed by adding moisture continuously was very similar to the first, but about twice the size.

Experiment Three: Insects concentrated by artificial heat--no moisture added

Experiment Three was conducted to determine the ability of the granary weevil to develop a hot spot in wheat without the aid of excess moisture. This phenomenon was noticed in one-gallon glass culture jars containing weevil stock cultures in the laboratory. Granary weevil cultures were maintained by periodically transferring a few hundred weevils from an old culture in which the wheat was spent, to a new jar full of uninfested wheat. The only means of air circulation in these culture jars was by way of a screened opening in the cover, so that most of the moisture produced by the metabolism of these insects was retained in the wheat. There also was considerable moisture condensation on the inside of the jar due to heat generated by the insects. This was evidenced by the fact that in an old established culture the layer of material next to the glass was damp and sticky while that in the center was usually dry. No attempt was made to measure the amount of heat produced in these culture jars, but heat production was evident when the temperature of the jars containing old cultures was compared to jars containing new cultures during handling operations. Heating was noticeable over a period of three to four months.

A box similar to those used for Experiments One and Two was used for Experiment Three. The only difference was in the placement of additional thermocouples next to the glass in the latter test in anticipation of a hot spot originating near the glass. The box was filled with uninfested hard white wheat with a moisture content of 12.5 percent. A piece of cardboard with a two inch circular opening at the center was fastened to the outside of the glass wall of the box. A circular piece of aluminum foil was affixed across the opening so that it lay next to the glass. A small microscope lamp was turned on the aluminum foil and adjusted until the temperature recorded by a thermocouple mounted on the inside of the glass opposite from the aluminum foil registered 90 degrees F. At that time 1500 granary weevils from laboratory cultures were added to the surface of the wheat in the box. No moisture was added.

Artificial heating with the microscope lamp was maintained at the same spot for four weeks. The temperatures as recorded in Table 4 (pages 115 and 116) show a constant high temperature (83.5-94 degrees F) maintained at thermocouple 12 next to the glass for the entire period. The lowest of these temperatures indicates a failure of heat due to the lamp bulb burning out during the night. The lamp was removed at the end of four weeks and the temperature at thermocouple 12 dropped immediately to 79 degrees F. The temperature at thermocouples two and three near the center of the grain mass, but adjacent to thermocouple 12, did not drop lower than four degrees above the lowest temperature within the box. A gradual increase was noted over a period of three months to a maximum of 14 degrees above the lowest temperature within the box (Figure 13, page 43). During that time it was possible to observe the spread of this artificially induced insect hot spot from the center of the grain mass to the glass on both sides, and subsequently outward and upward until the entire upper two-thirds of the mass of grain was involved. The granary weevils utilized almost every kernel of wheat in the

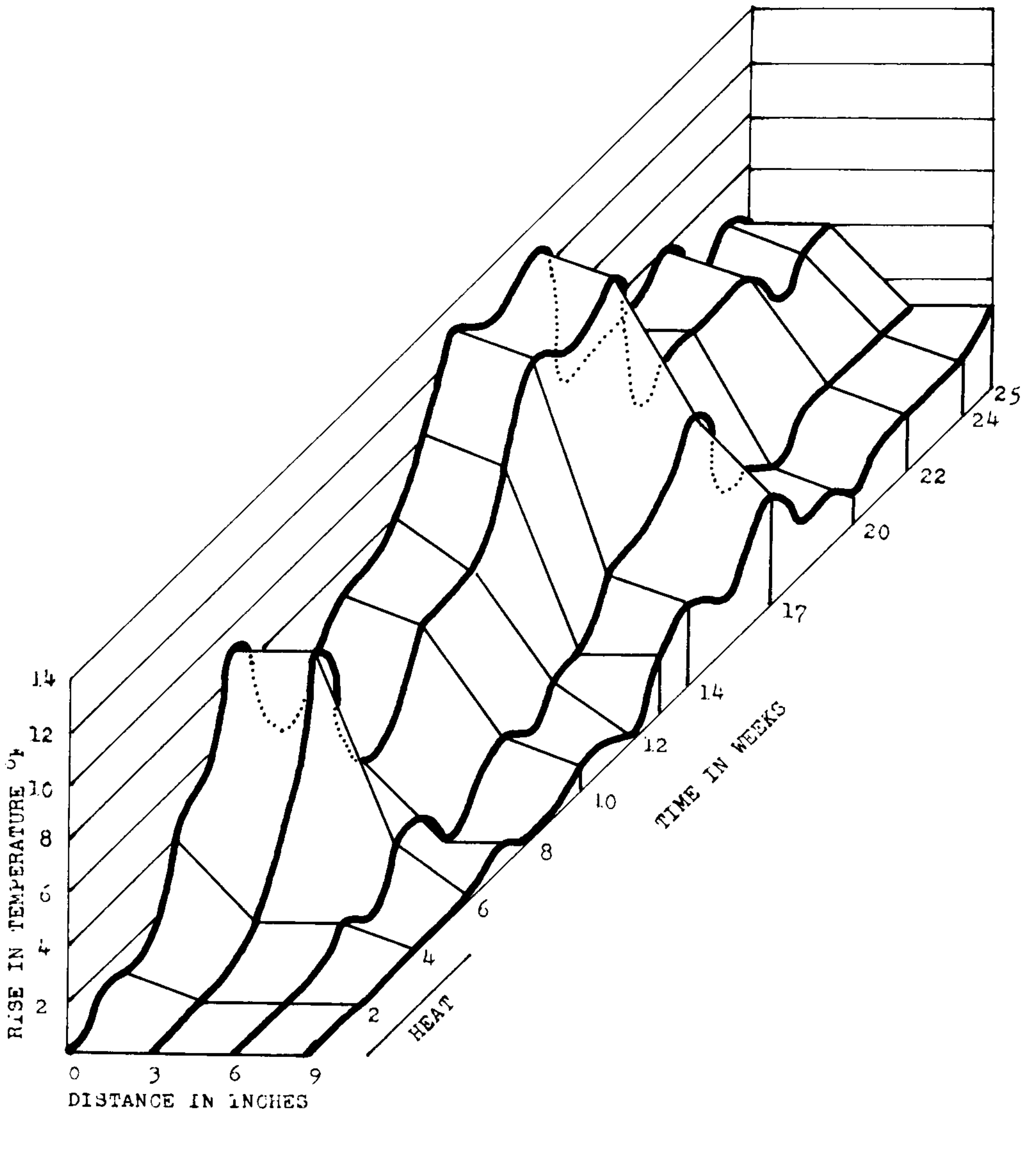

Figure 13. Experiment Three. Insect-initiated hot spot with granary weevil (no moisture added).

area of infestation and left behind them a moldy dark-colored mass of debris.

The relative humidity elements were arranged with one in the center of the grain and three next to the glass on the side where the heat was applied. As the record of relative humidity readings showed, there was a slight increase in moisture next to the glass where the heat was applied. After the heat source was removed the moisture continued to increase near the center of the grain, and gradually spread further from the center as the hot spot spread to the glass. The relative humidity in the later stages of development rose to 100 percent next to the glass, where condensation produced a sticky mass.

Experiment Four: Moisture-initiated hot spot with red flour beetles

This experiment was performed to determine the capacity of the red flour beetle, *Tribolium castaneum*, in influencing the development of a hot spot.

The grain used in this experiment was also hard white wheat but one-fourth of it was processed in a blender before being placed in the box and then mixed so that broken kernels and small particles were present throughout the grain mass. This was done to make the medium more suitable for the development of the red flour beetle, because it is recognized (Cotton 1963) that these beetles feed mostly on broken grain and grain dust. The box, identical to those used in previous experiments, then was infested with 1500 red flour beetles from the laboratory cultures. Moisture was added in the same way and in the same amount as in Experiment One. Figure 14 (page 46) shows the same rapid initial rise in temperature in this experiment as was shown for Experiment Two, where no insects were involved. The short peak and rapid drop also is similar to that noted in Experiment Two, except that the subsequent decline to room temperature was a little more gradual in Experiment Four. Temperature and humidity readings were taken for seven and one-half months, during which time there was no further indication of a rise in temperature or humidity. Probe samples taken during this experiment showed the red flour beetles to be active generally throughout the box, but with no concentrations evident. When the box was dismantled, a small area of moldy and sprouting grain was found around the sponge in the center of the box to which moisture had been added. It had the same appearance as the one shown in Figure 10 (page 34).

Cultures of the red flour beetle had been observed previous to Experiment Four in the same laboratory and on the same shelf with heating granary weevil cultures. The red flour beetle cultures showed no evidence of heating at this time.

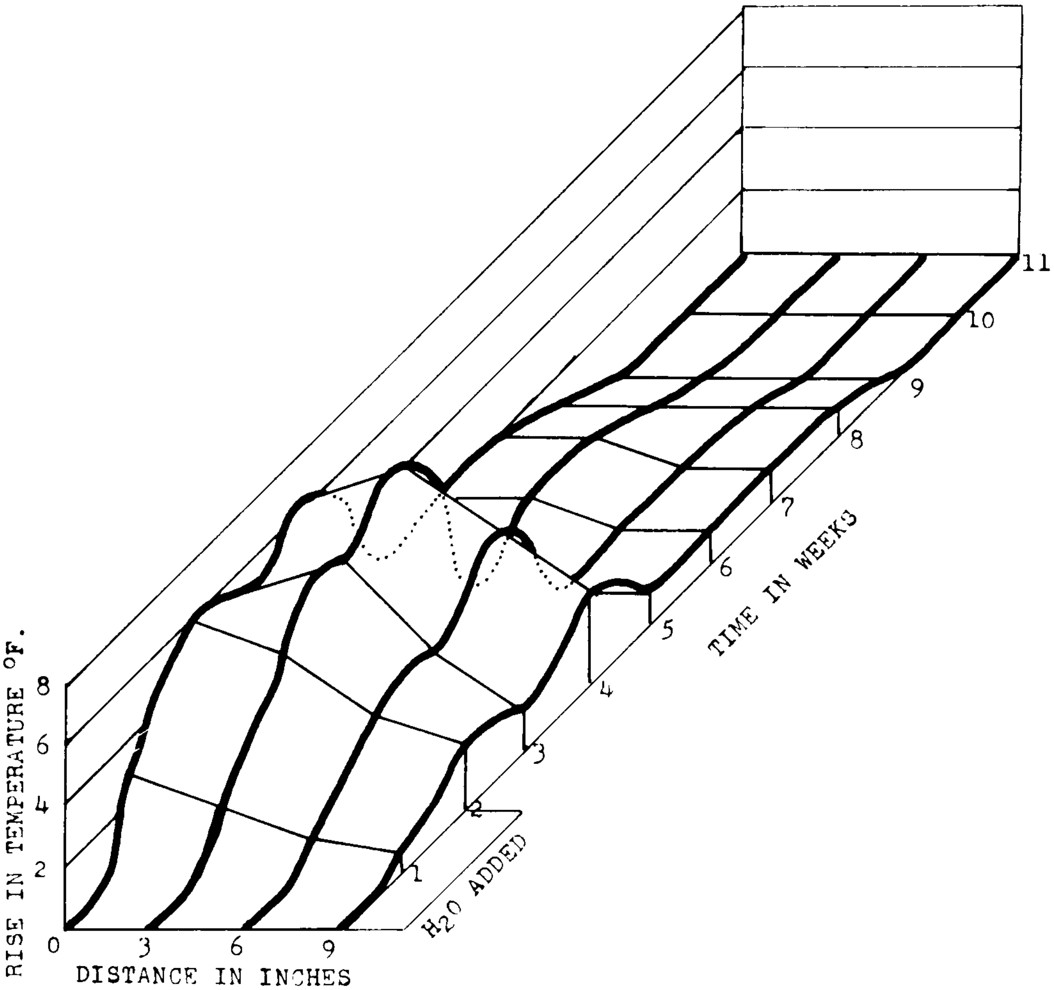

Figure 14. Experiment Four. Moisture-initiated hot spot with red flour beetle.

Experiment Five: Moisture-initiated hot spot with saw-toothed grain beetles

This experiment was conducted in order to determine the ability of the saw-toothed grain beetle, Oryzaephilus surinamensis to influence the development of a hot spot in wheat. A box identical to that used in Experiment One was filled with clean hard white wheat. The saw-toothed grain beetle, like the red flour beetle, feeds mostly on broken grain and grain dust. One-fourth of the grain in this box was processed in a blender as in Experiment Four, and mixed with the rest of the grain in the box to provide suitable conditions for the development of the saw-toothed grain beetle. The box was infested with 1500 saw-toothed grain beetles from the laboratory cultures. Moisture was added in the same way and in the same amount as indicated for Experiment One. Figure 15 (page 48) shows the same rapid initial rise in temperature in Experiment Five as was shown in Experiment Two, where no insects were involved. This graph also is remarkably similar to that for Experiment Four with red flour beetles (Figure 14, page 46). The sudden decline and subsequent gradual return to room temperature is practically the same as in Experiment Four. Experiment Five was continued for seven and one-half months, as was Experiment Four, and with similar results; no indication of any subsequent rise in temperature or humidity. Probe samples

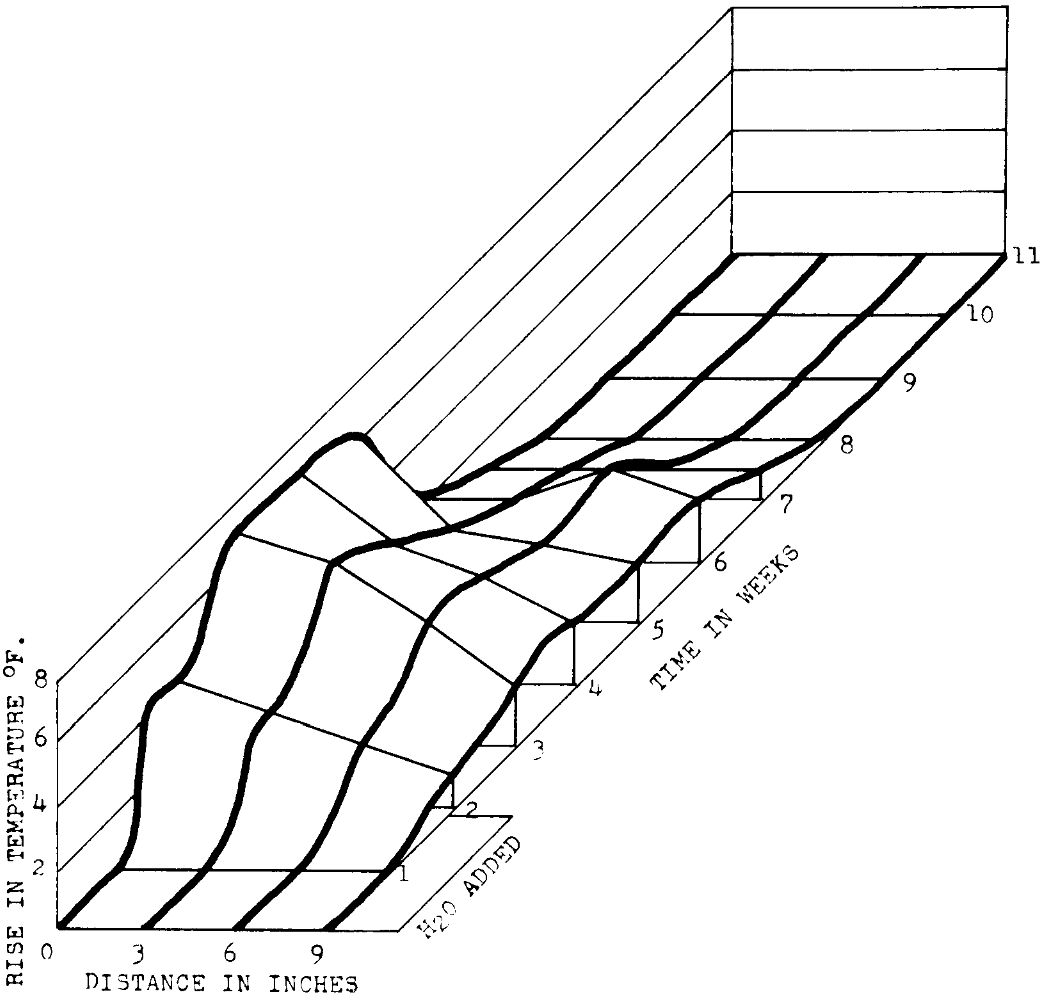

Figure 15. Experiment Five. Moisture-initiated hot spot with saw-toothed grain beetle.

taken during this experiment showed the saw-toothed grain beetles to be active and multiplying throughout the box of wheat, but with no evident concentrations.

When the box was dismantled, a small area of moldy and sprouting grain was found around the sponge in the center of the box to which moisture had been added. Its appearance was similar to the sponge from the experiment on the red flour beetle (Figure 10, page 34).

Laboratory cultures of the saw-toothed grain beetle reared in gallon jars did not show any evidence of mold growth and heating.

Experiment Six: Moisture-initiated hot spot with the lesser grain borer

This experiment was conducted to determine the ability of the lesser grain borer, *Rhizopertha dominica*, in influencing the development of heating in stored wheat. A box like that used in Experiment One was filled with hard white wheat. Moisture was added during the first 11 weeks of the experiment in five milliliter increments, with 75 milliliters being added during the first week and about 20 milliliters added each week thereafter. This was sufficient to keep the sponge moistened as in the second part of Experiment Two. Approximately 1500 lesser grain borers were added to the box as it was filled.

Figure 16 (page 51) shows the initial rise in temperature at the center to have been similar to that in Experiment Two, but not as marked. The subsequent decline to room temperature was similar to that seen in the second part of Experiment Two, where continuous moisture was added. After a period of four months, however, the temperature did rise near the center of the mass to 15 degrees above room temperature. There was some peripheral heating in an area involving approximately one-fourth of the volume of wheat in the box. The heating area was adjacent to and surrounding the center of the box.

The grain next to the glass sides of the box began to show evidence of grain borer activity at about the time when the temperature began its second rise. Evidence of moisture accumulation next to the glass occurred during the fourth and fifth months, but the humidity indicator at the center of the mass gave evidence of a high moisture content in the central portion throughout the experiment.

Sampling showed the lesser grain borer to be more active initially near the center of the box, but considerably more widespread during the latter part of the experiment.

Experiment Seven: Moisture-initiated hot spot with granary weevils and saw-toothed grain beetles

This experiment was conducted in order to determine the

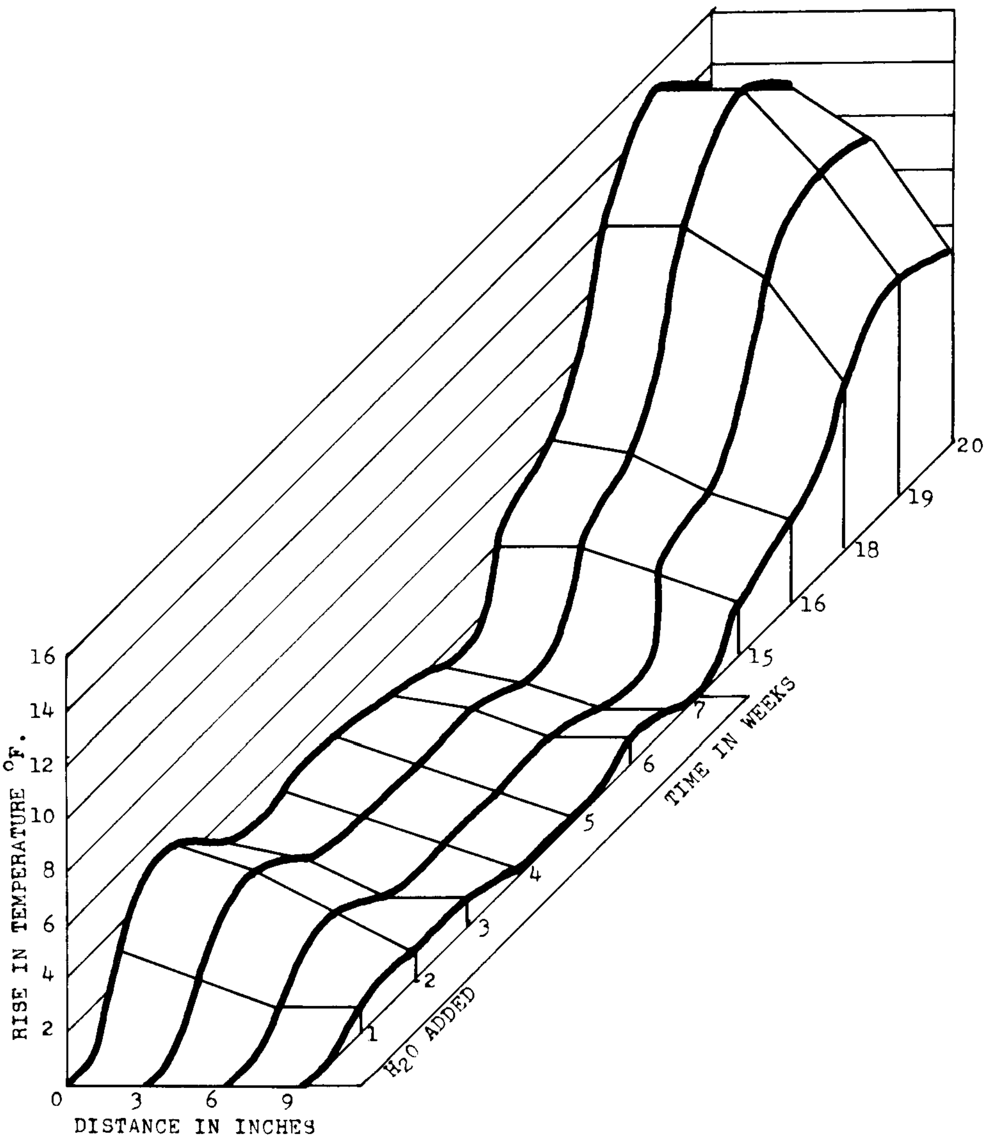

Figure 16. Experiment Six. Moisture-initiated hot spot with lesser grain borer.

influence of the granary weevil and the saw-toothed grain beetle on the development of a hot spot. A box was constructed in the same way as for Experiment One and filled with hard white wheat. A total of 1500 granary weevils and 1500 saw-toothed grain beetles was added to the wheat. Moisture was provided continuously in the same amounts as were added in Experiment Six. The same initial rapid rise in temperature was noted in Experiment Seven (Figure 17, page 53). A high temperature was maintained for about 12 days, after which it lowered somewhat, but not to room temperature. Six weeks after the first peak in temperature, the center of the box was back to a higher temperature than noted in the initial rise. This high temperature was maintained over a period of five months, during which time the concentration of insect activity and its resulting hot spot spread throughout the box in very much the same pattern as that observed in Experiment One. Probe samples showed the granary weevil to be concentrated mainly in the area of heating, and the saw-toothed grain beetle scattered throughout the grain mass.

Experiment Eight: Moisture-initiated hot spot with four insects involved

This experiment was conducted to demonstrate the influence of several insect species in combination on the development of a hot spot. The four insects used were those used in previous experiments;

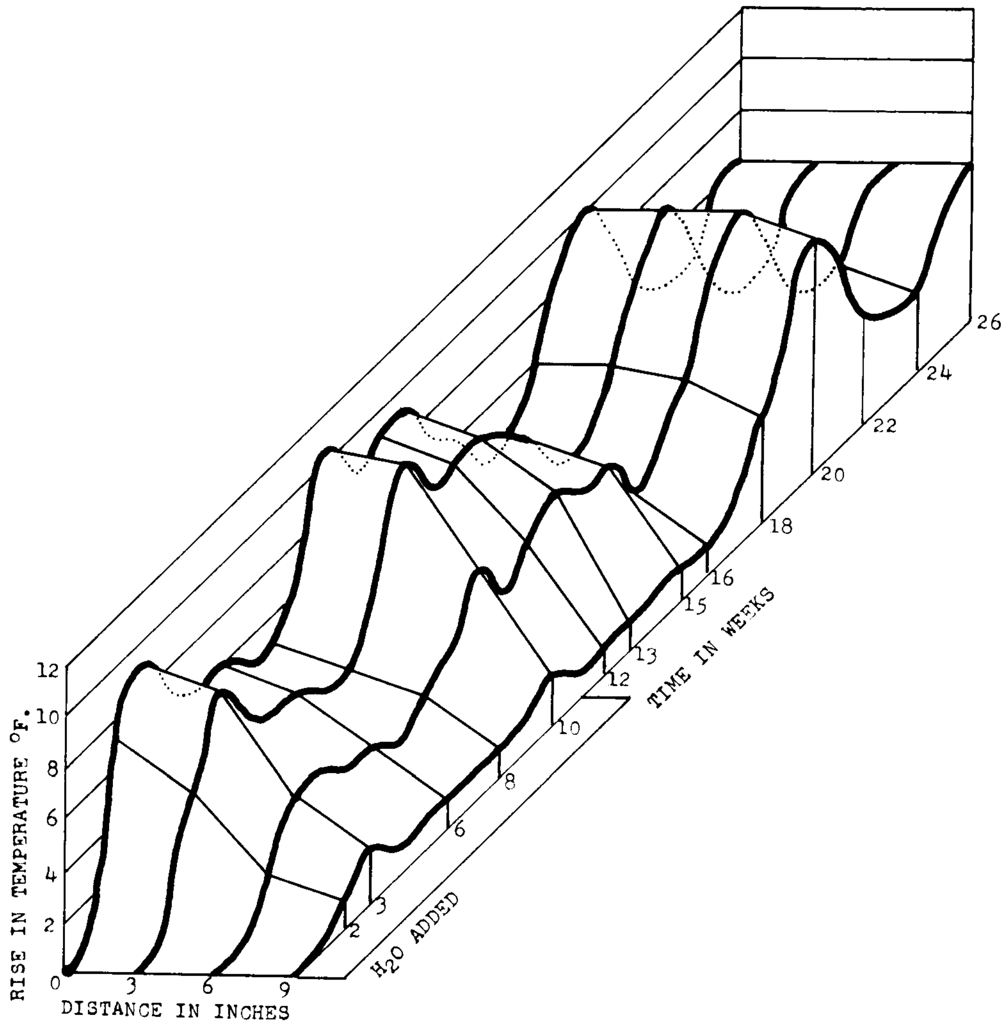

Figure 17. Experiment Seven. Moisture-initiated hot spot with granary weevil and saw-toothed grain beetle.

the granary weevil, saw-toothed grain beetle, lesser grain borer and red flour beetle.

A box identical to those used for the previous experiments was filled with hard white wheat. The four species of insects were obtained from laboratory cultures, 1000 of each being added to the box as it was filled. Moisture was added in the same way and in the same amounts as for the previous two experiments. It may be seen from the graph in Figure 18 (page 55) that the temperature pattern for Experiment Eight is basically the same as for Experiment Seven (granary weevil and only one other insect).

Experiment Nine: Moisture-initiated hot spot with two secondary invaders

This experiment was conducted in order to determine the influence of two secondary invaders on the development of a hot spot in wheat. The two secondary invaders used in previous experiments (the saw-toothed grain beetle and the red flour beetle) were used in this experiment.

A box identical to that used for Experiment One was filled with hard white wheat, to which was added 1500 saw-toothed grain beetles and 1500 red flour beetles. Moisture was added continuously as in Experiment Seven and Eight. The graph in Figure 19 (page 56) shows that the results were similar to those of Experiment Two,

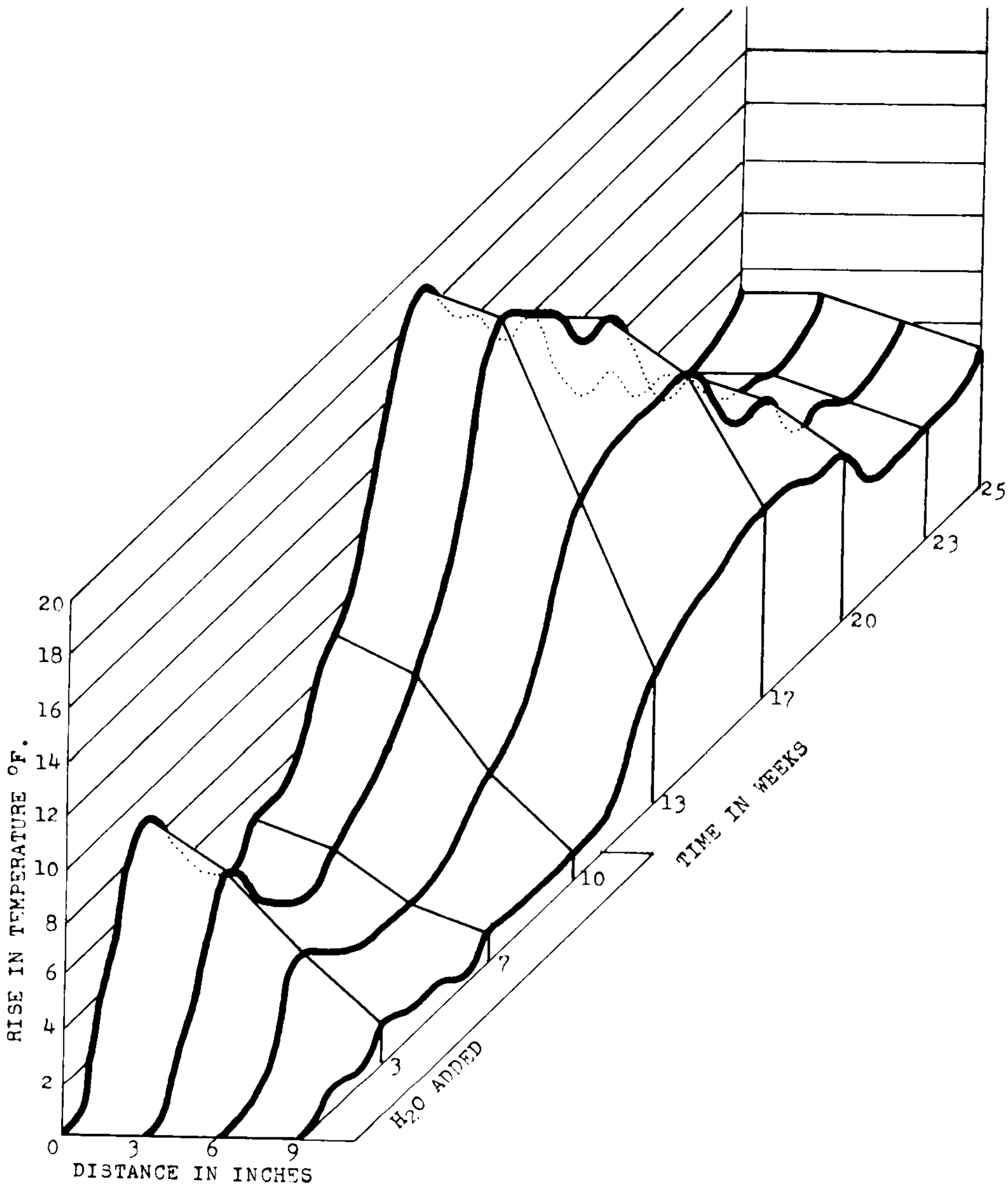

Figure 18. Experiment Eight. Moisture-initiated hot spot with four insects involved.

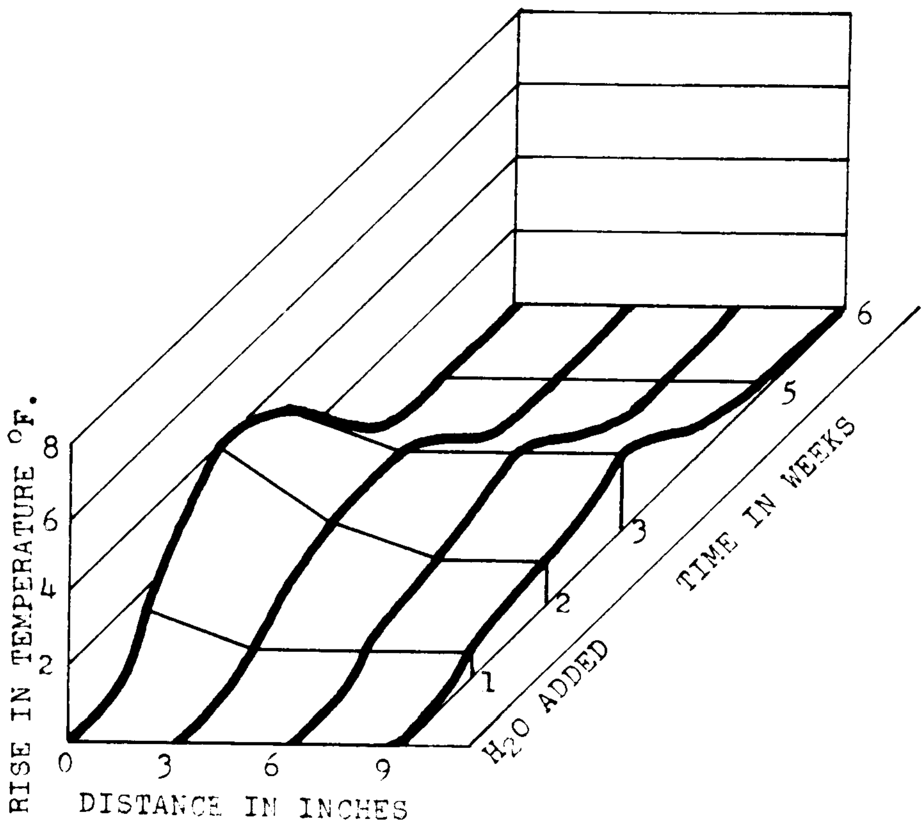

Figure 19. Experiment Nine. Moisture-initiated hot spot with red flour beetle and saw-toothed grain beetle.

in which no insects were involved. Probe samples taken during the latter part of Experiment Nine showed the two beetles to be spread widely throughout the box, and not concentrated in the area of moisture at the center of the box. Moisture was added continuously to the box, but in small enough quantities so that it did not penetrate more than two inches in any direction from the sponge in the center.

Experiment Ten: Moisture-initiated hot spot with two primary invaders

This experiment was conducted to determine the influence of two primary invaders on a developing hot spot. The two insects chosen for this experiment were the granary weevil and the lesser grain borer.

A box identical to those used in previous experiments was filled with hard white wheat, and 1500 granary weevils and 1500 lesser grain borers were added to the box as it was filled. Moisture was added continuously and in the same amounts as in Experiments Seven and Eight. The graph in Figure 20 (page 58) shows that the heating in this box was very similar to that in Experiment Two and also in Experiment Nine. Probe samples during the latter part of this experiment showed evidence of lesser grain borer activity, but no live specimens of either lesser grain borers or granary weevils. (Something apparently went wrong with this experiment

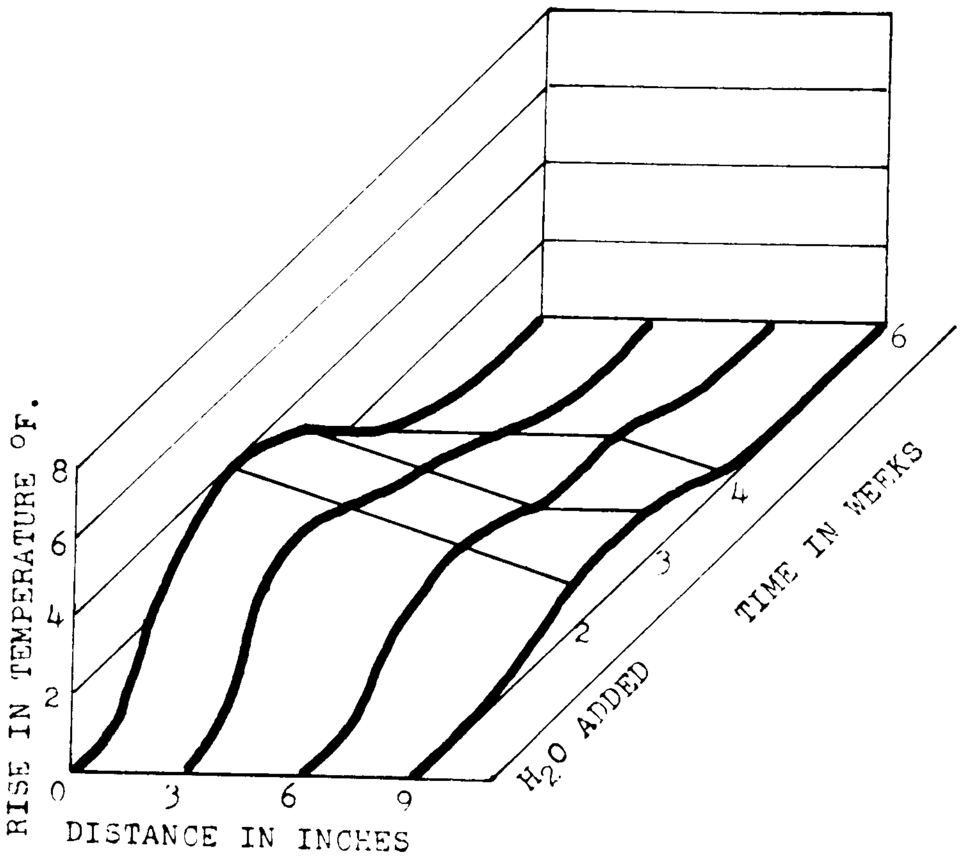

Figure 20. Experiment Ten. Moisture-initiated hot spot with granary weevil and lesser grain borer.

and it was suspected that fumes from a recently fumigated insect collection next to it might have had some effect.)

Experiment Eleven: Moisture-initiated hot spot with granary weevils (variation)

This experiment was an attempt to initiate heating with damp grain added at the time of infestation.

One of the boxes from the previous experiments was cleaned and fumigated and refilled with hard white wheat that had been fumigated. One quart of the wheat was humidified in a closed container containing 20 milliliters of water for four hours at 70 degrees F resulting in a moisture content of 14 percent. This moistened wheat was placed at the center of the box, and 750 granary weevils were placed upon it and then covered with dry (11.5 percent moisture content) wheat. Water was added in the same manner as in earlier experiments, but in greater quantities. A total of 170 milliliters was added during the first six days in an attempt to moisten a larger mass of wheat surrounding the central area. There was no significant rise in temperature in the box and the granary weevils showed no activity, apparently having died soon after they were introduced into the box.

A second attempt to initiate heating in the same box was made at the end of two months by addition of even larger amounts of water (up to 200 milliliters per week) for four weeks. This resulted in sporadic heating at various places in the moistened area, usually amounting to 6 - 12 degrees for 3 - 8 days.

The final results of this experiment was a general swelling of wheat throughout the area moistened which exerted sufficient pressure on the glass sides of the box to break them, thus terminating the experiment.

Experiment Twelve: Moisture-initiated hot spot with grain mites

This experiment was conducted to determine what effects mites have on heating in damp grain.

A box from one of the previous experiments was cleaned and fumigated, and refilled with uninfested hard white wheat. One quart of wheat was moistened sufficiently to raise its moisture content to 15 percent and placed at the center of the box, with provisions for adding moisture as in previous experiments. Approximately one teaspoon (5 milliliters) of a mixed culture of *Acarus siro* and *Tyrophagus putrescentiae* was added to the moistened grain at the center of the box. Moisture was added (25 milliliters) during the first week in quantities sufficient to maintain a relative humidity reading at near 80 percent at the center of the box.

A slight rise in temperature (3-4 degrees) which lasted only four days, was recorded during the second week. There was no indication after that time of a temperature increase. Mites were not in evidence after the second week, and probe samples failed to show them from the central moistened area.

Addition of moisture was resumed in the sixth week at the rate of 30 milliliters a day and continued until the end of the experiment. Probe samples during the tenth week still failed to show any mites, at which time another four milliliters of the same mixed mite culture was added. The relative humidity indicator at the center of the box registered 100 percent soon after the addition of moisture was resumed, indicating a saturated condition at the center of the box. Concurrently, the temperature began to rise in that area, and continued heating as long as moisture was being added.

This experiment, like the previous one, finally was discontinued due to the glass walls breaking from the pressure of the swelling wheat when large amounts of moisture were added.

Experiment Thirteen: Moisture-initiated hot spot with no insects involved, but with excessive moisture and fungus spores added

This experiment was conducted to demonstrate the effects of large continuous amounts of moisture on wheat that had been inoculated with fungus spores.

One of the boxes used in previous experiments was cleaned and fumigated and filled with uninfested hard white wheat. One quart of this wheat was moistened and mixed with a small amount of wheat from a previous hot spot, the latter having been incubated in a warm moist chamber to allow growth of fungi. Moisture was added to the central area of the fungi-infected grain but in greater amounts than in previous tests. The addition amounted to 50 milliliter increments every two or three days, averaging 200 milliliters each week.

The temperature at the center of the box began to rise on the fifth day, and increased rapidly to a peak of 95 degrees F on the 12th day. This constituted a total rise of 18 degrees F. The temperature also declined rapidly, dropping ten degrees in five days after the peak was reached. There were various fluctuations of temperature throughout the box during the next eight weeks, but at no time did the temperature reach as high as during the first peak.

Experiment Thirteen, like others in which large amounts of water were added, was terminated due to the breaking of the glass sides of the box from pressure exerted by the swelling grain. The moisture had been confined to a broad cone-shaped area, with its apex at the center of the mass where the moisture was introduced, and its base at the bottom of the box where excess moisture ran out of the ventilation holes.

Experiment Fourteen: Moisture-initiated hot spot with the granary weevil

Experiment Fourteen was a replicate of Experiment One. The box was prepared in the same way and with the same type of grain. Moisture and insects were added in the same way and in identical amounts (see page 35).

The data from this experiment was almost identical to those of Experiment One (Table 1 , page 111) and the appearance of the hot spot produced was the same (Figures 7 and 8, pages 31 and 32).

Experiment Fifteen: Moisture-initiated hot spot with two primary invaders

This experiment was conducted as a replicate of Experiment Ten using the granary weevil and the lesser grain borer as primary invaders. The preparation of the box, and the addition of moisture and insects, was carried out as described in that test (see page 57

The trends noted during the first three weeks of this experiment paralleled those seen in Experiment Six (Table 7 , page 117) but, after a period of no apparent activity, heating again was resumed. At the end of nine weeks, there was a temperature rise of 14 degrees. Probe samples showed an active population of both the granary weevil and the lesser grain borer in the central heating area. The hot spot produced had the same configuration as that of Experiment One in which the granary weevil alone was involved (Figure 21, page 64). This attempt to replicate Experiment Ten strengthened the supposition that something went wrong in

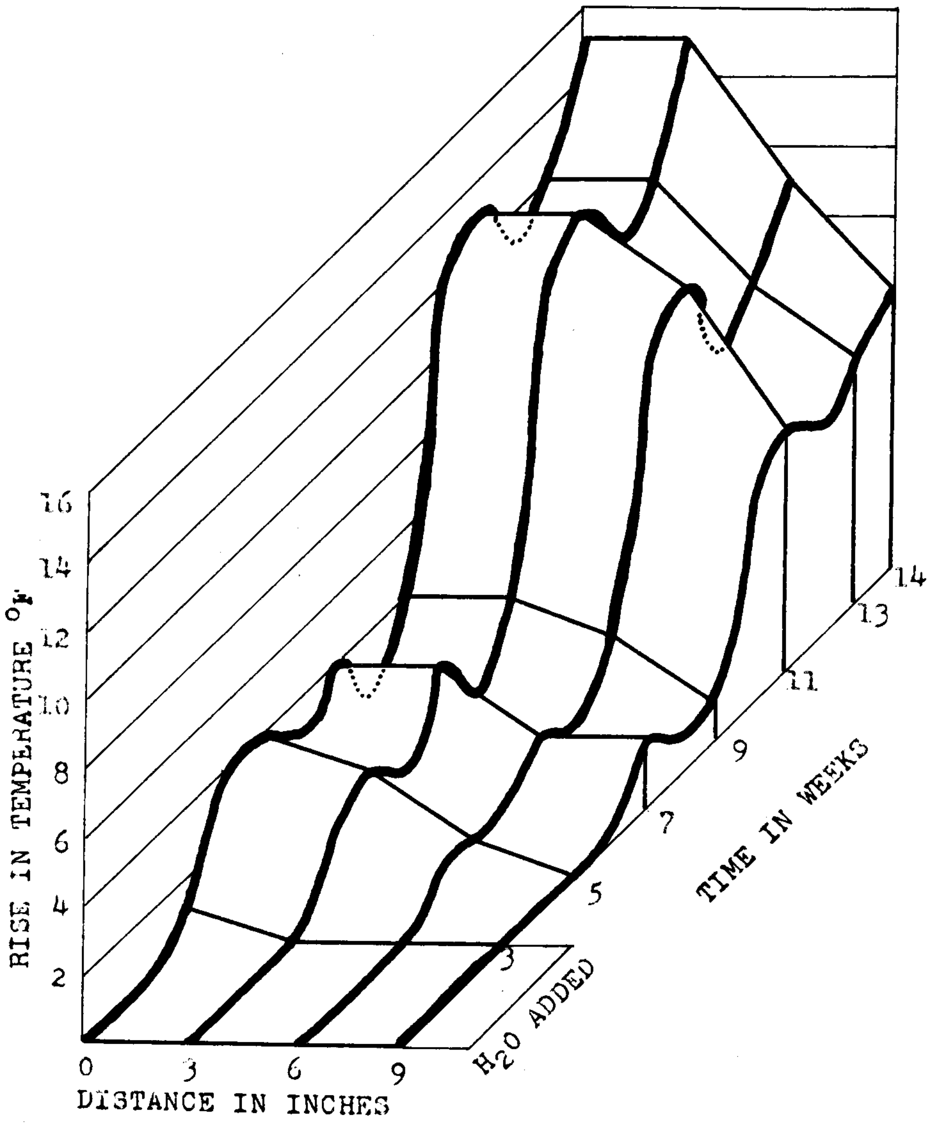

Figure 21. Experiment Fifteen. Moisture-initiated hot spot with granary weevil and lesser grain borer.

Experiment Ten and a third replication was started (see Experiment Eighteen, page 66).

Experiment Sixteen: Insect-initiated hot spot with no moisture added

Experiment Sixteen constituted an attempt to produce heating in one of the laboratory boxes without the aid of a fungus hot spot, or an artificial heat source. The test was performed partly as a check to determine whether the granary weevil might be capable of producing a hot spot in a small grain mass with no concentrating factor involved. This was essentially the same condition as found in the laboratory culture jars, but on a larger scale.

Temperature readings were recorded from this box for eight weeks with no indication of any rise in temperature at any place within the grain mass. Probe samples showed a small population of granary weevils in the upper one-third of the box, but there was no indication of concentration in any one area.

Experiment Seventeen: Moisture-initiated hot spot with saw-toothed grain beetles

This experiment was performed as a replicate of Experiment Five and was conducted in the same way as described on page 47

The data recorded for this experiment over a period of eight weeks showed the same pattern as that of Experiment Five, with the development of a small fungus hot spot and no subsequent heating or spreading. Probe samples indicated a thriving population of saw-toothed grain beetles scattered widely throughout the box.

Experiment Eighteen: Moisture-initiated hot spot with two primary invaders

This experiment was conducted as a third replicate of Experiment Ten. Experiment Fifteen, the second replicate of Experiment Ten, demonstrated the development of a moisture-insect related hot spot with the granary weevil and the lesser grain borer involved as two primary invaders where Experiment Ten had failed (page 57). Experiment Eighteen was necessary, therefore, to verify the pattern of Experiment Fifteen. The development of a moisture-insect related hot spot in Experiment Eighteen followed the same pattern as that of Experiment Fifteen.

Field Experiments

The field experiments herein described were conducted in order to confirm the results obtained from laboratory experiments. The small size of the laboratory boxes allowed for a rapid heat loss, and somewhat restricted the movements of the insects involved, therefore, it was felt that the larger mass of wheat used in the Butler bin at the O. S. U. Entomology Farm would produce conditions closer to what might be expected in farm stored grain. The rather elaborate mechanism described in the chapter entitled METHODS (page 18) was made ready in the Fall of 1963 with Field Experiment One being initiated in February of 1964. The grid of thermocouples and relative humidity sensing elements which comprised the mechanism was buried in 600 bushels of hard white wheat which previously had been fumigated with a carbon tetrachloride-ethylene dichloride mixture sufficient to destroy all insect life that might be in it. Time for aeration had elapsed before the initiation of the first experiment, so that no residue of the fumigant remained.

Field Experiment One: Moisture-initiated hot spot with no insects involved

A comparison was made between laboratory experiments and field storage conditions by conducting an experiment similar to laboratory Experiment Two (page 38), but in a larger mass of grain.

It was observed in the laboratory that a hot spot could be produced without insects in a small mass of grain simply by adding moisture. These conditions were met in the Butler bin by adding moisture to a piece of cellulose sponge near the center of the thermocouple-relative humidity system which was buried in hard white wheat. The sponge was placed 24 inches below the surface of the grain and water was added by means of a glass tube. Water was added in ten milliliter increments over a period of 35 days up to a total of 2200 milliliters.

A recording thermograph was used to determine air temperatures in the Butler bin during the field experiments. The sensing element of the thermograph was placed next to the wood partition holding the grain and three feet from the floor of the Butler bin. The top thermocouples of the system were above the level of the wheat, so that they indicated the air temperature immediately above the grain mass. The air temperatures recorded by the thermograph during the first four weeks varied from 28-58 degrees F. The highest temperature within the grain mass during the first four weeks was 49 degrees F at the middle of the thermocouple system, and the lowest was 45 degrees F at the bottom of the system. A period of warm weather during the fifth week raised the air temperature at the thermograph to 68 degrees F, during which time the temperature at the center of the thermocouple system (Column 4, Row 4, Number 5)reached 54 degrees F. The air temperatures remained below 58 degrees F during the sixth week, while the temperature at the center of the thermocouple system reached 73 degrees F. Air temperatures remained below 62 degrees F during the seventh week, but the temperature at the center of the thermocouple system continued to rise to 90 degrees F. A range of air temperatures from 33-64 degrees F was noted during the eighth week, and the center of the thermocouple system recorded 93 degrees F. Temperatures at the center of the thermocouple system started a gradual decline during the ninthweek, even though the air temperatures virtually remained the same. This was considered the termination point of Field Experiment One.

A difference of 30 degrees F between the center thermocouple and the nearest adjacent thermocouple (Column 3, Row 4, Number 5, six inches away) was recorded at the end of eight weeks. The moisture was confined to the center so that no effect was noted on the nearest relative humidity element, also six inches away. This would indicate that the extent of heating was extremely limited (Figure 22, page 70; Table 14, page 122).

Field Experiment Two: Moisture-initiated hot spot with granary weevils

Evidence from the laboratory experiments indicated that the granary weevil was the most active of the four insects tested in promoting the spread of a hot spot. For this reason the granary weevil was selected to add to the heating area established in Field Experiment One, the object being to compare heating in a larger grain mass with that of the small laboratory bins.

A total of 4000 granary weevils from laboratory cultures were added to the 600 bushels of wheat in the Butler bin where a hot spot had been produced earlier by addition of water only (Field Experiment One). These weevils were added during the ninth week from the beginning of Field Experiment One. The temperature at the

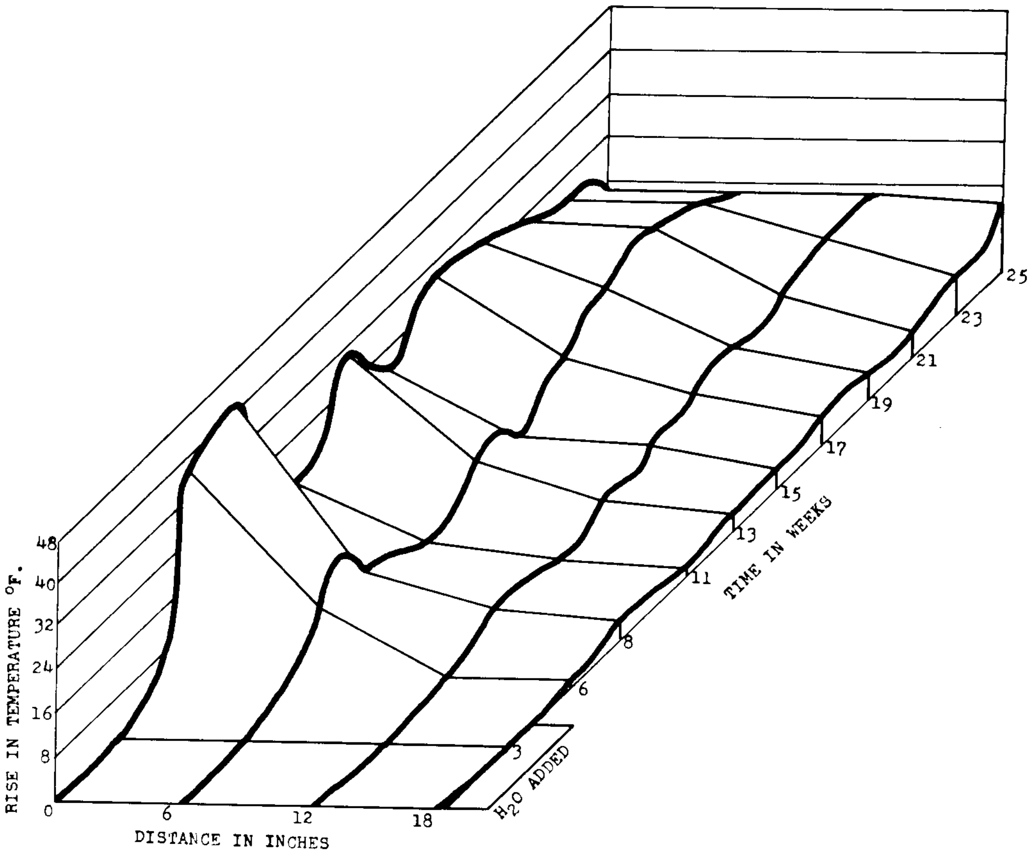

Figure 22. Field Experiments One and Two. Moisture-initiated hot spot with no insects involved followed by infestation with granary weevil.

center of the thermocouple system (Column 4, Row 4, Number 5) continued to decline gradually between the ninth and the 11th week, while the air temperatures recorded by the thermograph during this time were approximately the same as during the ninth week. A sudden rise in temperature from 69 - 77 degrees F at the center of the hot spot occurred during the 12th week with the air temperature during that time varying from 40 - 72 degrees F. The hot spot reached a peak of 89 degrees F during the 13th week, and slowly declined to 78 degrees during the 15th week before starting upward again (Figure 22, page 70). The air temperatures during this time fluctuated between about 50 and 70 degrees F. The hot spot reached a peak again during the 16th week at 93 degrees F, and remained within two degrees of that peak until Field Experiment Two was terminated (25 weeks after the beginning of Field Experiment One). The air temperatures at the thermograph reached 86 degrees F during the latter part of the experiment, but usually varied from 60 - 70 degrees F.

The insect-infested hot spot started out as an area not more than four inches across as was indicated by readings from surrounding thermocouples (Table 15, page 123). Five weeks after the insects were added, temperature readings of surrounding thermocouples indicated an enlargement of the heating area, which continued to spread during a period of eight more weeks until it covered an area 24 inches in diameter (Figure 22, page 70). It was difficult to determine the actual extent of the hot spot during the latter part of this experiment because of the influence of rising air temperatures on the grain mass.

Probe samples taken during the 20th week showed the greatest granary weevil activity to be near the center of the hot spot, but scattered over an area 18 inches across. Probe samples during the 22nd week showed granary weevil activity over an area of 24 inches, and an increase in activity of saw-toothed grain beetles which probably were introduced from the field.

The relative humidity readings indicated an increase in moisture in the area of heating. The relative humidity in areas outside of the hot spot decreased gradually from about 50 percent at the bottom to 40 percent near the top, while those within the hot spot were as high as 60 percent.

Field Experiment Two was terminated at the end of 25 weeks by cooling the entire grain mass with a forced air system described in the chapter entitled METHODS (page 25).

Field Experiment Three: Moisture-initiated hot spot with granary weevils and saw-toothed grain beetles

The apparent dryness of the grain was believed to be responsible for the slow spread of granary weevils in the previous Field Experiment Two. Material examined from the outer edge of the hot spot was found to have a moisture content of only 12. 7 percent. The warm, dry summer weather produced an extreme drying effect due to warm air circulating through the wheat by way of the perforated floor of the Butler bin. This resulted in a reduction of the insect activity and a general rise in the temperature of the entire mass of wheat to the point where it was difficult to determine the area of heating due to insect activity. The blower described in the chapter entitled METHODS (page 25) was used to force air through the grain mass during the cool part of the day in order to lower the temperature throughout the mass, including the heating area. The data in Table 16 (page 128) shows the sudden drop throughout the mass from temperatures of 80-94 degrees F to 69-72 degrees F. Field Experiment Three was an attempt to re-establish heating in the same area as in Experiments One and Two by raising the moisture content of that area. A total of four gallons of water was added to the area of the former hot spot by pouring one gallon at a time on the surface of the grain directly above the central area of previous heating. The water was added at nine o'clock in the morning and five o'clock in the evening on two consecutive days.

Heating began almost immediately in the area where water was added. The temperature at the center of the thermocouple system rose 42 degrees during the first 48 hours after the moisture was added. This involved a change from 77-119 degrees F while the air temperatures at the thermograph ranged from 50 - 72 degrees F.

The temperature at the center of the grain mass continued to rise and reached a peak of 137 degrees F on the 12th day of Field Experiment Three. This was 57 degrees above surrounding grain temperatures and the highest reached in these experiments. This heating area was quite broad in extent, with its center somewhat higher in the grain mass than that of Field Experiment Two. The hot spot extended over an area of 24-30 inches, the center being about 12 inches below the surface of the grain.

The temperatures of the hot spot in Field Experiment Three began a gradual decline after the sudden increase to 137 degrees F (Figure 23, page 75). Probe samples taken just before the initiation of this experiment showed evidence of former granary weevil activity in the center of the hot spot, but at this time the adults were dead. A probe sample on the 15th day of the experiment showed slight granary weevil activity. Twenty-two days after the initiation of Field Experiment Three, approximately 5000 granary weevils were added to the wheat in the area of heating. Sixty milliliters of a mixed culture of granary mites (*Acarus siro* and *Tyrophagus putrescentiae*) were added simultaneously to the same area.

The temperatures of this hot spot continued to decline slowly over a period of about ten weeks. Probe samples indicated a gradually declining population of granary weevils and, concurrently, a great increase in saw-toothed grain beetles. Coincident with

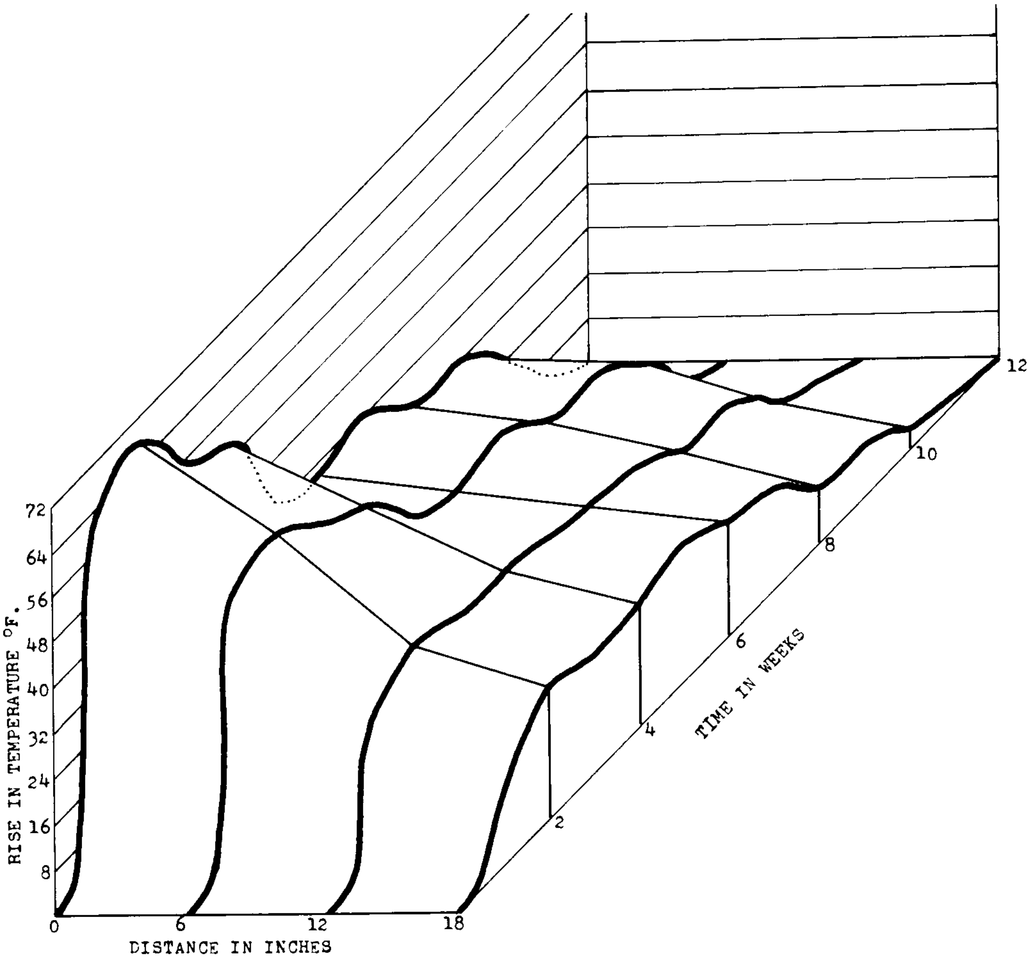

Figure 23. Field Experiment Three. Moisture-initiated hot spot with granary weevil and saw-toothed grain beetle.

this phenomenon was a sudden "explosion" of the bethylid parasite Cephalonomia tarsalis which was found in all probe samples and observed crawling and flying everywhere in the Butler bin. Granary weevil activity mostly was confined to the outer edges of the hot spot and was never observed to be as intense as had been observed in the laboratory experiments. The saw-toothed grain beetles appeared everywhere except at the center of the hot spot, where the extremely high temperatures charred the grain (Figure 9, page 33). The mite population thrived for a short time about two inches below the surface of the grain where moisture was high.

The relative humidity indicators in the grain mass showed the increase in moisture that resulted from the addition of four gallons of water. One relative humidity sensing element at the center of the hot spot registered 100 percent, and then gradually declined as the moisture evaporated. The relative humidity system showed an upward movement of moisture in the area of the hot spot over a period of eight weeks after the water was added.

Heating was negligible on November 16 (about 12 weeks after the beginning of Field Experiment Three) with temperatures of 50 - 66 degrees F throughout the grain mass. A small and apparently declining population of granary weevils was indicated by probe samples, but a thriving population of saw-tooth grain beetles and a scattered population of rusty grain beetles (Cryptolestes ferrugineus) was evident. The parasite Cephalonomia tarsalis still was abundant, while the mite population had declined to a few scattered pockets near the surface. By December 7, the temperatures had declined to 44-53 degrees F.

<u>Field Experiment Four: Moisture-initiated hot spot involving a large area</u>

Field Experiment Four was initiated in an area separated from the original site of heating by about 12 inches, but still within the framework of thermocouples and relative humidity sensing elements. It was initiated for the purpose of establishing a hot spot involving several insects in a comparatively large area. Moisture was added in quantities similar to those used in Experiment Three (page 73), but spread over an area about 12 inches in diameter and added during a period of four days. An initial rapid rise in temperature took place about four weeks later in a manner which resembled the fungus hot spots of previous experiments, but which involved a larger area. The central area reached a peak of 124 degrees F during the month of January when surrounding grain temperatures were at 49 degrees F and the air temperature frequently was below freezing. One week later the highest temperature in the central area was 96 degrees F. At that time, about 6000 granary weevils from the laboratory cultures were added to the grain directly above the heating area. One week after the addition of the insects, the temperatures in the center of the heating area rose to 110 degrees F and then gradually declined over a period of eight weeks to 81 degrees F. Probe samples during Field Experiment Four showed the granary weevil population to be concentrated in the area of heating. A large population of saw-toothed grain beetles, red flour beetles, rusty grain beetles, and psocids had migrated to the vicinity of the hot spot, but probe samples did not give any evidence of concentrations of these insects within the area of heating.

V. DISCUSSION

The laboratory grain bins described in the chapter entitled METHODS (page 14) provided the first information obtained in this series of experiments. Data from Experiment One (Table 1, page 111) seemed to indicate that the beginning of an insect-initiated hot spot occurs about ten days after the introduction of insects. Experiment Two, however, showed that a similar rise in temperature could be obtained by adding moisture to the wheat with no insects involved (Table 2, page 113). Experiment Three illustrated that a similar hot spot could be developed by insects without adding any moisture if enough time was allowed, and if the insects were concentrated into one small area (Table 4, page 115). The first three laboratory experiments indicated a difference between moisture-initiated hot spots, insect-initiated hot spots and moisture-insect-initiated hot spots.

Moisture-Initiated Hot Spots

The first rapid rise in temperature in all moisture-initiated hot spots was shown to be similar to the pattern observed in Laboratory Experiment Two, where no insects were involved (Figure 12, page 39). The temperature declined rapidly in Experiment Two after the initial rise and gave no indication of further heating. The heating area of the grain mass was found, upon dismantling the experiment after seven weeks, to involve only a small amount of wheat that was in contact with the moistened sponge. This central mass was bound together by a growth of fungi and also gave evidence of sprouting grain (Figure 10, page 34).

The variation of Experiment Two (page 40) provided further evidence that a moisture-initiated hot spot does not expand or continue heating, even with additional moisture. The appearance of the central mass after two months of additional moisture was quite similar to that of the first part of Experiment Two in which water was added for only ten days. It was noticed that moisture was absorbed by the central mass very slowly after the first week, which would indicate that the fungus growth formed a "wall" around the mass preventing the spread of moisture to surrounding grain. No insects were present to break through this "wall" and, even though moisture continued to be added, it was retained within the central core.

The time interval between the addition of moisture and the first rise in temperature was the time required for the growth of fungi and the germination of the wheat. These two factors appeared to be responsible for the heating in experiments where no insects were involved.

The growth of fungi in stored grain was studied by C. M. Christensen (1957) and others. Samples of wheat from the hot spots in both the laboratory and field experiments of this study were sent to Dr. Christensen at the University of Minnesota for determination of the fungi involved. He found *Aspergillus flavus* and *A. candidus* to be equally abundant in samples from an active hot spot in the field experiments. Samples from the laboratory hot spots also showed *A. flavus* and *A. candidus* to be the most abundant with a smaller amount of *A. ochraceus* present and numerous colonies of *Penicillium*. It appeared that *Aspergillus flavus* and *A. candidus* were the most active agents in producing heat at the beginning of moisture-initiated hot spots.

The results from the field experiments showed an interesting correlation with the laboratory experiments. The initial rapid rise of temperature in Field Experiment One (Figure 22, page 70) was very similar to that of Laboratory Experiment Two (Figure 12, page 39). No insects were involved and the temperature rose rapidly in both cases within a small area where moisture was added. The most obvious differences were a longer period of time between the addition of moisture and the beginning of heating, and a higher temperature rise in the field experiments.

The period of time between the addition of moisture and the first rise in temperature varied according to the temperature of the environment. A period of five - ten days was sufficient to initiate heating in the laboratory where a room temperature of 70 degrees F was maintained rather constantly, but as much as 30 days was necessary to initiate heating in Field Experiment One where the environmental temperature fluctuated between approximately 30 and 50 degrees F. The greater mass of grain in the field experiments acted as an insulating cover to prevent loss of heat, which resulted in a much greater rise in temperature during the heating period.

Probe samples taken during Field Experiment One, in which no insects were present, indicated that the actively heating area was restricted to grain within three inches of the point where moisture was added. There was no evidence of any subsequent spreading of heating during this experiment.

Heating in Laboratory Experiment Two, where no insects were involved, occurred after the total amount of moisture had been added and the relative humidity indicator in the area of heating registered 100 percent, as compared to about 40 - 60 percent in the surrounding grain. This would indicate a higher moisture content of the grain in the area of heating than in the surrounding grain mass. The period of heating in Experiment Two was relatively short-lived when moisture was added for only ten days, as compared to experiments under similar conditions where insects were involved.

The initial rapid rise in temperature was similar in every experiment of this study in which moisture was added to initiate heating. The fact that the same pattern of heating developed in experiments with no insects involved supported the idea that the initial heat production in all experiments where moisture was added was due to the growth of fungi. This type of non-insect related hot spot will be referred to hereafter as a fungus hot spot.

The three experiments in which an excess of moisture was added in an attempt to produce a larger hot spot (Experiments Eleven and Thirteen) showed a typical fungus hot spot initially. Additional moisture was forced into the area surrounding the initial hot spot, and produced subsequent heating there. A large conical area of fungus-covered grain resulted, with heating restricted to the area of fungus growth. When no insects were present to promote the spread of the fungus hot spot, the heating declined when the addition of moisture was stopped.

Insect-Initiated Hot Spots

Experiment Three illustrated the fact that insects can produce a typical hot spot without the aid of additional moisture if they are concentrated in a small area (Figure 13, page 43). The concentrating factor in this experiment was a higher temperature in one area, which made the area more suitable for the establishment of brood. The optimum conditions for reproduction of the granary weevil (the insect used in Experiment Three) have been shown to be about 90 degrees F in grain with a moisture content above 12 percent

(O'Brien 1959). The area of concentration of granary weevils in the experiment was that portion of the grain mass which was artificially heated to a temperature of 80 - 90 degrees F. A hot spot developed in that area which was similar in nature to those initiated with moisture. It was noted that the upper range of heating due to addition of moisture in similarly constructed experiments also was 80 - 90 degrees F. The metabolism of the large number of insects involved in a relatively small area no doubt increased the moisture content in that area as was indicated by higher relative humidity readings. Condensation of moisture due to the temperature differential established between the heating grain and the cooler room temperature also increased humidity in the heating grain.

The fact that the insects in Experiment Three were attracted to an area of higher temperature would indicate that this is at least one of the factors of a moisture-initiated hot spot that induces insect concentration in developing hot spots.

Moisture-Insect-Initiated Hot Spots

In those experiments involving moisture and insects, a second period of heating occurred after the fungus hot spot had subsided. The hot spot of Experiment One, for example, appeared similar during the first two weeks to that of Experiment Two, where no insects were involved (Figures 11 and 12, pages 37, 39). It was during the third week that the major difference began to be noticed. The temperature of the non-insect related hot spot of Experiment Two began a steady decline, but the insect related hot spot of Experiment One continued to higher temperatures after a very brief decline. It appears that the fungus hot spot is not able to maintain itself after the initial rise in temperature, whereas the insect-related hot spot, while initiated by fungus activity, is maintained by insect activity.

The graph of Experiment One (Figure 11, page 37) shows a restricted area of heating near the center of the grain mass which gradually widened throughout the experiment until almost the entire mass was involved. This phenomenon also was shown by the appearance of the hot spot against the glass sides of the laboratory boxes. The activities of the granary weevils as observed through the glass were concentrated in an area surrounding the darkened mass of grain which comprised the oldest and hottest portion of the hot spot. This fringe area of insect activity spread outward as the hot spot enlarged. The fringe portion of the hot spot represented the area that was most suitable for establishment of brood, and it was the continual outward movement of this activity that was recognized as a major factor in the spread of hot spots by insects. Figure 7 (page 31) shows a hot spot at a relatively early stage of development where the heating and insect activity was restricted to the center of the mass. Figure 8 (page 32) shows a more mature laboratory hot spot which involved almost all of the grain mass. It was interesting to note the triagonal shape of the larger hot spot, a condition which indicated a spread upward and outward, leaving the lower corners of the box unaffected. The layer of approximately one-half inch of grain on the surface that appears unaffected probably was due to the rapid loss of moisture from that portion of the grain mass.

The laboratory boxes revealed a greater concentration of moisture in the grain next to the glass sides than elsewhere when they were dismantled after the experiments were completed. The grain next to the glass was completely saturated in well-developed hot spots such as that of Experiment One, producing a sticky mass. The grain throughout the rest of these boxes was compacted but crumbly, and registered relative humidity readings between 75 and 95 percent.

A study of the graph in Figure 11 (page 37) indicates an apparent cycling of temperature peaks on a three week period with the highest points at six and 12 weeks. According to Cotton (1963) the granary weevil may complete its life cycle in summer weather in 26 days. It seems that under the ideal conditions of temperature and moisture such as were provided in the laboratory experiments, enough weevils were completing their life cycles in three weeks to give a cyclical appearance to the heating as shown in Figure 11 (page 37).

Experiments Four to Ten were conducted in an effort to compare three other grain insects with the granary weevil as to their ability to influence the development of hot spots. Experiment Four, involving the red flour beetle, indicated some heating during the first four weeks (Figure 14, page 46) which corresponded somewhat to the pattern of heating in Experiment One for the same period of time. The rest of Experiment Four, however, showed a rapid decline in temperature with no further evidence of heating. This would suggest that the red flour beetle does not have the same ability as that of the granary weevil to produce heating in stored grain.

Probe samples taken during Experiment Four showed an active and increasing population of red flour beetles scattered throughout the grain mass. There was no indication of concentration of insects in any one area. When the experiment was dismantled at the end of six months, a ball of previously moistened grain was found surrounding the sponge in the center, a situation similar to that found in Experiment Two where no insects were involved. This further indicates that the red flour beetle does not have the same ability as the granary weevil to promote heating in stored grain.

Experiment Five involved the saw-toothed grain beetle under conditions similar to those for Experiments One and Four. The pattern of heating is shown in Figure 15 (page 48) and resembles that of Experiment Four with the red flour beetle, the main difference being a broader peak at the center of the box where moisture was added.

This experiment was carried on for six months with no further indication of heating. Probe samples indicated a thriving population of saw-toothed grain beetles with no evidence of concentration in any area. Experiment Five illustrates that the saw-toothed grain beetle is similar to the red flour beetle in that it does not have the ability of the granary weevil to promote the development of a hot spot in wheat.

The saw-toothed grain beetle and red flour beetle are secondary invaders, utilizing the chaff and broken kernels rather than entering whole kernels like the granary weevil and other primary invaders. The larvae of these secondary invaders are free to move about through the grain mass and are not restricted to the area in which the adults lay the eggs. The highest temperature reached in Experiment Four was 91 degrees F and that for only a short period of time. The temperature in Experiment Five never exceeded 87 degrees F. It appears that the larvae are not attracted to the area of heating in sufficient numbers to promote heating after the decline of the fungus hot spot.

Experiment Six was conducted to compare the ability of the lesser grain borer, a primary invader, with that of the granary weevil to promote a hot spot. The graph in Figure 16 (page 51) indicates a failure of the lesser grain borer to maintain heating in the area of the fungus hot spot. The initial rise in temperature corresponds with that of Experiment Two where no insects were involved. The fact that the temperature did not decline to the base (room temperature) after the initial heating at the center of the grain mass indicates some activity in that area by the lesser grain borer, but not as much as was shown by the granary weevil in Experiment One.

The production of heat in Experiment Six was at a minimum during an eight week period between the seventh and the 15th weeks. It was thought that the lesser grain borer had ceased activity during this time, but there was a sudden resumption of heating beginning with the 15th week which produced a very high peak of temperatures. The highest temperature recorded in the laboratory experiments for the granary weevil hot spots was 14 degrees above ambient room temperature, while the high point in the lesser grain borer hot spot was 15 degrees above ambient room temperature.

The data from Experiment Six would indicate that the lesser grain borer has an ability to promote the development of a hot spot in wheat equal to that of the granary weevil, but requires a longer period of time to build up large populations. The appearance of the lesser grain borer hot spot as it developed against the glass sides of the laboratory box was similar to that of the granary weevil hot spot (Figures 7 and 8, pages 31 and 32). It showed evidence of the accumulation of fine powdered grain that is typical of the workings of the lesser grain borer. Probe samples gave evidence of lesser grain borer activity being more concentrated in the area of heating than elsewhere in the box. At the termination of the experiment the upper two-thirds of the box of wheat was heating, and the entire mass was infested by the lesser grain borer.

Results of the combined activities of the granary weevil and the saw-toothed grain beetle are shown in Figure 17 (page 53). This experiment shows the same initial rapid rise in temperature as that in Experiment Two, which would indicate fungus growth due to the addition of moisture. The temperature declined to a lower level after the initial heating and remained low for a period of four weeks. This was followed by a secondary temperature rise in the tenth week and subsequent fluctuations of considerable magnitude.

The results of Experiment Seven differed in several respects from those of Experiments One and Five in which the granary weevil and the saw-toothed grain beetle were separated. For example, there was a greater cessation of activity after the initial heating in Experiment Seven than was noted in Experiment One. The peaks of heating were never as high above ambient room temperature as those of Experiment One, nor do the peaks of heating in Experiment Seven correspond in time with the peaks of heating in Experiment One. It could be inferred that the period of life cycles was altered due to interference by the saw-toothed grain beetle. This is rather unlikely, however, due to the fact that the two insects do not occupy the same niche in the wheat substrate. The saw-toothed grain beetle is a secondary invader which utilizes the broken kernels and grain dust. The granary weevil, on the other hand, is a primary invader and lays its eggs within the whole kernels. In a series of competition studies, O'Brien (1959) observed that the granary weevil could reproduce as well in the presence of saw-toothed grain beetles as by itself under conditions of high temperatures and moderately high humidity. He also noted, however, that at lower temperature and moisture levels the activity of saw-toothed grain beetles appeared to interfere with the reproduction of granary weevils. This could account for the failure of the granary weevils in Experiment Seven to initiate heating during a period of four weeks when temperature levels were low. It does not explain the sudden rapid increase in temperature at the end of that time, or the subsequent fluctuations.

The slight rise in temperature at the ends of the box (nine inches from the center) indicates heat due to radiation from the central hot spot during the early parts of Experiment Seven. The greater rise in temperature later in the experiment at these same points more likely represents insect activity. This is borne out particularly in Experiment Seven where there occurred three major peaks of heating, seven and ten weeks apart, all of similar magnitude. The thermocouple placed nine inches from the center registered a rise of only two degrees during the first two peaks, but during the third peak it registered a rise of nine degrees (only one degree less than at the center). Probe samples indicated widespread insect activity during the third peak.

Experiment Eight combined all four test insects in relationship to a moisture-initiated hot spot. The initial rapid rise in temperature (Figure 18, page 55) again was similar to that in Experiment Two with no insects involved. The decline in temperature following initial heating was greater in Experiment Eight than any other involving either the granary weevil or the lesser grain borer. This substantial decline may reflect a mutual interference that delayed the development of at least the granary weevil.

The conspicuous absence of temperature fluctuations in Experiment Eight is noteworthy. There was a steady increase in temperature after the low point following the initial fungus heating, which resulted in a peak higher than any observed in previous experiments. This was followed by a rapid decline to moderate temperatures which persisted throughout the remainder of the experiment. The extreme high temperature probably was a reflection of the larger number of insects involved due to a greater initial density. A total of 4000 insects was introduced into the same volume of wheat used for previous experiments involving 1500 insects. The high peak in temperature resulting in a typical hot spot would seem, in the light of previous experiments, to be due to the activities of the primary invaders, the granary weevil and the lesser grain borer. The appearance of the hot spot next to the glass sides of the box was similar to those of previous experiments involving the granary weevil. Probe samples taken near the end of the experiment indicated a mixed population of all four insects throughout the box.

Experiment Nine was, in a sense, a replication of Experiments Four and Five. It differed in having the saw-toothed grain beetle and the red flour beetle together in one box, and in that moisture was added over a longer period of time. Even with these differences the results were comparable to those of Experiments Four and Five. This indicates that the saw-toothed grain beetle and red flour beetle do not have the ability of the granary weevil to promote heating in stored wheat.

Field Experiment Two was initiated by adding 4000 granary weevils from laboratory cultures to the area immediately above the fungus hot spot of Field Experiment One. The insects were added during the eighth week after the initiation of the field experiments, and at a time when the grain temperature was dropping rapidly from the previous high peak. The temperatures continued to drop during a period of about three and one-half weeks after the granary weevils were added and then began to rise again (Figure 22, page 70). No moisture was added during this time. Five weeks after the insects were added, the temperature in the area of previous heating reached a peak of 33 degrees above the surrounding grain temperature (Table 15, pages 123 to 127). This apparently was due solely to activity of the granary weevils, because no more moisture was added.

The total pattern of Field Experiments One and Two resembles that of the laboratory experiments; i. e. a rapid initial rise in temperature which tapers off quickly if no insects are involved, a prompt resumption of heating if the granary weevil is present, a slightly fluctuating high level of temperatures at the center of the hot spot that may be correlated with the life cycle of the insect, and a gradual spreading of the heating area as the insects invade a larger area of wheat (Figure 22, page 70).

The high temperatures in Field Experiment Three were due, at least in part, to the presence of a large amount of fungal material which began to grow immediately as soon as moisture was added and also to the movement of remaining scattered insects into the moistened area.

An extensive population of saw-toothed grain beetles was observed in the grain mass during the course of Field Experiment Three. Probe samples indicated these insects, which most likely were the result of an invasion by natural populations in the area, were scattered widely throughout the grain mass with areas of greatest concentration outside the damp, heating area. At no time was there any indication of a center of heating developed by the saw-toothed grain beetle population. This observation corresponded closely with results of laboratory experiments involving the saw-tooth grain beetle. It is probable that these secondary invaders contributed to the overall rise in temperature of the entire grain mass, but, even with a thriving population, they did not alter the steady gradual decline of the temperatures in Field Experiment Three to the ambient environmental temperature. Probe samples near the end of the experiment showed an increasing population of saw-toothed grain beetles in the area of previous granary weevil activity. The granary weevils were at an extremely low level of activity at the point of termination.

The rusty grain beetle, Cryptolestes ferrugineus was found in areas of previous heating in the field experiments, particularly in charred, moldy grain. There was no indication of heating due to these secondary invaders.

The extremes of temperature in the hot spot developed in Field Experiment Three were, no doubt, detrimental to the reproduction of the granary weevil. This would account for the fact that the heating period was short, and that the temperature continued to decline through a period of nine weeks until there was no more evidence of heating. The surrounding grain still was too dry to be favorable for rapid insect reproduction, and the grain within the hot spot was charred and dried by the extreme temperatures (Figure 9, page 33).

The extreme temperature gradients in Field Experiment Four resulted in condensation of moisture in a broad area surrounding the central heating core, and in areas of temperature favorable to the development of the granary weevil. These conditions resulted in a gradual spread of this insect-related hot spot to involve a larger area of the grain mass, after which the temperatures declined as in previous field experiments.

The presence of mites in both laboratory and field experiments had no apparent effect on the hot spots involved. Experiment Twelve was an unsuccessful attempt to establish a mite-promoted hot spot in that as soon as the addition of moisture was stopped and the fungus hot spot cooled and dried, the mite population died out. Experiment Fourteen contained a large mite population along with the granary weevils, but the resulting hot spot was the same as that of the granary weevil alone, indicating again that the mites had no apparent effect on hot spot development.

Experiment Fourteen, a replicate of Experiment One, reinforced the data from other experiments involving the granary weevil (Table 12, page 121). The hot spot produced in Experiment Fourteen was the same as Experiment One (Figure 11, page 37). The granary weevil appeared to have a pronounced effect on hot spots either by itself or in conjunction with other insects.

The data from Experiment Fifteen showed an interesting correlation with Experiments One and Six, in which the two primary invaders were used separately in experiments with moisture-initiated fungus hot spots. The granary weevil promoted heating and the spread of the hot spot almost immediately after the fungus hot spot temperatures began to decline in Experiment One. The lesser grain borer required a period of about 16 weeks to initiate a further rise in temperature in Experiment Six. The granary weevil and the lesser grain borer together initiated further heating in Experiment Fifteen and promoted the spread of a hot spot in about nine weeks. These three experiments illustrated a degree of competition between the granary weevil and the lesser grain borer which prevented the granary weevil from initiating a rapid growth of population sufficient to raise the temperature to the degree achieved when it was reared alone.

Probe samples during Experiment Fifteen showed a thriving population of both the granary weevil and the lesser grain borer in the area of heating, but very few elsewhere within the grain mass. This was in contrast to the widespread activity of the secondary invaders in Experiments Four, Five and Nine, where no hot spot was produced by insect activity.

The fact that no hot spot was produced in Experiment Sixteen where the granary weevils were not concentrated by either heat or moisture does not indicate that granary weevils are unable to thrive in a grain mass that does not show heating, but rather shows that they can maintain a population at lower density levels. The larger size of the grain mass and the greater circulation of the air in the laboratory boxes prevented an accumulation of heat and moisture from insect metabolism sufficient to start the growth of fungi, a pattern often seen in culture jars. This dissipation of heat and moisture from the laboratory box would be more rapid than in a large grain mass where the insulating action of the grain would tend to concentrate both heat and metabolic moisture, resulting in a concentration of the insects. An insect-induced hot spot could develop in large grain masses in this way without the addition of moisture from the outside. The temperature gradients could be sufficient to produce condensation of moisture in quantities great enough to start the growth of fungi, and also to attract insects scattered throughout the grain. This type of heating in large bulk grain storage has been described by Howe (1962) and by Wallace and Sinha (1962).

The addition of small amounts of moisture from the outside, as was done in many of the described experiments, hastened the development of a hot spot in the field tests and provided a start in the laboratory experiments where, because of air circulation and heat dissipation, hot spot formation would either have been impossible or extremely slow.

Experiment Seventeen was a replication of Experiment Five with the saw-toothed grain beetle and gave similar results. This provided additional evidence that secondary invaders do not have the ability to initiate and promote the spread of hot spots, an ability possessed by the granary weevil.

VI. SUMMARY AND CONCLUSIONS

The series of experiments performed in this study produced data concerning the relationships of four insects to heating in stored grain. The experiments were carried out on a small scale in the laboratory and then on a larger scale in field storage. A method was devised for observing the changes in temperature and moisture within the grain mass where heating was induced by the addition of moisture and insects.

Heating due to excess moisture was demonstrated without insects both in the small laboratory grain boxes and in the larger mass of grain in the field experiments. The rapid increase in temperature that resulted when moisture was added was attributed to the growth of microorganisms and to the metabolism of sprouting grain. Fungi of the genera Penicillium and Aspergillus were determined from samples taken from hot spots in these experiments. The size of the hot spot was greatly restricted when no insects were involved, and no indication of spreading was noted unless moisture was forced into adjacent non-heating areas.

The experiments in which heating was induced by the addition of moisture (with or without insects) showed a similar, initial rapid rise in temperature. This was a reflection of a developing fungus hot spot in which high temperatures were brought about by the metabolic activity of microorganisms and sprouting grain. The granary weevil, when present, concentrated its activity in the immediate vicinity of the fungus hot spot and, after a period of time sufficient for the establishment of a brood (which varied according to the temperatures), it produced subsequent elevations in temperatures in the area of the fungus hot spot. As the temperature within the hot spot exceeded the optimum for the granary weevils they moved gradually outward, establishing a series of broods as they moved and causing the hot spot to spread. Hot spots of this type usually reached higher peaks of temperature than that attained in the fungus hot spots, and followed a typical pattern of spreading upward and outward through the grain mass.

Experiments with the lesser grain borer, a primary invader like the granary weevil, illustrated their ability to promote the spread of moisture-induced hot spots, but at a much slower rate. An experiment involving only the lesser grain borer in conjunction with a moisture-induced hot spot appeared at first to be similar to a fungus hot spot with no insects involved, but, after an extended period of time, a typical insect-related hot spot developed which was similar in form to that initiated by the granary weevil.

The red flour beetle and the saw-toothed grain beetle both failed to induce or promote the spread of a hot spot. They had no apparent effects on fungus hot spots, even when present during hot spot formation. Experiments were extended over a period of nine months after initiation of a fungus hot spot, but there was no further indication of heating. The two insects were tested separately and in combination, with similar results each time.

The granary weevil, in combination with the saw-toothed grain beetle, produced subsequent heating and spreading of the heating area similar to that produced by the granary weevil alone. One difference between the former and latter experiments was a greater fluctuation in temperature after the initial fungus hot spot in the case of the granary weevil and saw-toothed grain beetle combination, which gave evidence of a cyclical nature in the heat produced over a period of 26 weeks. This hot spot eventually spread upward and outward in a pattern similar to that caused by the granary weevil alone.

All four insects in combination produced subsequent heating following a fungus hot spot similar to the pattern brought about by the granary weevil alone. The combination experiment differed in that a longer period of time was required to resume heating after the decline of the fungus hot spot. When heating was resumed, however, it reached a higher peak than seen in the granary weevil tests, and spread throughout the box more rapidly.

The granary weevil was introduced into the grain mass of the field experiments in the vicinity of the declining fungus hot spot. A period of five weeks was necessary for the establishment of brood in the restricted area of fungus heating. The temperature reached a second peak due to insect activity at the end of that time and produced a typical insect-related hot spot. This hot spot did not spread and the insect population declined at the end of 12 weeks due to the extreme dryness of the grain caused by circulating air.

The granary weevil also demonstrated the capacity to initiate a hot spot in the laboratory without a fungus hot spot as a triggering mechanism. This was done by concentrating the weevils in one area by means of artificial heat. The hot spot produced in this way was similar in all respects to those initiated by moisture and promoted by the granary weevil.

The failure of the red flour beetle and the saw-toothed grain beetle to promote the spread of fungus hot spots is due, in part, to the nature of their feeding. As secondary invaders, they feed primarily on grain dust and chaff. The larvae wander freely throughout the grain mass and are not concentrated in any one place. An observation on the reaction of the red flour beetle to varying percentages of humidity indicated that it prefers areas of relatively low humidity over those of higher humidity. When placed on a screen directly above containers of salt solutions producing relative humidities of 75 percent, 86 percent, and 99 percent they congregated over the container producing 75 percent relative humidity, especially when placed in the dark. Food material was placed over the container producing 99 percent relative humidty. The red flour beetles were observed to feed briefly and then return to the area of lower humidity and after a period of 24 hours the food material had been moved to the area of lower humidity where all of the insects were feeding continuously. This would explain the lack of concentration of these insects in the vicinity of a fungus hot spot.

The data from the field experiments supported the observations made in the laboratory tests. A fungus hot spot developed in the field experiment where moisture was added with no insects involved, that was similar in nature to the fungus hot spots in the laboratory experiments, showed no indication of spreading beyond the area actually moistened. The addition of granary weevils resulted in subsequent elevations in temperature and a gradual spread of the heating area. A much greater rise in temperature over a longer period of time in the field experiments was due to the greater insulating action of the larger mass of grain. The granary weevil was the only one of the insects used in the field experiments which gave evidence of promoting the spread of the hot spot.

Three types of hot spots were demonstrated in these experiments. Moisture-initiated hot spots were shown to be due to the growth of fungi such as *Aspergillus* and *Penicillium* and metabolism of sprouting grain when no insects were involved. Insect-initiated hot spots were initiated by the concentrations of insects in one area until they were sufficiently established to produce a typical hot spot. Moisture-insect-initiated hot spots were produced by the addition of moisture to produce a fungus hot spot which was subsequently promoted and expanded by granary weevils. Hot spots involving the granary weevil were the only ones that expanded beyond the original area of heating.

The first rapid rise in temperature of all moisture-initiated, as well as moisture-insect-initiated hot spots, was attributed to the growth of microorganisms. This was evidenced by the fact that the initial rapid rise in temperature in moisture-insect-initiated hot spots occurred before the insects had time to establish brood, and was very similar in pattern to that of the moisture-initiated hot spot with no insects involved.

A fungus hot spot in the presence of a thriving population of grain mites (*Acarus siro* and *Tyrophagus putrescentiae*) showed no signs of continuing or spreading after the first rapid rise in temperature. The mite population declined as the fungus hot spot dried out and cooled off, and did not maintain itself. Expanding granary weevil hot spots in some experiments were infested with a large population of *Tyrophagus putrescentiae*, but did not show any apparent differences from other granary weevil hot spots that were not infested with mites. It was concluded, therefore, that these mites were incapable of promoting the spread of a hot spot under the conditions of the experiments, and did not interfere with the activities of the granary weevil in promoting the spread of a hot spot.

The granary weevil demonstrated the greatest capacity of the four insects used in this study to initiate and promote the spread of hot spots in stored wheat, with that of the lesser grain borer being considerably less. The saw-toothed grain beetle and the red flour beetle were ineffectual both in hot spot initiation and spread.

The decline of the moisture-insect-initiated hot spots in the field experiments after a defined period of heating was considered to be due to the low moisture content of the surrounding mass of grain. Circulation of air through the perforated bottom of the Butler bin resulted in a rapid loss of moisture to the extent that the granary weevils were unable to expand beyond a limited area into which moisture from the fungus hot spot had moved.

A further study in a much larger mass of grain might provide some answers to the question of how far a granary weevil hot spot can expand.

The relationship of the parasite Cephalonomia tarsalis to the insect populations in the field experiments was not determined in this study. This parasite and others present would provide an interesting topic for further investigations.

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APPENDIX

TABLE 1. Temperature data from Laboratory Experiment One. Temperatures in degrees F.

Thermocouple	April											May															
Date	17	18	19	23	24	25	26	27	28	29	30	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
#1	65	71	73	73	73	73	74	74	72	75	75	74	73	73	73	74	74	75	74	75	74	75	76	76	77	75	76
#2	61	71	73	74	74	74	75	75	74	76	78	75	74	75	75	75	75	76	76	78	77	78	79	79	80	78	78
#3	61	71	74	75	75	75	77	78	77	79	81	79	78	79	79	79	81	81	82	84	83	84	84	85	85	84	83
#4	62	71	74	75	76	77	80	83	81	84	86	83	82	82	82	83	84	84	85	87	85	85	86	87	87	86	85
#5	62	71	74	74	75	75	76	78	76	78	80	78	77	78	78	79	80	81	81	83	82	83	83	84	85	83	83
#6	62	71	73	74	74	74	75	76	74	76	78	76	75	75	75	76	76	76	76	78	77	78	78	79	80	79	79
#7	64	71	73	73	73	73	74	74	73	75	76	74	73	74	74	74	74	74	74	76	75	75	75	76	77	75	76
#8	64	70	73	73	74	74	75	75	74	76	78	76	74	75	75	75	76	75	75	77	75	76	77	78	78	77	77
#9	62	70	73	74	75	76	77	80	79	81	82	80	79	79	79	79	80	80	81	82	81	81	82	82	83	82	81
#10	64	71	73	74	74	74	75	76	75	77	79	77	76	76	76	77	78	78	79	80	80	81	81	82	82	81	81
#11	66	71	73	73	73	74	74	75	74	75	77	77	74	74	74	75	75	75	75	77	76	77	77	78	79	77	77
#12	70	72	73	73	73	73	73	73	72	74	75	73	73	73	73	73	73	73	73	74	73	74	74	75	75	74	74

May												June															
19	20	21	22	23	24	25	27	28	29	30	31	2	3	5	6	7	9	10	11	12	13	14	16	17	18	19	20
80	84	87	80	77	77	78	78	79	79	80	78	76	76	75	76	76	75	77	79	80	81	82	86	86	86	82	80
83	87	89	83	78	80	80	80	82	83	83	82	79	79	78	79	79	78	80	82	83	84	85	89	89	89	85	84
88	92	94	89	85	86	86	87	89	89	90	88	85	84	83	84	84	82	84	86	88	89	90	93	93	93	90	87
91	94	96	90	87	88	88	89	91	91	91	90	86	86	85	85	85	83	85	87	88	89	90	93	94	93	90	87
88	91	94	88	84	85	85	86	88	88	89	87	84	84	82	83	83	81	83	86	87	88	89	92	92	92	89	87
84	87	90	84	80	80	80	81	82	83	84	82	79	79	79	79	79	78	80	82	84	84	85	89	90	90	86	84
81	85	87	80	77	77	78	78	79	79	80	78	76	76	75	76	76	75	77	79	80	81	82	86	86	86	82	81
82	86	88	82	79	79	79	80	81	82	83	81	79	79	78	78	78	78	79	81	83	84	85	88	89	89	85	83
87	90	93	87	84	84	85	86	88	89	89	87	84	84	83	83	83	82	84	86	87	88	89	92	93	93	90	87
86	90	92	86	82	83	84	83	85	85	86	84	82	81	80	81	81	80	81	84	85	86	87	90	91	91	87	85
82	86	88	82	78	79	80	79	80	81	81	80	78	77	77	77	77	77	78	80	82	82	83	87	87	87	83	81
79	83	85	78	75	75	76	75	77	77	77	76	74	74	74	74	75	74	75	77	79	79	80	84	84	84	80	78

June								July																			
21	22	24	25	26	27	28	30	1	2	3	4	5	8	9	10	11	12	14	15	16	17	18	19	22	23	24	25
78	74	73	74	77	81	80	80	81	82	85	85	83	82	82	81	82	85	89	88	86	84	83	87	83	83	81	82
81	76	76	77	80	84	83	84	85	86	88	89	88	86	86	86	87	89	91	91	89	87	86	89	85	85	84	84
85	80	80	81	84	88	88	88	89	91	92	93	91	89	89	89	90	91	93	92	90	88	87	90	86	87	85	86
85	80	80	81	84	89	88	88	90	91	92	93	91	89	89	89	89	91	93	92	90	88	87	90	86	87	85	86
85	80	79	81	84	88	88	88	90	91	92	93	91	89	89	89	90	91	93	92	90	88	87	90	86	87	86	86
82	77	77	78	81	85	84	85	86	88	90	91	89	88	88	87	88	90	92	92	90	88	87	90	86	86	85	85
79	74	73	75	77	81	80	80	81	83	85	86	84	82	83	82	83	86	89	89	87	85	84	87	83	84	82	83
81	76	76	77	79	83	82	82	84	85	87	88	86	84	84	83	84	85	89	89	87	85	84	87	83	83	82	82
85	80	80	81	84	88	87	88	89	90	92	93	91	89	88	88	88	90	92	91	89	87	86	89	85	86	85	85
83	78	77	79	82	87	86	86	88	89	91	92	89	87	87	87	88	90	92	92	89	87	87	90	86	86	85	86
79	75	75	76	79	83	82	82	83	85	87	88	85	83	84	83	84	86	90	90	87	85	85	88	84	85	83	84
76	72	72	73	75	78	77	77	77	79	80	81	79	76	76	76	76	78	83	83	81	79	78	81	77	77	75	76

TABLE 1. (Continued)

	July				August																						Sept.
Date	26	29	30	31	1	2	5	6	7	8	9	12	13	15	16	18	19	20	21	22	23	26	27	28	29	30	3
#1	85	85	86	85	85	86	86	88	85	90	90	86	81	83	86	84	84	82	80	80	79	78	82	83	84	79	81
#2	87	88	88	88	87	88	87	90	88	92	93	89	83	85	87	86	86	84	82	82	81	80	84	86	87	82	83
#3	88	89	89	89	88	89	88	91	89	93	93	90	84	86	89	87	87	86	84	83	82	81	85	87	88	83	85
Thermocouple #4	88	89	89	89	88	89	88	91	89	93	93	90	84	86	89	87	87	86	84	83	82	81	85	87	88	83	85
#5	88	89	89	89	88	89	88	91	89	92	93	90	84	86	88	87	87	86	84	83	82	81	85	87	87	82	85
#6	88	89	88	88	87	89	88	90	88	92	93	89	83	85	88	86	86	85	82	82	81	80	84	86	87	82	84
#7	85	86	86	86	85	86	85	88	85	90	90	86	81	83	86	84	84	82	80	80	79	78	82	84	85	80	82
#8	84	85	85	85	85	86	85	87	85	89	90	87	81	83	85	83	84	82	80	80	79	77	81	84	84	80	80
#9	87	88	88	87	87	88	87	89	88	91	93	90	84	85	88	86	86	85	83	83	82	80	84	86	87	82	83
#10	88	89	89	88	88	89	88	90	88	93	93	89	83	86	88	87	86	85	83	83	82	81	85	87	88	83	86
#11	86	87	87	87	86	87	87	88	85	91	90	86	81	84	87	86	85	83	81	81	80	79	83	85	86	81	85
#12	79	80	80	80	79	80	80	82	78	85	85	80	76	78	81	79	79	77	75	75	74	73	77	79	79	74	75

September																			October								
4	5	6	8	9	10	11	12	13	16	17	18	19	20	23	24	25	27	30	1	2	3	4	7	8	11	14	15
85	86	86	87	88	85	86	84	84	81	79	81	83	84	80	81	83	85	81	81	81	78	79	76	79	82	80	80
87	88	88	89	90	89	88	86	86	82	81	83	85	86	82	82	84	87	83	83	83	79	80	78	80	83	81	81
88	89	89	90	91	90	89	87	87	83	82	83	85	86	83	83	84	88	83	84	84	80	81	79	81	83	82	82
88	89	89	90	91	90	89	87	87	83	82	83	85	86	83	83	84	88	83	84	84	80	81	79	81	84	82	82
88	89	89	90	91	90	89	87	87	83	82	83	85	86	83	83	84	88	83	84	84	80	81	79	81	83	82	82
87	88	88	89	90	89	88	86	86	82	81	83	85	86	82	82	84	87	83	83	83	79	80	78	80	83	81	81
85	86	86	88	89	87	86	84	84	81	79	82	83	84	81	81	83	85	81	81	81	77	79	76	79	81	80	80
83	84	85	85	86	85	84	82	82	78	77	78	80	81	78	78	80	82	79	79	79	75	76	74	76	79	77	77
86	87	88	88	89	88	87	85	85	81	80	81	83	84	81	81	82	85	81	82	82	78	79	77	79	81	80	80
89	90	90	91	92	91	90	88	88	84	83	85	82	88	85	85	87	89	85	85	85	81	82	80	83	85	84	84
87	89	89	91	91	90	89	87	88	84	83	85	82	87	85	85	87	89	85	85	85	81	82	79	82	85	84	84
79	80	80	82	88	80	80	79	79	74	72	75	77	77	74	74	76	78	75	75	75	71	74	71	74	76	74	74

October											November													December							
16	17	18	21	22	23	25	28	29	30	31	1	4	5	6	7	8	11	12	14	18	20	26	29	2	6	9	13	16	19	23	27
80	81	81	75	76	77	73	74	74	74	76	76	75	78	78	77	78	78	78	79	75	75	80	74	73	75	75	76	77	77	78	79
81	82	82	75	78	78	75	75	75	75	77	77	77	79	80	78	80	79	79	80	77	76	81	75	74	76	76	78	78	78	79	80
82	83	83	76	79	79	75	75	76	76	78	78	77	80	81	79	80	80	80	81	77	77	81	75	75	76	77	78	78	78	79	80
82	83	83	76	79	80	75	75	76	76	78	78	77	80	81	79	80	80	80	81	77	77	81	75	75	76	77	78	78	78	79	80
82	83	83	76	78	79	75	75	76	76	78	78	77	80	81	78	80	80	80	81	77	77	81	75	75	76	77	78	77	77	79	79
81	82	82	75	77	78	74	75	75	75	77	77	76	79	79	77	79	79	79	80	76	76	81	75	74	76	76	77	77	77	78	79
80	81	81	74	76	77	73	74	74	74	75	76	75	78	78	76	78	78	78	79	75	75	79	74	72	74	75	76	76	76	77	78
77	78	78	72	74	74	71	71	72	72	73	73	72	75	76	74	76	75	75	76	73	72	77	72	71	74	73	74	73	73	78	74
80	81	81	74	76	77	73	73	74	74	75	76	75	78	78	77	78	78	78	79	75	75	80	73	73	75	75	76	76	76	76	77
84	85	85	78	80	81	77	77	78	78	80	80	79	82	82	80	82	81	81	82	78	78	82	76	75	77	78	79	80	80	81	82
84	85	85	78	81	81	77	78	78	78	80	80	80	82	82	80	82	82	82	82	78	78	82	76	75	77	78	80	80	80	82	82
74	75	75	70	71	71	68	69	69	69	70	70	70	73	73	71	74	72	72	74	70	70	74	69	68	71	70	71	71	71	71	71

Table 2. Temperature data from Laboratory Experiment Two. Temperatures in degrees F.

	July																		
Date	2	4	5	8	9	10	11	12	14	15	16	17	18	19	22	23	24	25	26
Thermocouple #1	78	80	78	75	75	74	75	76	82	82	80	78	77	80	76	76	74	75	78
#2	78	80	78	76	76	75	75	77	83	83	81	79	77	80	77	77	75	75	78
#3	78	80	78	76	76	75	76	78	84	84	82	79	78	81	76	77	75	75	78
#4	77	80	78	76	76	75	76	79	87	87	84	81	79	82	76	76	75	75	77
#5	78	81	79	77	76	75	76	78	85	85	82	80	78	81	77	77	76	76	78
#6	79	81	79	77	77	76	76	78	84	84	82	80	78	81	78	78	76	76	79
#7	80	82	80	77	77	76	77	78	84	84	81	79	78	81	77	78	76	76	79
#8	78	80	78	76	76	75	75	77	83	83	81	79	77	80	76	77	75	75	78
#9	78	80	78	76	76	75	76	78	84	85	82	80	78	81	77	77	75	75	78
#10	78	80	78	76	76	75	75	78	84	84	81	79	78	81	77	77	75	75	78
#11	78	80	78	76	76	75	75	77	83	83	80	78	77	80	77	77	75	75	78
#12	78	80	77	75	75	74	74	76	81	81	79	77	76	80	75	75	74	74	77

July			August									
29	30	31	1	2	5	6	7	8	9	12	13	19
79	79	79	78	80	79	81	78	84	84	80	75	77
79	79	79	78	80	79	81	79	84	84	83	75	77
79	79	79	78	80	79	81	79	84	84	83	75	77
79	79	79	78	80	79	81	79	84	84	83	75	77
80	79	79	78	80	79	81	79	84	84	83	75	77
80	79	79	78	80	79	81	79	84	84	83	75	77
80	79	79	78	80	79	81	77	84	84	80	75	77
79	79	78	78	78	79	81	78	84	84	82	75	77
79	79	78	78	79	78	81	79	84	84	82	75	77
79	79	79	78	80	78	81	79	84	84	82	75	77
79	79	79	78	80	78	81	78	84	84	82	75	77
78	78	78	77	79	78	80	77	84	84	77	75	77

Table 3. Temperature data from Laboratory Experiment Two A. Temperatures in degrees F.

	September														October				
Date	10	11	12	13	16	17	18	19	20	23	24	25	27	30	1	2	3	4	7
Thermocouple #1	79	79	78	77	73	71	74	76	76	73	73	75	78	74	74	74	71	71	70
#2	80	80	79	78	75	74	75	77	78	75	74	77	79	76	76	76	72	72	71
#3	81	81	80	79	76	75	77	79	80	77	77	78	82	77	77	77	73	73	72
#4	82	82	81	82	79	78	80	83	84	80	80	82	86	80	80	80	75	75	73
#5	81	81	79	79	76	74	76	78	79	76	76	79	82	77	77	77	73	73	72
#6	80	80	78	78	74	73	75	77	78	74	74	76	79	75	75	75	72	72	71
#7	79	79	77	77	73	71	74	75	76	73	73	75	77	74	74	74	71	71	70
#8	79	79	78	77	73	72	74	76	77	75	73	75	78	74	75	75	71	71	70
#9	81	80	79	79	75	74	76	78	79	76	76	78	81	77	77	77	73	73	72
#10	80	80	79	79	74	74	76	78	79	76	76	78	81	77	77	77	73	73	72
#11	80	79	78	78	75	72	75	76	77	74	74	76	79	75	75	75	72	72	71
#12	79	78	77	76	73	70	73	74	75	72	72	74	76	73	73	73	70	70	69

October																November					
8	10	11	14	15	16	17	18	21	22	23	25	28	29	30	31	1	4	5	6	7	8
73	73	75	73	73	73	75	73	69	69	71	68	69	69	69	70	70	70	70	73	73	73
74	74	76	74	74	74	75	73	69	69	72	69	69	69	69	71	71	70	70	74	74	74
74	74	76	74	74	74	75	74	70	70	72	70	69	69	69	72	72	70	70	74	74	74
76	76	78	75	75	74	76	74	70	70	73	70	70	70	70	72	72	71	71	75	75	75
74	75	76	75	75	75	76	74	70	70	72	69	69	69	69	72	72	71	71	74	74	74
73	74	76	74	74	74	75	73	69	69	72	69	69	69	69	71	71	70	70	74	74	73
73	73	75	74	74	74	74	72	69	69	71	68	69	69	69	70	70	70	70	73	73	73
73	73	75	74	74	74	74	72	69	69	71	68	69	69	69	70	70	69	69	73	73	73
73	75	76	74	74	74	75	74	69	69	72	69	69	69	69	71	71	70	70	74	74	73
73	74	76	74	74	74	75	74	69	69	72	69	69	69	69	71	71	70	70	74	74	74
73	74	76	74	74	74	75	73	69	69	72	69	69	69	69	71	71	70	70	74	74	73
72	72	75	73	73	73	73	72	69	69	70	67	68	68	68	69	69	69	69	72	72	73

Table 4. Temperature data from Laboratory Experiment Three. Temperatures in degrees F.

	July																						August				
Date	3	4	5	8	9	10	11	12	14	15	16	17	18	19	22	23	24	25	26	29	30	31	1	2	5	6	7
#1	82	83	81	79	78	77	77	79	85	85	83	81	80	83	80	80	79	79	82	84	81	81	81	82	81	84	83
#2	84	85	83	81	80	78	79	80	86	86	84	82	82	84	81	81	81	81	84	87	83	83	82	84	83	86	84
#3	81	83	81	79	78	76	77	78	85	84	82	80	79	82	79	79	79	79	81	84	82	82	81	82	82	85	83
Thermocouple #4	84	85	82	80	80	78	79	81	86	85	83	80	81	84	80	80	80	80	82	83	79	78	77	79	78	80	77
#5	82	83	80	77	78	76	77	79	84	83	81	78	79	82	78	78	77	77	80	81	79	78	78	79	78	80	77
#6	83	84	81	78	79	76	78	80	85	85	82	80	81	83	79	79	79	80	82	83	79	79	78	80	79	81	78
#7	81	82	79	76	77	75	76	78	83	82	80	77	78	81	77	77	76	76	79	80	79	78	78	79	78	80	78
#8	89	89	86	84	85	81	82	84	91	90	87	85	87	89	85	85	85	85	88	89	79	79	78	79	79	80	78
#9	85	86	83	81	81	79	80	81	87	86	84	82	82	85	81	82	81	80	83	85	79	79	78	79	79	81	78
#10	86	86	84	82	82	79	80	82	88	87	85	82	85	86	82	82	83	84	87	88	80	79	79	80	79	81	78
#11	84	85	82	79	79	77	78	80	86	85	83	80	81	84	80	80	80	80	83	84	79	79	78	80	78	81	78
#12	93	91	88	89	89	84	85	87	93	92	90	86	94	92	88	88	91	92	94	96	79	79	79	80	79	81	78

August																	September										
8	9	12	13	15	16	18	19	20	21	22	23	26	27	28	29	30	3	4	5	6	8	9	10	11	12	13	16
87	88	86	79	81	83	81	81	80	77	77	77	75	78	81	82	77	78	81	82	84	85	86	85	84	83	82	78
88	90	87	80	82	85	82	83	81	79	79	78	76	80	82	83	78	79	83	84	85	87	88	86	86	84	84	80
88	89	87	80	82	84	82	82	80	78	78	77	75	79	82	83	77	78	82	83	84	85	87	85	85	83	82	79
83	83	78	75	77	80	78	77	75	74	74	73	72	75	76	77	72	74	76	78	79	80	81	80	78	78	77	73
83	83	78	75	78	80	79	78	76	75	75	74	72	76	76	77	73	74	77	78	80	81	82	80	79	78	77	74
84	84	80	76	78	81	79	78	77	75	75	74	72	76	77	77	73	74	77	78	80	81	83	80	80	79	78	75
84	83	78	76	78	81	79	78	76	75	75	74	72	76	76	77	72	74	77	78	80	81	82	80	79	78	77	74
84	83	80	76	78	81	79	78	76	75	75	74	72	76	76	77	73	74	77	78	80	81	82	80	79	78	78	74
84	83	80	76	78	81	79	78	76	75	75	74	72	76	77	78	73	74	77	78	80	81	83	81	80	79	79	75
84	84	80	76	79	81	80	79	77	75	75	74	72	76	77	78	73	75	77	78	80	81	83	82	80	79	79	75
84	84	80	76	79	81	80	79	77	75	75	74	72	76	77	78	73	75	77	78	80	81	83	80	80	79	79	74
84	84	80	76	78	81	80	79	77	75	75	74	72	76	77	78	73	75	77	78	80	81	83	81	80	79	79	75

September									October																			
17	18	19	20	23	24	25	27	30	1	2	3	4	7	8	10	11	14	15	16	17	18	21	22	23	25	28	29	30
77	79	81	82	79	79	81	86	83	84	85	82	82	83	85	86	88	86	85	86	87	85	82	85	85	83	83	83	83
79	80	82	83	81	80	83	87	84	85	86	83	83	84	86	87	89	87	86	87	88	86	83	86	86	84	84	84	84
77	79	81	82	79	79	82	85	83	84	85	82	82	83	85	86	89	86	85	87	87	86	82	85	85	83	83	83	83
71	73	75	76	73	74	74	77	74	74	74	72	72	71	74	75	77	75	72	74	75	73	71	73	73	70	71	71	71
71	74	75	76	74	75	75	79	76	77	77	75	75	74	78	78	80	78	75	73	79	77	74	77	77	74	75	75	75
71	75	76	77	75	76	76	81	79	80	80	78	78	79	82	82	85	83	80	84	85	82	80	85	85	82	84	84	84
71	74	75	76	73	75	75	79	76	77	76	75	75	74	78	78	80	77	75	77	83	76	74	77	77	73	75	75	75
71	74	76	76	74	75	75	79	76	77	76	74	74	74	77	78	79	76	74	76	78	76	73	75	75	73	74	74	74
72	74	76	77	74	75	75	80	77	78	78	76	76	76	79	80	82	79	77	78	80	78	75	79	79	76	77	77	77
72	75	77	78	75	76	76	81	79	80	79	78	78	78	81	82	84	82	80	83	84	81	79	84	84	81	83	83	83
71	75	76	76	75	75	75	79	76	77	77	75	75	75	79	80	81	79	76	79	80	78	76	79	79	76	78	78	78
71	75	76	76	75	76	75	80	77	78	78	75	75	75	79	80	82	79	76	79	80	78	75	79	79	76	78	78	78

Table 4 (Continued)

		Oct	November														December							
	Date	31	1	4	5	6	7	8	11	12	14	18	20	22	26	29	2	6	9	13	16	19	23	27
	#1	82	81	76	79	80	80	79	79	79	79	76	76	76	80	74	75	76	76	77	76	76	76	76
	#2	83	82	77	79	80	80	80	79	79	79	76	76	76	80	75	75	76	76	77	77	77	76	76
	#3	82	81	76	79	80	80	79	79	79	79	76	76	76	80	75	74	75	75	77	76	76	76	76
	#4	70	71	70	72	72	72	73	72	72	73	69	69	70	73	68	67	70	70	70	70	70	70	70
Thermocouple	#5	74	74	72	74	74	74	75	74	74	75	71	71	73	75	70	69	72	72	72	72	72	72	72
	#6	80	80	77	79	79	79	80	79	79	79	75	75	77	80	74	73	76	76	76	76	76	76	76
	#7	73	74	72	74	74	74	75	74	74	74	70	70	72	75	70	69	72	72	72	72	72	73	73
	#8	73	73	72	74	73	73	75	73	73	74	70	70	71	75	69	69	71	71	71	71	71	71	71
	#9	74	75	73	74	75	75	76	75	75	75	71	71	73	76	71	70	73	73	73	73	73	73	73
	#10	78	79	76	78	78	78	79	78	78	78	74	74	76	78	73	72	75	75	75	75	75	75	75
	#11	75	78	73	75	75	75	76	75	75	75	71	71	73	76	71	70	73	73	73	73	73	73	73
	#12	75	78	73	75	75	75	76	75	75	75	71	71	73	76	71	70	73	73	73	73	73	73	73

Table 5. Temperature data from Laboratory Experiment Four. Temperatures in degrees F.

		July					August																					
	Date	18	26	29	30	31	1	2	5	6	7	8	9	12	13	15	16	18	19	20	21	22	23	26	27	28	29	30
	#1	76	78	79	80	80	79	80	79	81	80	84	87	86	80	81	81	79	79	77	75	75	74	73	76	78	79	75
	#2	76	78	81	81	81	80	81	80	83	81	86	90	91	85	82	83	80	80	78	75	75	74	73	76	78	79	75
	#3	76	79	84	83	83	82	83	82	85	85	89	92	91	85	84	85	81	80	79	75	75	75	74	77	79	80	76
	#4	76	80	86	85	85	83	84	82	85	83	88	91	90	83	83	85	82	81	79	77	76	75	74	77	79	80	76
Thermocouple	#5	76	78	81	81	81	80	81	80	83	82	86	88	89	83	81	84	84	84	81	78	77	76	74	77	79	80	76
	#6	76	78	80	80	80	79	81	79	82	80	85	87	87	80	80	83	84	85	84	80	79	77	74	77	79	80	76
	#7	76	77	79	79	79	79	80	79	81	79	84	85	84	87	79	81	81	83	84	82	81	77	74	77	79	79	74
	#8	76	77	80	80	80	79	80	79	82	80	84	87	86	78	79	81	79	79	77	75	75	75	73	76	78	79	75
	#9	76	79	84	83	83	82	83	81	84	82	86	88	89	81	81	84	81	80	79	76	76	75	73	76	78	79	76
	#10	76	78	81	81	81	80	81	80	83	81	86	88	88	81	83	87	82	81	79	76	76	75	74	77	79	81	76
	#11	76	78	80	80	80	79	80	80	82	80	85	87	86	79	81	85	82	81	79	76	76	75	74	77	79	80	76
	#12	76	77	78	78	78	77	79	78	80	77	83	84	84	78	77	79	78	77	76	74	74	73	73	75	77	78	73

	September											
	3	4	5	6	8	9	10	11	12	13	16	17
#1	75	77	80	80	82	83	82	81	79	79	75	73
#2	75	77	80	81	82	83	82	81	79	79	75	73
#3	75	77	80	81	82	83	82	81	79	79	75	73
#4	75	77	80	81	82	83	82	81	79	79	75	73
#5	75	77	80	81	82	83	82	81	79	79	75	73
#6	75	77	80	81	82	83	82	81	79	79	75	73
#7	75	77	80	80	81	83	81	80	78	78	74	72
#8	75	77	80	80	81	83	82	81	80	79	75	73
#9	75	77	80	80	81	83	82	81	78	78	75	73
#10	75	77	80	81	82	83	81	81	79	78	75	73
#11	75	77	80	81	82	83	81	80	79	78	75	73
#12	74	77	78	79	80	82	80	79	78	78	74	71

Checked until March 1
No Change

Table 6. Temperature data from Laboratory Experiment Five. Temperatures in degrees F.

	July				August																					September			
Date	18	29	30	31	1	2	5	6	7	8	12	13	15	16	18	19	20	21	22	23	26	27	28	29	30	3	4	5	6
Thermocouple #1	75	78	78	78	78	80	79	81	79	84	83	75	79	81	79	79	78	75	76	76	74	77	80	80	75	75	79	80	80
#2	75	79	79	79	79	80	79	82	80	85	85	78	80	84	80	81	79	77	76	76	74	77	80	81	76	75	79	80	80
#3	75	80	80	80	80	81	80	84	82	86	87	79	81	84	80	81	79	77	76	76	74	77	79	80	76	75	78	80	80
#4	75	81	81	82	81	82	82	84	83	87	87	79	80	82	80	81	79	76	75	75	73	76	78	79	75	75	78	80	80
#5	75	80	80	80	79	81	80	83	82	86	86	79	80	·82	80	80	78	76	75	75	73	76	78	79	75	75	78	80	80
#6	75	79	79	79	79	80	79	82	80	85	84	77	79	81	79	79	78	75	75	75	73	76	78	79	75	75	78	80	80
#7	75	79	79	79	78	79	79	81	78	84	82	75	78	80	79	79	77	75	74	74	72	76	78	78	74	75	78	80	80
#8	75	78	78	78	78	79	78	81	79	83	82	75	78	80	78	79	77	75	75	74	72	76	78	78	74	75	78	80	80
#9	75	80	80	80	80	81	80	82	81	85	85	77	79	81	79	79	78	76	75	75	73	76	78	79	75	75	78	80	80
#10	75	80	80	80	79	80	81	83	82	86	86	79	81	82	81	81	79	77	76	75	73	76	78	79	75	75	78	80	80
#11	75	79	79	79	79	80	79	82	80	85	84	78	80	82	81	80	79	76	75	75	73	76	78	79	74	75	78	80	80
#12	75	77	78	77	77	78	78	80	76	82	79	74	77	79	77	77	76	74	74	73	72	75	77	78	73	75	77	78	79

Checked until Mar. 1, 1964 No change.

Table 7. Temperature data from Laboratory Experiment Six. Temperatures in degrees F.

	September													October									November							
Date	10	11	12	13	16	17	18	19	20	23	24	25	27	16	17	18	21	22	23	25	29	30	1	4	5	6	7	8	11	14
Thermocouple #1	79	79	76	77	72	72	74	76	75	73	73	75	78	73	75	73	69	69	69	69	69	69	69	70	73	74	74	74	74	74
#2	79	79	78	77	74	73	74	77	77	74	74	76	78	74	75	74	69	69	69	69	70	70	70	71	74	75	75	75	75	75
#3	79	79	78	78	75	74	76	78	78	75	74	77	79	74	76	74	70	70	70	70	71	71	71	71	74	75	75	75	75	76
#4	79	79	78	79	76	75	77	79	79	76	75	76	79	75	76	74	71	71	71	71	71	71	71	72	75	76	76	76	76	77
#5	79	79	78	78	73	73	75	77	75	74	74	75	79	74	76	74	70	70	70	70	71	71	71	71	75	76	76	76	76	76
#6	79	79	78	77	73	73	74	76	75	74	74	75	78	74	75	73	70	70	70	70	70	70	70	71	73	74	74	74	74	75
#7	79	79	77	77	73	72	74	76	75	74	74	75	78	73	74	73	69	69	69	69	69	69	69	70	73	74	74	74	74	74
#8	79	79	77	78	72	72	74	75	75	74	74	75	78	73	75	73	69	69	69	69	69	69	69	70	73	74	74	74	74	74
#9	79	79	77	77	74	74	74	78	77	74	74	75	78	74	76	74	70	70	70	70	70	70	70	71	74	75	75	75	75	76
#10	79	79	77	76	74	73	74	77	77	74	74	75	78	74	76	74	70	70	70	70	70	70	70	71	74	75	75	75	75	75
#11	79	79	77	76	72	71	72	75	74	74	74	74	77	73	75	72	70	70	70	70	69	69	69	70	72	73	73	73	73	73
#12	79	79	76	76	72	70	72	75	74	74	74	74	77	72	74	72	69	69	69	69	68	68	68	69	72	73	73	73	73	73

November					December										January						February						March		
18	20	22	26	29	2	3	6	9	13	16	19	23	27	31	17	20	22	27	29	31	4	6	10	13	20	27	5	12	19
71	71	71	76	70	70	71	71	71	73	73	73	73	73	74	79	79	79	81	81	79	76	78	78	77	75	76	76	75	76
72	72	72	77	71	71	73	73	73	75	75	75	75	74	75	83	83	83	85	85	83	80	81	79	79	78	79	78	78	79
73	73	73	78	72	72	74	74	74	76	76	76	76	75	77	85	85	86	87	87	85	82	82	80	81	79	80	80	79	80
73	73	73	79	73	73	75	75	75	77	77	77	77	75	77	85	85	86	88	88	85	82	83	80	82	80	81	80	79	80
73	73	73	78	72	72	74	74	74	76	76	76	76	75	77	84	84	85	87	87	85	81	82	81	82	79	81	80	79	80
71	71	71	76	71	71	72	72	72	74	74	74	74	74	75	81	81	81	84	84	82	75	80	78	79	77	79	78	77	78
70	70	70	75	70	70	71	71	71	73	73	73	73	72	73	77	77	77	80	80	78	74	77	75	76	75	77	76	75	76
71	71	71	76	70	70	71	71	71	73	73	73	73	72	73	76	76	75	77	77	75	70	74	72	73	73	74	73	72	74
72	72	72	77	71	71	74	74	74	75	75	75	75	74	75	81	81	81	82	82	80	75	78	76	77	76	78	77	76	77
72	72	72	77	71	71	73	73	73	75	75	75	75	74	76	84	84	86	88	88	86	81	84	81	82	81	82	81	81	82
70	70	70	75	70	70	71	71	71	72	72	72	72	72	73	78	78	79	83	83	82	78	81	78	79	76	80	79	79	80
70	70	70	74	69	69	70	70	70	71	71	71	71	71	71	73	73	71	73	73	72	68	71	68	69	69	71	71	70	71

Table 8. Temperature data from Laboratory Experiment Seven. Temperatures in degrees F.

		September														October																
	Date	10	11	12	13	16	17	18	19	20	23	24	25	27	30	1	2	3	4	7	8	10	11	14	15	16	17	18	21	22	23	25
Thermocouple	#1	80	80	78	78	75	74	75	78	79	75	74	77	80	76	76	76	73	74	73	75	75	77	76	76	76	77	75	72	72	72	72
	#2	80	80	78	78	76	75	77	79	80	76	76	79	82	79	79	79	76	76	74	77	77	79	78	78	78	79	77	73	73	73	73
	#3	81	81	80	79	77	76	79	82	83	79	79	82	86	82	82	82	78	78	76	79	79	81	80	80	80	81	79	75	75	75	75
	#4	81	81	80	79	78	77	80	83	85	80	80	83	87	83	83	83	79	79	77	79	80	82	80	80	80	82	80	76	76	76	76
	#5	81	81	79	78	77	76	78	81	82	78	78	80	85	81	81	81	77	77	75	78	78	80	79	79	79	79	78	74	74	74	74
	#6	81	81	79	77	75	74	76	79	80	75	76	78	82	78	78	78	75	75	73	76	76	78	77	77	77	78	76	72	72	72	72
	#7	80	80	78	78	74	73	76	77	78	74	74	77	80	76	76	76	73	73	71	74	74	77	75	75	75	76	74	71	71	71	71
	#8	80	80	78	79	75	73	76	77	78	75	75	77	80	76	77	77	73	74	73	75	75	78	77	77	77	78	76	72	72	72	72
	#9	80	80	79	78	77	76	78	81	82	78	78	81	84	80	80	80	77	77	75	78	78	80	79	79	79	80	78	74	74	74	74
	#10	80	80	78	77	76	75	77	80	81	77	77	80	83	80	80	80	76	76	74	77	77	79	78	78	78	79	77	73	73	73	73
	#11	80	80	78	77	74	73	75	77	78	74	75	76	80	76	76	76	73	74	72	75	75	77	76	76	76	77	75	71	71	71	71
	#12	80	80	78	78	74	72	75	77	78	74	73	75	78	75	75	75	72	73	71	74	74	77	75	75	75	76	74	71	71	71	71

October			November															December										January		
28	29	30	1	4	5	6	7	8	11	12	14	18	20	22	24	26	29	2	3	6	9	13	16	19	23	27	31	6	17	20
71	71	73	73	73	73	75	75	76	77	77	78	76	75	76	81	82	77	78	80	81	82	83	83	83	82	83	84	83	86	83
72	72	75	75	75	75	78	78	79	81	81	81	79	78	80	85	86	82	83	85	85	86	87	86	86	85	85	86	85	87	83
74	74	76	76	76	76	80	80	81	85	85	84	82	82	84	88	89	85	86	87	88	88	88	87	87	86	86	86	85	87	83
75	75	77	77	77	77	81	81	82	86	86	84	83	83	84	89	90	85	86	88	88	88	88	87	87	86	86	86	85	87	83
73	73	75	75	75	75	79	79	79	82	82	82	80	81	82	88	88	84	85	88	88	88	88	87	87	86	86	87	85	87	84
71	71	74	74	74	74	76	76	76	79	79	79	77	77	79	84	84	80	82	84	85	86	87	86	86	86	86	87	85	88	84
70	70	72	72	72	72	74	74	75	76	76	77	74	74	76	80	81	76	77	79	80	81	82	82	82	82	83	84	82	86	83
71	71	74	74	74	74	77	77	77	80	80	80	77	77	79	88	84	79	79	81	82	82	83	82	82	81	82	82	80	82	79
74	74	76	76	76	76	80	80	81	85	85	84	82	82	83	87	88	84	84	86	86	86	87	85	85	84	84	85	83	85	82
72	72	75	75	75	75	77	77	78	80	80	81	79	79	81	86	86	82	84	86	86	87	87	86	86	86	86	87	85	88	85
70	70	72	72	72	72	74	74	75	75	75	77	74	74	76	80	80	76	76	79	79	80	81	81	81	81	82	84	82	87	85
70	70	72	72	72	72	74	74	75	75	75	78	75	74	76	80	81	77	77	79	80	81	81	81	81	81	82	82	79	78	77

January			February						March		
22	27	31	4	6	10	13	20	27	5	12	19
82	84	83	81	81	81	80	81	81	80	80	80
83	85	83	82	82	82	81	82	82	80	80	80
83	85	83	82	82	82	81	82	82	80	80	80
83	85	83	82	82	82	81	82	82	80	80	80
83	85	83	82	82	82	81	82	82	81	81	81
84	85	83	82	82	82	81	82	82	81	81	81
83	84	83	82	82	82	81	82	82	80	80	80
78	80	78	77	77	77	75	77	78	75	75	77
81	82	80	79	79	80	79	80	80	78	78	79
85	87	86	85	85	84	84	84	84	82	82	82
85	88	87	87	87	87	87	86	85	84	84	84
73	77	78	77	77	78	77	78	76	74	74	75

Table 9. Temperature data from Laboratory Experiment Eight. Temperature in degrees F.

	September														October															
Date	10	11	12	13	16	17	18	19	20	23	24	25	27	30	1	2	3	4	7	8	10	11	14	15	17	18	21	22	23	25
Thermocouple #1	80	80	78	78	75	73	75	77	78	75	74	77	80	77	77	77	74	74	73	75	76	77	76	76	77	76	72	72	74	72
#2	80	80	78	78	76	74	76	78	80	76	75	78	82	79	79	79	76	76	74	76	77	79	78	77	79	77	73	73	75	73
#3	81	81	79	78	77	75	77	80	82	78	78	81	85	82	82	82	78	78	76	78	79	80	80	79	80	79	75	75	77	75
#4	81	81	79	79	77	76	79	82	84	80	80	83	87	84	84	84	80	80	77	79	80	82	80	79	81	79	75	75	78	75
#5	81	81	79	78	76	75	77	80	81	78	78	81	85	82	82	82	79	79	76	79	79	81	79	79	81	79	74	74	77	74
#6	80	80	79	78	75	74	76	78	80	75	76	79	82	79	79	79	76	76	74	77	77	79	78	77	78	76	72	72	75	72
#7	80	80	78	78	74	73	75	77	77	74	74	77	79	76	76	76	73	73	72	75	75	77	76	75	76	74	71	71	73	70
#8	80	80	78	78	75	74	75	78	79	75	75	77	81	78	78	78	75	75	74	76	76	78	77	77	78	77	72	72	75	72
#9	80	80	79	78	76	75	77	80	81	78	78	80	84	81	81	81	78	78	76	78	78	80	79	79	80	79	74	74	77	74
#10	80	80	78	78	76	75	77	79	81	78	78	77	84	81	81	81	77	77	75	77	77	79	78	77	79	77	73	73	76	73
#11	80	80	77	77	74	73	75	77	78	74	75	77	80	77	77	77	74	74	72	75	75	78	76	75	77	75	72	72	74	71
#12	80	80	78	77	74	72	75	77	78	74	73	76	79	75	75	75	73	73	72	75	75	78	76	75	77	75	72	72	73	71

	October			November														December										January			
Date	28	29	31	1	4	6	7	8	11	12	14	18	20	22	24	26	29	2	3	6	9	13	16	19	23	27	31	6	17	20	22
#1	72	72	74	74	74	76	76	76	77	77	77	75	75	75	80	81	76	77	79	79	80	81	80	80	79	80	80	79	80	77	77
#2	73	73	75	75	75	78	78	78	80	80	80	77	77	79	84	85	81	84	85	85	86	87	86	86	85	85	85	82	82	79	79
#3	75	75	78	78	78	81	81	81	84	84	84	82	82	84	90	92	88	89	91	92	92	92	90	90	88	87	87	84	83	80	80
#4	75	75	78	78	78	82	82	82	85	85	85	83	84	86	93	94	90	91	93	93	92	92	90	90	88	87	87	83	83	80	80
#5	74	74	77	77	77	80	80	80	82	82	82	81	81	84	90	91	89	89	91	91	91	91	89	89	87	87	87	82	82	79	79
#6	72	72	75	75	75	77	77	77	79	79	79	77	77	79	85	86	82	84	86	86	87	87	86	86	84	84	84	81	81	78	78
#7	70	70	73	73	73	75	75	75	76	76	76	73	73	75	79	80	76	76	79	79	80	81	80	80	79	80	80	78	79	75	75
#8	72	72	75	75	75	78	78	78	80	80	80	78	78	79	84	85	80	80	82	81	81	81	80	80	77	77	77	75	76	74	74
#9	74	74	78	78	78	81	81	81	84	84	84	82	87	84	91	91	87	87	89	89	88	87	86	86	83	82	82	79	79	76	76
#10	73	73	76	76	76	78	78	78	80	80	80	78	78	81	86	88	84	85	88	89	89	90	89	89	89	89	89	86	86	83	83
#11	71	71	73	73	73	75	75	75	76	76	76	74	74	75	80	81	76	77	80	80	81	82	82	83	87	84	84	85	86	84	84
#12	71	71	73	73	73	75	75	75	76	76	76	73	73	74	78	78	73	73	74	74	75	75	74	74	73	73	73	72	74	71	71

	January			February						March		
Date	27	29	31	4	6	10	13	20	27	5	12	19
#1	78	78	77	76	76	76	76	77	77	75	75	76
#2	80	80	79	78	78	78	77	78	78	77	77	78
#3	81	81	80	78	78	78	78	79	79	78	78	78
#4	81	81	80	79	79	79	78	79	79	78	78	79
#5	80	80	79	78	78	78	77	79	79	77	77	78
#6	79	79	78	77	77	77	76	77	77	76	76	77
#7	77	77	76	75	75	75	75	76	75	74	74	75
#8	76	76	75	74	74	74	74	75	75	74	74	75
#9	78	78	77	76	76	76	76	77	77	76	76	77
#10	84	84	82	81	81	81	80	80	80	79	79	79
#11	85	85	83	82	82	82	81	81	80	79	79	79
#12	74	74	73	72	72	72	72	73	72	72	72	72

Table 10. Temperature data from Laboratory Experiment Nine. Temperatures in degrees F.

		September									October		
	Date	16	17	18	19	20	23	24	25	27	30	1	2	3
Thermocouple	#1	74	73	75	77	77	74	73	75	78	75	74	75	71
	#2	74	73	75	77	77	74	74	75	79	75	74	75	72
	#3	75	73	75	78	79	75	76	78	80	75	75	75	72
	#4	75	74	75	79	80	77	77	79	81	76	76	76	72
	#5	75	73	75	78	79	75	75	77	80	75	75	76	72
	#6	75	73	75	77	78	74	74	76	79	75	75	76	72
	#7	74	72	75	77	77	74	73	75	78	74	74	76	72
	#8	75	72	75	77	77	74	73	75	78	74	74	76	72
	#9	75	74	75	78	80	76	76	78	81	74	75	76	72
	#10	74	73	75	77	78	74	75	76	78	74	75	76	72
	#11	74	72	75	76	77	73	73	75	78	74	74	76	72
	#12	74	71	75	75	76	73	73	75	77	73	74	74	72

Checked to March 1, 1964. No change.

Table 11. Temperature data from Laboratory Experiment Ten. Temperatures in degrees F.

		September					October		November			December	
	Date	23	24	25	27	30	1	2	1	18	22	19	23
Thermocouple	#1	73	72	75	78	74	74	75	71	70	70	70	69
	#2	74	73	75	79	75	74	75	72	71	71	70	69
	#3	76	74	77	80	76	75	76	72	72	72	71	70
	#4	75	75	79	82	77	76	77	72	73	73	71	70
	#5	74	74	78	80	76	76	77	72	72	72	71	70
	#6	73	73	77	79	75	75	75	71	71	71	70	70
	#7	73	72	75	78	74	74	74	71	70	70	70	70
	#8	75	73	75	78	75	75	75	71	71	71	70	70
	#9	74	75	78	81	76	76	76	72	72	72	71	70
	#10	73	74	77	79	75	75	75	72	71	71	70	69
	#11	73	72	75	78	74	74	74	71	70	70	70	70
	#12	73	71	75	77	73	74	74	71	70	70	70	70

Checked to March 1, 1964. No change.

Table 12. Temperature data from Laboratory Experiment Fourteen. Temperatures in degrees F.

	November								December							January			February					March			April			May	
Date	9	11	16	18	20	23	27	30	2	4	7	11	14	18	28	11	18	25	1	8	15	17	22	15	22	29	5	13	19	7	10
Thermocouple #1	70	71	70	71	71	71	71	72	72	72	73	72	72	72	73	74	74	73	74	74	75	76	75	76	76	76	76	75	77	74	79
#2	70	71	71	72	72	72	72	74	74	74	75	74	75	75	77	80	79	78	79	80	80	81	79	80	80	79	80	78	80	77	82
#3	71	72	72	73	73	74	74	76	76	76	77	77	78	78	82	84	82	82	82	82	82	84	81	81	81	81	81	78	81	77	83
#4	73	74	73	75	75	77	76	79	80	80	79	78	79	79	83	84	83	82	83	83	83	84	81	81	81	81	81	79	81	77	83
#5	71	72	72	73	72	74	74	77	77	77	78	78	78	78	82	84	82	81	82	82	81	83	80	81	81	81	81	79	81	77	83
#6	70	71	71	72	71	72	72	74	73	74	74	74	74	74	76	78	77	77	78	78	78	80	78	78	78	78	79	77	79	76	82
#7	70	71	70	71	71	71	71	72	71	72	72	72	72	72	73	74	73	73	74	74	74	76	74	75	75	75	76	74	77	73	79
#8	70	71	70	71	71	71	71	72	72	72	72	72	72	72	73	74	74	74	75	76	76	78	76	76	76	76	76	74	77	74	80
#9	72	73	72	73	72	73	73	75	75	75	76	75	76	76	79	81	80	80	81	82	81	83	80	80	80	80	80	78	80	76	82
#10	72	72	72	74	73	75	75	78	78	78	78	87	78	78	82	83	81	81	82	82	82	83	81	80	80	80	81	80	81	78	82
#11	70	71	71	72	71	72	72	74	73	73	74	73	74	74	75	76	76	75	77	77	77	80	77	78	77	78	80	80	81	77	82
#12	70	70	70	71	70	71	71	71	70	71	71	70	71	70	71	71	71	70	71	71	71	73	71	71	72	72	73	71	73	69	74

Table 13. Temperature data from Laboratory Experiment Fifteen. Temperatures in degrees F.

	February												March									April					May	
Date	1	2	4	8	10	12	15	17	19	22	24	26	2	4	9	12	15	17	18	22	29	5	13	16	19	30	7	10
Thermocouple #1	71	71	71	71	71	71	71	72	72	71	73	72	74	73	75	75	72	71	72	72	73	79	76	79	80	79	73	80
#2	71	71	72	71	71	72	71	73	72	72	74	73	75	74	76	75	73	71	72	72	75	82	80	81	82	81	76	84
#3	71	72	72	71	72	72	71	74	73	73	76	75	76	75	77	77	74	72	73	73	76	85	82	84	85	84	80	87
#4	72	72	72	71	72	73	72	75	75	75	77	76	78	76	78	77	74	72	73	73	76	85	82	84	85	84	80	86
#5	72	72	72	71	72	72	72	74	73	73	75	74	76	75	77	76	74	72	73	73	76	83	80	82	82	83	79	85
#6	71	72	72	71	71	72	71	73	73	72	74	73	75	75	76	76	74	72	73	73	75	81	78	79	81	81	75	83
#7	71	72	72	71	71	72	71	72	72	71	73	72	74	73	75	74	73	71	72	72	73	77	75	76	78	78	72	80
#8	71	72	72	71	71	72	71	73	72	72	74	73	75	74	76	75	73	71	72	72	73	75	72	74	75	77	70	79
#9	71	72	71	71	72	72	72	75	74	74	76	76	77	76	77	76	74	72	72	72	74	79	76	78	80	80	74	73
#10	71	72	71	71	72	73	72	75	74	74	76	76	77	76	77	76	74	72	72	72	74	79	76	78	80	80	74	83
#11	71	71	71	70	71	71	71	73	72	72	73	72	75	74	75	74	73	71	72	72	75	82	78	80	80	77	74	82
#12	71	71	71	70	71	71	71	72	71	71	72	72	73	73	74	73	71	70	71	71	72	73	69	72	74	72	65	76

Table 14. Temperature data from Field Experiment One. Temperatures in degrees F.

		February	March																April		
Date		27	28	1	2	4	6	12	16	19	22	27	29	30	31				2		3
Column-		4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	7	1	4	1	4
Row		4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	7	1	4	1	4
	#11	41	41	49	50	49	44	40	55	53	50	56	75	69	63	63	65	63	55	56	62
	#10	43	43	48	46	48	43	42	49	48	46	49	63	60	57	57	57	58	52	53	55
	#9	46	46	48	45	47	44	44	46	47	45	46	55	54	55	54	55	55	52	53	51
	#8	48	48	49	46	48	46	46	46	47	45	46	52	51	53	52	53	53	52	53	52
	#7	49	49	49	47	49	47	46	46	47	45	47	51	50	52	51	51	51	53	52	53
Thermocouple	#6	49	49	49	47	49	47	47	46	47	46	48	52	51	53	50	50	50	55	51	56
	#5	49	49	49	47	49	47	48	47	49	47	50	54	53	55	49	49	49	59	50	61
	#4	49	49	49	47	49	47	48	47	49	47	50	54	54	56	49	49	48	60	49	62
	#3	47	47	49	47	48	47	47	46	48	47	49	54	52	55	48	48	47	57	48	59
	#2	46	46	48	46	48	47	47	46	47	46	47	50	49	50	48	48	47	51	47	52
	#1	46	46	46	45	47	46	46	45	46	45	45	48	47	48	47	48	47	48	47	49

April																						
5			6			7			8	10	12	14			15			17				
4	4	1	4	4	1	4	4	1	4	4	4	4	4	1	4	3	1	4	3	2	1	1
4	5	7	4	5	7	4	5	7	4	4	4	4	5	7	4	4	7	4	4	4	4	7
55	55	54	65	66	63	70	70	67	69	60	63	71	71	69	63	63	61	59	58	56	56	56
52	52	51	55	54	53	58	56	55	59	60	62	61	60	57	61	60	58	56	53	53	52	52
53	52	51	52	51	50	54	53	51	57	60	58	59	57	53	62	59	56	58	55	54	53	52
54	53	51	53	52	49	55	53	49	57	62	62	61	59	52	64	60	54	62	57	55	54	52
56	54	51	56	54	49	58	55	48	61	64	65	65	62	51	68	61	54	67	60	56	54	52
61	56	51	63	56	48	66	57	48	71	75	76	76	66	51	79	62	53	77	62	56	54	52
69	57	50	73	57	48	80	59	48	85	89	90	90	68	50	93	63	52	92	63	56	53	52
72	56	50	77	57	48	83	58	47	87	89	90	90	66	49	91	63	52	89	62	56	52	51
68	55	49	71	55	47	77	57	47	81	83	84	84	63	49	85	60	51	84	60	55	52	51
56	52	49	56	52	47	59	53	47	61	64	66	65	58	49	66	57	50	65	56	54	51	51
51	51	48	50	50	47	51	50	46	52	54	55	55	54	49	56	54	50	55	54	52	50	50

April																							
19				21				22				23				24				26			
4	3	2	1	4	3	2	1	4	3	2	1	4	3	2	1	4	3	2	1	4	3	2	1
4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
71	71	69	68	70	68	67	64	59	59	59	58	66	63	64	61	66	66	65	64	63	61	61	60
63	61	59	59	63	59	57	56	58	57	57	56	59	56	55	54	63	62	59	58	58	57	56	56
61	59	57	55	60	56	56	55	60	58	57	56	58	55	54	54	61	60	58	57	59	57	56	56
63	59	57	55	61	57	56	55	64	60	58	56	62	57	55	54	64	61	58	57	62	59	57	56
67	61	57	54	68	59	56	54	70	63	58	56	68	59	57	54	70	64	59	57	67	61	58	56
76	63	57	54	79	62	56	54	82	65	58	56	79	62	57	54	79	66	59	57	75	64	58	56
90	64	57	54	93	62	56	54	93	66	58	55	89	63	57	54	88	67	59	56	81	64	58	56
88	64	56	53	88	61	56	53	88	64	57	55	84	62	56	54	84	65	58	56	78	62	57	56
83	61	55	53	82	59	54	53	81	66	56	54	78	59	55	53	79	63	57	55	73	60	57	54
66	57	54	52	66	56	53	52	66	58	55	54	64	56	53	52	66	60	56	55	63	58	55	54
56	55	53	52	57	53	52	51	52	56	54	53	56	53	52	51	58	57	54	54	57	55	54	53

Table 15. Temperature data from Field Experiment Two. Temperatures in degrees F.

		April								May													
Date		27				29				1				3					4				
Column-		4	3	2	1	4	3	2	1	4	3	2	1	4	4	3	2	1	4	4	3	2	1
Row		4	4	4	4	4	4	4	4	4	4	4	4	4	5	4	4	4	4	5	4	4	4
	#11	64	62	62	60	60	59	59	58	58	58	57	57	68	66	68	65	63	62	62	62	61	60
	#10	57	57	56	55	59	57	57	57	57	57	55	55	61	59	60	57	56	59	58	58	56	56
	#9	59	57	56	55	60	59	58	57	58	58	56	56	58	58	57	56	55	58	58	58	56	56
	#8	61	58	57	56	62	60	58	57	62	60	58	57	60	60	59	57	55	60	60	59	57	56
	#7	65	61	58	56	65	61	58	57	66	63	59	58	65	63	61	58	56	64	62	60	57	56
Thermocouple	#6	73	62	58	56	72	62	58	57	72	64	60	58	71	65	63	58	57	70	64	62	58	57
	#5	80	63	58	56	77	63	58	57	76	64	60	58	74	65	63	58	56	74	65	62	58	57
	#4	75	61	57	55	73	62	58	56	72	64	59	58	70	63	62	58	56	69	63	61	58	56
	#3	72	59	56	54	70	60	57	55	69	62	58	56	66	61	58	57	56	66	61	60	57	56
	#2	62	57	55	54	62	58	56	55	62	60	57	56	61	59	58	56	55	60	59	58	56	55
	#1	56	54	54	53	57	56	55	54	58	58	56	55	57	57	57	55	54	57	57	57	55	55

May																								
6					8					11					12					14				
4	4	3	2	1	4	4	3	2	1	4	4	3	2	1	4	4	3	2	1	4	4	3	2	1
4	5	4	4	4	4	5	4	4	4	4	5	4	4	4	4	5	4	4	4	4	5	4	4	4
67	66	66	65	61	67	66	65	64	63	77	76	75	73	70	58	57	57	57	57	66	65	65	65	62
60	57	57	55	54	60	59	58	57	56	66	62	62	60	59	58	58	57	58	57	60	58	58	57	57
57	56	55	54	53	58	57	56	55	55	59	58	57	55	55	60	59	59	59	57	58	58	57	57	57
59	57	57	55	55	58	58	57	56	55	59	58	57	55	55	61	60	59	58	57	59	59	58	57	57
63	61	59	56	55	62	60	58	56	55	61	59	57	55	54	63	61	59	58	57	62	60	59	57	57
68	62	60	57	55	67	62	59	56	55	66	60	58	55	54	68	62	60	57	56	67	61	60	57	56
71	63	60	57	55	70	62	60	57	55	69	61	58	55	54	70	62	60	57	56	69	61	60	57	56
67	61	59	56	55	66	60	58	56	55	64	59	57	55	54	65	60	59	57	55	64	60	58	56	56
64	60	58	55	55	62	59	57	56	55	60	58	56	55	53	62	59	58	56	55	61	58	57	55	55
59	58	56	55	54	58	57	56	55	55	57	56	55	54	53	58	57	57	55	55	57	57	55	55	55
56	56	55	54	53	56	56	55	54	54	55	55	54	53	53	56	56	55	55	55	55	55	54	54	54

May																								
15					18					20					21					22				
4	4	3	2	1	4	4	3	2	1	4	4	3	2	1	4	4	3	2	1	4	4	3	2	1
4	5	4	4	4	4	5	4	4	4	4	5	4	4	4	4	5	4	4	4	4	5	4	4	4
69	68	68	67	66	80	78	78	76	74	65	64	65	65	65	70	70	69	69	68	70	69	68	68	66
63	61	61	60	59	70	67	68	65	64	65	64	65	64	64	65	63	63	62	62	65	63	62	62	61
60	59	59	58	58	63	63	63	61	60	65	64	65	63	63	63	62	61	61	61	63	62	61	61	60
61	60	59	58	58	63	62	61	60	59	65	64	64	62	61	64	62	61	60	60	65	63	62	61	60
63	61	60	58	57	64	62	62	59	58	67	64	64	61	60	67	63	62	60	59	70	65	64	61	60
68	61	60	58	56	70	63	61	58	57	75	65	64	60	59	77	64	63	59	58	82	66	65	60	59
70	62	60	58	56	72	62	61	57	57	77	64	64	59	58	79	63	62	59	58	84	65	65	60	58
65	60	59	57	56	66	61	61	57	56	68	62	62	59	58	68	61	61	58	57	71	63	61	58	57
61	58	57	56	55	61	59	58	56	55	63	60	60	58	57	61	59	58	56	56	63	60	59	57	57
57	57	56	56	55	58	58	57	56	55	59	59	58	57	56	58	57	56	56	55	59	58	57	56	56
56	56	55	55	55	56	56	56	55	55	57	57	57	56	56	56	56	55	55	55	57	57	56	56	55

Table 15. (Continued)

Date		24					25					26					27				
Column		4	4	3	2	1	4	4	3	2	1	4	4	3	2	1	4	4	3	2	1
Row		4	5	4	4	4	4	5	4	4	4	4	5	4	4	4	4	5	4	4	4
Thermocouple	#11	78	77	77	75	73	71	70	70	69	67	81	80	80	79	76	82	81	81	79	76
	#10	71	68	69	66	65	66	64	64	63	62	72	69	70	67	66	73	69	70	68	66
	#9	66	65	65	63	62	65	63	63	62	61	67	65	65	63	62	68	66	65	64	63
	#8	68	65	65	62	61	67	64	64	61	60	68	65	65	62	61	69	66	66	63	62
	#7	74	67	67	62	60	74	67	66	61	60	74	67	66	61	60	74	68	67	62	61
	#6	87	69	69	61	59	87	68	68	61	59	86	68	69	61	60	85	69	70	62	60
	#5	89	68	68	61	59	88	68	68	61	58	87	68	68	61	59	87	69	69	61	59
	#4	75	65	65	59	58	75	64	64	59	58	76	65	65	60	58	76	65	66	60	58
	#3	65	62	61	58	58	65	61	60	58	56	66	61	61	58	57	66	62	61	59	57
	#2	60	59	59	58	57	59	59	58	57	56	60	59	58	57	56	61	59	58	57	57
	#1	58	58	57	57	56	57	57	56	56	55	57	57	57	56	56	58	57	57	56	56

May 29					31					June 2					5					7				
4	4	3	2	1	4	4	3	2	1	4	4	3	2	1	4	4	3	2	1	4	4	3	2	1
4	5	4	4	4	4	5	4	4	4	4	5	4	4	4	5	4	4	4	4	4	5	4	4	4
82	81	81	79	76	80	79	79	78	77	79	77	77	76	74	73	72	71	71	69	71	71	71	70	69
74	71	72	69	67	76	73	74	72	71	72	69	70	68	67	68	66	65	66	65	69	67	67	65	65
69	67	68	66	64	72	71	71	69	68	69	68	68	67	66	68	67	66	66	66	68	67	67	65	65
70	68	68	65	63	72	70	70	67	66	72	70	69	67	66	70	68	67	66	65	71	69	69	66	65
75	69	69	64	62	76	71	71	66	64	76	71	70	66	65	73	67	69	66	65	74	70	70	67	65
85	70	71	64	61	85	71	73	65	63	83	71	72	66	64	80	70	70	66	64	80	70	71	66	65
86	69	71	63	60	85	70	72	64	62	83	70	71	65	63	80	69	69	65	63	80	69	71	66	64
76	66	67	61	59	76	67	68	62	61	75	67	67	63	61	74	67	66	64	62	74	67	68	65	63
67	63	63	60	58	68	65	65	61	60	67	64	64	62	60	67	65	63	62	61	68	65	65	63	62
61	60	60	58	57	63	62	62	60	59	63	62	61	60	59	63	62	61	60	60	64	63	63	62	60
59	59	59	57	56	60	60	60	59	58	61	60	59	59	58	61	61	59	60	59	62	62	61	61	60

June 9					10					11					15					17				
4	4	3	2	1	4	4	3	2	1	4	4	3	2	1	4	4	3	2	1	4	4	3	2	1
4	5	4	4	4	4	5	4	4	4	4	5	4	4	4	4	5	4	4	4	4	5	4	4	4
66	65	64	65	62	68	67	67	67	67	79	79	79	78	76	71	71	71	70	70	65	65	65	65	65
62	61	60	61	61	67	67	67	66	65	74	71	73	70	69	70	69	69	68	68	66	65	65	65	65
64	63	62	63	62	68	67	67	66	65	69	68	69	66	65	71	70	70	68	68	69	68	67	66	65
68	66	64	64	63	70	69	69	67	65	70	69	69	66	65	74	71	71	68	67	74	71	71	68	66
72	67	67	65	64	74	70	70	67	65	74	70	71	66	65	79	72	73	68	67	81	74	75	69	67
78	67	68	66	63	80	71	72	67	65	81	71	72	66	65	89	73	77	68	66	92	75	79	69	66
78	67	68	65	63	81	70	72	66	65	82	70	72	66	65	90	73	76	68	65	93	74	78	68	66
73	66	65	63	62	75	68	69	65	64	76	68	70	65	63	83	70	72	66	64	87	71	73	67	65
67	64	63	62	61	67	66	66	64	63	69	66	67	64	63	72	67	68	65	63	74	68	68	65	64
63	62	60	61	60	64	64	64	63	62	65	64	65	63	62	66	65	65	64	63	66	65	65	64	63
61	61	59	60	59	63	63	62	62	61	63	63	63	62	61	64	64	63	63	62	64	64	64	63	62

Table 15. (Continued)

Date	June 18					19					21					22				
Column	4	4	3	2	1	4	4	3	2	1	4	4	3	2	1	4	4	3	2	1
Row	4	5	4	4	4	4	5	4	4	4	4	5	4	4	4	4	4	4	4	4
Thermocouple #11	72	71	71	70	69	79	77	76	76	72	83	81	82	81	79	83	82	81	81	76
#10	68	66	66	66	65	71	68	67	67	65	77	74	76	73	70	75	71	71	70	69
#9	69	67	67	66	65	69	67	66	66	64	74	71	72	69	66	73	71	70	69	67
#8	74	71	71	68	66	74	70	69	67	64	77	73	74	69	66	76	73	72	70	67
#7	82	74	75	69	66	81	73	74	69	64	84	75	77	70	66	84	75	74	70	66
#6	92	76	80	69	66	91	75	78	69	65	92	77	81	70	66	91	77	80	70	66
#5	92	75	79	69	66	92	74	75	68	64	92	76	81	70	65	91	76	79	70	66
#4	87	71	74	67	65	87	71	72	67	64	89	73	76	68	65	88	73	74	68	65
#3	74	68	68	65	64	73	67	67	65	63	76	69	70	66	64	75	69	69	66	64
#2	66	65	65	64	63	66	65	64	64	62	67	66	67	64	63	67	66	65	65	63
#1	64	63	63	63	62	63	63	61	62	61	64	64	64	63	62	64	64	63	63	63

June 23					24					26					29					30				
4	4	3	2	1	4	4	3	2	1	4	4	3	2	1	4	4	3	2	1	4	4	3	2	1
4	5	4	4	4	4	5	4	4	4	4	5	4	4	4	4	5	4	4	4	4	5	4	4	4
86	85	84	83	80	84	82	83	82	79	92	90	91	89	86	80	79	78	78	74	73	72	71	72	70
79	75	75	74	72	79	75	76	75	73	83	79	81	78	75	74	72	70	71	64	71	70	69	70	68
75	73	73	71	70	76	74	74	72	70	78	75	76	73	71	75	73	72	71	69	75	73	72	71	69
78	74	74	71	68	79	75	75	71	69	79	76	77	72	70	79	76	75	72	70	79	76	75	72	69
84	76	77	71	67	86	77	79	71	68	86	78	80	72	69	86	79	79	73	69	86	79	79	73	69
91	77	81	71	67	91	78	82	71	67	92	80	83	72	68	91	81	82	73	69	91	81	82	73	69
92	77	80	70	66	92	78	81	70	66	92	78	82	71	67	91	79	80	72	69	91	80	81	72	68
88	74	75	69	65	89	74	76	69	65	89	74	77	69	66	89	75	75	70	67	89	76	76	70	67
75	70	70	67	65	76	70	71	67	64	77	70	71	67	65	77	71	70	68	66	78	71	70	68	66
68	66	66	65	63	68	67	67	65	64	69	67	67	66	64	69	68	66	66	64	69	68	67	66	64
65	64	63	64	62	65	64	64	64	62	65	65	65	64	63	65	65	64	65	64	65	66	65	64	63

July 1					3					5					7					9				
4	4	3	2	1	4	4	3	2	1	4	4	3	2	1	4	4	3	2	1	4	4	3	2	1
4	5	4	4	4	4	5	4	4	4	4	5	4	4	4	4	5	4	4	4	4	5	4	4	4
75	74	73	73	71	68	68	66	67	65	78	77	76	76	73	80	80	79	79	77	76	75	74	74	71
73	71	70	70	69	68	68	66	67	66	74	72	71	70	69	76	75	74	75	73	73	72	71	71	69
76	74	73	71	70	74	73	71	71	69	76	74	73	71	70	78	77	75	74	72	77	76	75	73	71
81	78	77	73	70	80	77	75	73	70	81	78	77	73	70	81	79	77	74	71	83	81	78	75	71
88	81	80	79	70	87	81	80	74	70	88	82	81	74	71	88	83	80	74	71	90	85	82	75	71
92	84	84	74	70	92	84	83	74	70	93	85	84	74	70	92	86	84	74	70	93	88	85	75	71
92	82	83	73	69	92	83	82	73	69	93	85	83	73	70	93	86	84	74	69	93	88	85	74	70
91	78	78	71	68	91	78	77	71	68	93	80	79	72	69	93	81	80	72	69	93	83	81	73	69
80	73	72	69	67	80	73	72	69	67	82	75	74	70	67	84	76	74	70	68	86	77	75	71	68
70	69	69	67	66	71	69	68	67	66	72	70	70	68	66	73	71	69	68	67	74	72	71	69	67
67	67	66	65	64	67	67	65	66	65	68	68	67	66	65	68	68	66	67	66	69	69	67	67	66

Table 15. (Continued)

Date	July 10					12					13					14				
Column	4	4	3	2	1	4	4	3	2	1	4	4	3	2	1	4	4	3	2	1
Row	4	5	4	4	4	4	5	4	4	4	4	5	4	4	4	4	5	4	4	4
Thermocouple #11	78	76	75	75	73	95	95	95	93	93	82	82	83	82	79	73	73	73	73	73
#10	75	74	72	73	71	93	90	92	86	85	81	80	80	79	77	77	78	77	76	76
#9	78	77	75	74	72	87	85	86	81	80	83	82	81	78	77	84	83	82	79	77
#8	83	81	78	75	72	88	86	86	80	77	87	85	83	78	75	89	87	85	80	77
#7	89	85	82	76	72	93	90	89	79	76	91	88	86	78	74	93	91	88	80	77
#6	92	89	85	76	71	95	92	91	78	75	93	91	88	78	73	95	93	90	80	75
#5	93	88	85	75	71	96	92	91	78	74	94	91	88	77	72	95	92	90	77	75
#4	93	84	81	73	69	96	88	87	76	73	94	87	84	75	71	95	89	86	76	74
#3	86	78	76	71	68	90	82	82	74	71	88	81	79	73	70	90	83	81	74	72
#2	75	72	71	69	67	79	76	77	72	70	77	75	74	70	69	79	77	76	72	70
#1	69	69	67	67	66	72	72	73	70	69	71	70	70	69	68	73	72	72	70	69

July 16					17					20					22					24				
4	4	3	2	1	4	4	3	2	1	4	4	3	2	1	4	4	3	2	1	4	4	3	2	1
4	5	4	4	4	4	5	4	4	4	4	5	4	4	4	4	5	4	4	4	4	5	4	4	4
74	74	72	73	71	77	76	75	76	73	77	77	76	76	74	80	79	79	78	76	82	82	81	80	78
74	73	71	72	71	76	75	73	75	73	78	78	76	76	74	79	79	77	76	74	81	81	79	77	76
80	79	76	75	73	82	81	78	77	74	84	83	81	78	76	84	84	81	78	75	86	85	82	79	77
87	85	81	78	75	88	86	82	79	75	89	88	85	79	76	89	88	86	80	76	90	89	86	81	77
91	90	85	79	75	92	90	86	80	75	93	91	88	81	76	93	92	89	81	76	93	92	89	82	77
93	92	88	79	74	93	92	89	80	75	94	93	91	81	76	93	94	91	81	76	94	93	90	82	77
93	92	87	78	73	94	92	89	79	75	94	93	90	80	75	93	94	90	80	75	94	94	91	81	76
93	88	84	76	72	94	89	85	77	73	94	91	87	78	74	94	92	87	78	74	94	92	87	79	75
89	82	78	74	70	89	83	79	74	71	91	86	82	76	73	91	87	82	76	73	91	87	83	76	73
78	76	73	71	69	79	77	75	72	70	81	79	77	73	71	82	80	77	73	71	84	81	78	74	72
72	71	69	69	68	73	72	70	70	68	74	74	73	71	70	75	75	73	71	69	76	75	73	72	70

July 27					30					31					August 3					5				
4	4	3	2	1	4	4	3	2	1	4	4	3	2	1	4	4	3	2	1	4	4	3	2	1
4	5	4	4	4	4	5	4	4	4	4	5	4	4	4	4	5	4	4	4	4	5	4	4	4
95	95	95	94	90	76	76	76	76	76	77	77	76	76	75	76	75	74	74	73	84	83	83	83	80
90	88	88	84	81	82	83	82	80	78	81	81	80	78	76	78	78	77	76	74	82	81	80	78	75
89	87	87	82	79	89	89	88	84	80	87	87	86	82	80	85	85	83	80	77	86	85	84	81	76
91	90	89	83	78	92	92	91	86	81	91	91	91	86	81	90	84	88	84	79	90	89	88	84	78
92	92	91	83	78	94	94	94	89	81	94	94	93	87	82	92	91	91	86	80	91	91	90	86	79
92	92	92	83	77	94	94	94	86	80	94	94	93	86	81	93	92	91	86	80	92	91	91	86	80
92	92	91	82	77	94	94	93	85	79	94	94	93	85	80	93	93	91	85	79	92	92	91	85	79
93	92	89	80	75	94	93	91	82	78	94	94	91	82	78	93	92	89	83	78	92	91	89	83	78
91	88	84	77	74	93	91	88	79	76	93	91	88	80	77	92	91	87	80	76	91	90	87	80	76
84	82	80	75	73	86	85	83	77	74	88	86	83	77	75	89	86	83	77	74	88	86	84	77	74
76	76	74	73	71	79	79	78	74	73	80	79	78	75	73	81	79	78	75	73	80	80	78	75	72

Table 15. (Continued)

		August																				
	Date	7					24					26 (8:30 A.M.)					26 (12 noon)					
	Column	4	4	3	2	1	4	4	3	2	1	4	4	3	2	1	4	4	3	2	1	1	1
	Row	4	5	4	4	4	4	5	4	4	4	4	5	4	4	4	4	5	4	4	4	7	1
Thermocouple	#11	88	87	87	86	83	81	82	79	82	80	69	69	69	71	72	84	83	84	84	84	84	83
	#10	87	85	85	82	78	84	85	82	87	87	79	82	79	83	85	84	82	84	84	84	84	83
	#9	89	88	87	83	78	91	91	88	92	90	90	91	89	91	91	85	83	84	84	84	83	82
	#8	91	91	90	86	80	92	92	90	93	92	94	94	92	93	93	85	83	84	84	83	82	81
	#7	92	92	92	87	80	93	93	90	93	91	94	94	93	93	93	85	82	84	83	81	81	79
	#6	93	92	92	87	80	92	92	90	92	91	94	94	93	93	93	85	82	83	82	80	79	77
	#5	93	92	92	86	80	92	92	90	92	90	94	94	93	93	92	85	82	83	81	79	77	76
	#4	93	92	90	84	78	92	92	90	91	89	94	94	92	92	91	84	81	82	80	79	75	74
	#3	92	91	89	81	86	91	91	89	90	87	93	93	92	90	89	83	81	81	78	75	74	74
	#2	89	88	85	78	75	90	90	88	87	83	92	91	92	88	85	80	79	80	77	74	73	74
	#1	82	81	80	76	73	87	89	84	83	79	88	88	87	84	81	77	77	77	75	74	73	74

August																								
26 (2 P.M.)							27 (8A.M.)							27 (5P.M.)							28 (9 A.M)			
4	4	3	2	1	1	1	4	4	3	2	1	1	1	4	4	3	2	1	1	1	4	4	3	2
4	5	4	4	4	7	1	4	5	4	4	4	7	1	4	5	4	4	4	7	1	4	5	4	4
78	77	78	77	78	78	77	67	67	66	68	69	69	69	74	74	75	75	76	76	76	63	63	62	64
78	77	78	77	78	78	77	69	69	69	70	70	70	71	76	75	76	75	75	76	76	64	65	64	48
78	77	78	77	78	77	76	70	70	70	71	70	71	71	76	74	75	74	74	74	74	71	70	70	71
79	77	78	77	77	76	75	71	71	70	71	70	70	71	75	74	75	74	73	75	75	74	72	72	72
79	77	78	77	76	75	74	71	71	71	71	70	70	71	76	74	75	73	73	75	75	75	73	74	73
79	77	78	76	75	74	73	71	72	71	71	70	69	70	76	74	76	73	72	75	75	80	74	75	73
78	77	78	75	74	73	72	72	72	71	71	70	69	69	77	74	77	73	72	75	75	85	75	76	73
78	77	77	75	73	72	72	72	72	71	71	70	69	69	77	75	77	73	72	74	75	87	75	76	73
78	76	76	74	72	71	72	72	72	71	71	69	69	69	77	75	77	73	72	74	75	82	76	76	73
75	74	75	73	72	71	72	71	71	71	71	69	69	69	76	75	77	72	71	74	75	78	76	76	72
73	73	74	72	72	71	72	70	70	70	70	69	69	69	74	73	75	72	71	74	74	74	74	74	71

			28 (5 P.M)					29					30					31				
1	1	1	4	4	3	2	1	4	4	3	2	1	4	4	3	2	1	4	4	3	2	1
4	7	1	4	5	4	4	4	4	5	4	4	4	4	5	4	4	4	4	5	4	4	4
64	64	64	76	75	75	75	75	67	67	68	68	70	78	76	76	76	76	70	68	68	68	66
69	69	69	76	74	75	73	74	80	72	74	73	73	86	79	79	74	74	82	72	72	68	68
72	72	72	75	73	75	73	74	88	77	79	74	74	97	82	84	75	75	106	83	85	74	73
72	72	72	75	74	75	74	73	93	80	83	75	74	106	87	90	78	76	114	92	94	79	75
71	71	72	77	75	76	74	73	102	83	87	76	74	114	93	97	80	76	118	97	101	83	76
71	71	71	83	76	78	74	72	116	88	95	78	74	120	97	105	82	76	121	100	108	85	76
71	71	71	92	78	81	74	72	119	91	101	79	74	120	100	111	84	76	120	102	112	87	77
71	70	70	99	78	81	74	72	119	91	101	79	74	120	99	110	84	76	118	100	111	87	76
70	70	70	90	79	81	73	72	109	90	97	78	74	113	97	105	83	76	113	98	106	85	76
70	69	70	81	79	80	73	72	94	87	91	77	74	99	92	98	80	75	101	93	100	81	74
70	69	70	77	76	78	73	71	83	80	85	75	72	86	83	88	77	73	87	84	91	77	72

Table 16. Temperature data from Field Experiment Three. Temperatures in degrees F.

		September																	
	Date	1					3					4					6		
	Column	4	4	3	2	1	4	4	3	2	1	4	4	3	2	1	4	4	3
	Row	4	5	4	4	4	4	5	4	4	4	4	5	4	4	4	4	5	4
Thermocouple	#11	77	74	74	73	72	82	79	78	77	75	81	78	75	75	72	76	73	71
	#10	96	81	81	74	72	104	86	85	77	73	103	85	83	77	73	102	86	85
	#9	117	93	95	80	76	126	99	101	84	77	128	100	101	86	79	132	106	108
	#8	123	100	104	85	79	131	105	109	90	81	134	108	110	92	83	136	113	116
	#7	124	103	109	89	80	132	108	113	93	83	134	110	114	95	86	135	115	119
	#6	124	105	113	91	81	129	108	116	94	84	130	110	117	97	86	132	113	121
	#5	121	106	116	92	82	125	108	119	95	84	126	109	119	97	86	127	111	121
	#4	119	104	114	91	81	123	105	116	93	83	123	107	116	95	85	122	108	117
	#3	114	101	109	89	80	116	102	109	90	82	116	103	109	91	83	115	104	110
	#2	103	96	104	85	78	103	96	102	86	79	103	97	101	87	80	103	98	102
	#1	91	88	96	81	75	91	88	94	81	75	91	89	94	82	76	93	91	94

September

6		7					9					11					13		
2	1	4	4	3	2	1	4	4	3	2	1	4	4	3	2	1	4	4	3
4	4	4	5	4	4	4	4	5	4	4	4	4	5	4	4	4	4	5	4
73	71	74	71	70	71	71	68	66	64	66	64	79	78	75	76	73	77	76	74
81	77	101	87	85	82	78	89	81	77	79	75	90	84	81	81	78	86	85	82
91	84	132	107	109	93	86	124	113	103	91	84	117	100	99	95	85	110	100	98
97	88	137	114	117	99	91	131	112	113	98	89	124	108	109	97	89	119	108	108
100	90	135	115	120	101	92	131	113	117	100	91	127	110	113	99	91	125	110	113
100	90	132	114	121	101	93	130	112	118	100	92	128	110	116	99	91	129	111	116
100	88	126	112	121	100	91	125	109	118	91	91	124	108	115	98	91	126	109	117
97	86	122	108	116	97	90	120	105	112	96	89	118	104	109	95	89	120	104	110
94	83	114	103	109	94	87	110	101	104	92	87	108	99	101	91	87	109	100	102
89	79	103	98	101	89	85	100	96	97	88	84	97	94	94	88	84	98	95	96
84	74	94	92	96	85	80	92	91	93	85	80	92	90	91	85	81	94	92	93

September

13		16					17					18					21		
2	1	4	4	3	2	1	4	4	3	2	1	4	4	3	2	1	4	4	3
4	4	4	5	4	4	4	4	5	4	4	4	4	5	4	4	4	4	5	4
76	75	76	75	74	75	74	74	74	73	74	73	77	76	75	75	74	76	76	74
83	81	82	83	81	83	81	80	81	79	81	79	81	82	80	80	78	81	82	80
92	87	102	97	95	91	88	99	95	93	90	85	99	95	93	89	86	98	95	93
97	91	112	104	104	96	91	110	102	102	95	89	109	102	101	94	89	107	101	101
99	92	120	109	111	99	92	118	106	108	97	90	117	106	107	97	91	115	105	106
100	92	127	110	115	100	92	125	108	113	98	90	125	107	112	97	91	122	106	110
99	92	125	108	115	98	92	124	107	114	97	90	124	106	112	97	90	122	105	110
96	90	119	104	110	96	91	117	103	108	95	89	116	102	106	95	89	114	101	105
93	88	107	100	101	93	89	105	98	100	92	87	104	98	99	92	88	103	97	97
90	86	98	96	96	91	87	97	95	94	89	85	97	94	94	90	86	96	94	94
87	83	94	93	94	89	85	93	92	92	88	83	93	92	92	88	84	93	92	92

Table 16. (Continued)

	Date	September 21		23					25					28				
	Column	2	1	4	4	3	2	1	4	4	3	2	1	4	4	3	2	1
	Row	4	4	4	5	4	4	4	4	5	4	4	4	4	5	4	4	4
Thermocouple	#11	75	72	83	82	81	81	79	74	73	72	73	73	82	81	79	79	77
	#10	80	78	89	89	88	86	88	85	86	84	83	82	86	86	85	84	82
	#9	89	85	103	98	98	92	88	102	99	98	91	89	99	97	96	91	88
	#8	94	89	108	102	102	95	90	107	102	102	95	91	104	99	100	94	91
	#7	96	91	113	104	106	97	91	111	104	105	96	92	105	100	101	95	91
	#6	97	91	120	105	110	98	92	117	105	107	97	92	109	100	102	96	92
	#5	97	91	121	105	110	97	91	118	104	108	96	92	110	100	102	95	92
	#4	94	90	113	101	105	95	91	111	101	103	95	91	104	98	98	94	91
	#3	92	89	103	98	99	94	90	102	98	98	93	90	98	95	95	93	90
	#2	91	87	96	95	95	91	88	96	95	95	92	89	95	94	93	92	89
	#1	89	85	94	93	93	90	87	94	93	93	91	88	93	92	92	91	88

September 30					October 2					5					7					9		
4	4	3	2	1	4	4	3	2	1	4	4	3	2	1	4	4	3	2	1	4	4	3
4	5	4	4	4	4	5	4	4	4	4	5	4	4	4	4	5	4	4	4	4	5	4
65	66	65	67	69	77	76	77	77	77	92	91	91	89	86	74	73	72	73	72	71	70	70
81	82	82	82	81	86	86	87	84	82	93	93	93	87	84	82	83	82	81	79	81	82	81
98	97	97	91	89	97	96	97	91	89	98	97	90	90	95	94	95	95	89	86	95	94	95
103	100	100	95	92	101	99	100	94	92	100	97	98	92	90	99	96	96	92	89	100	97	97
104	101	101	96	93	102	99	100	95	93	99	95	97	93	91	99	95	96	92	90	100	96	97
105	100	101	96	93	102	98	100	95	94	99	95	96	93	91	99	95	95	92	90	100	95	96
105	99	100	96	93	102	97	99	95	94	98	94	95	92	91	98	94	94	93	90	100	94	95
101	98	98	95	93	99	96	97	95	93	96	93	94	92	91	95	92	92	92	90	97	93	93
98	96	96	95	92	97	95	96	94	92	94	92	93	92	90	93	92	91	91	90	93	92	92
95	95	95	93	92	95	94	95	93	92	92	92	92	91	90	91	90	90	90	89	91	90	91
94	93	94	92	90	94	93	94	92	91	91	91	91	90	89	90	89	89	89	88	90	89	89

October 9		12					14					16					19					23	
2	1	4	4	3	2	1	4	4	3	2	1	4	4	3	2	1	4	4	3	2	1	4	4
4	4	4	5	4	4	4	4	5	4	4	4	4	5	4	4	4	4	5	4	4	4	4	5
70	70	76	75	74	74	71	65	64	65	66	65	67	67	67	67	65	72	71	70	70	66	66	65
80	78	80	81	80	77	74	79	79	79	77	75	78	79	79	75	71	75	77	76	73	68	75	75
88	84	93	92	91	85	80	94	94	94	87	81	92	92	93	85	79	89	89	89	82	75	89	89
91	88	98	95	95	89	84	100	97	97	91	85	99	96	97	90	83	95	93	93	87	79	94	93
92	89	100	95	95	91	86	101	97	98	92	87	100	96	98	91	86	96	94	94	88	82	95	93
92	90	100	94	95	91	87	102	96	97	91	88	101	95	97	91	86	97	92	92	88	83	94	91
92	90	99	93	94	90	87	100	94	96	91	88	99	93	95	90	87	95	90	91	87	83	91	88
92	90	95	91	91	89	87	96	92	94	90	88	95	91	92	89	86	91	88	88	85	83	87	86
91	89	91	90	89	88	86	92	91	91	89	87	91	89	90	88	86	87	86	86	84	82	84	83
90	89	89	88	88	87	86	89	89	89	88	87	88	87	88	86	85	84	84	83	83	81	81	81
89	88	87	87	86	86	85	87	87	87	86	85	86	86	86	85	84	82	82	81	81	80	79	78

Table 16. (Continued)

		October								November								
Date		23			26					2					9			
Column		3	2	1	4	4	3	2	1	4	4	3	2	1	4	4	3	2	1
Row		4	4	4	4	5	4	4	4	4	5	4	4	4	4	5	4	4	4
Thermocouple	#11	64	64	61	61	60	60	60	59	68	67	67	66	63	55	55	55	55	53
	#10	89	72	67	73	74	74	70	66	74	73	74	69	64	60	60	60	59	57
	#9	89	82	74	88	88	88	81	73	82	82	82	75	69	68	68	68	65	61
	#8	92	85	78	94	92	92	85	77	87	85	86	79	71	73	73	72	69	65
	#7	92	86	79	94	92	92	86	79	87	86	86	79	73	76	75	75	71	67
	#6	90	86	80	92	90	91	85	79	86	84	84	79	74	76	76	75	72	68
	#5	88	84	80	89	88	88	83	79	83	82	81	78	74	74	75	74	71	69
	#4	85	83	80	85	85	85	81	79	79	79	79	76	74	72	73	72	71	69
	#3	82	81	79	82	82	82	80	78	76	76	76	75	73	71	71	70	70	68
	#2	80	80	78	79	80	80	79	77	74	74	74	73	72	69	70	69	69	68
	#1	77	78	77	77	77	77	77	76	72	72	72	72	71	68	68	67	68	67

November										December				
16					30					7				
4	4	3	2	1	4	4	3	2	1	4	4	3	2	1
4	5	4	4	4	4	5	4	4	4	4	5	4	4	4
54	54	54	53	51	51	51	51	50	50	44	44	44	44	44
53	52	53	51	50	51	51	51	50	50	44	44	44	44	44
56	55	56	54	53	51	51	51	50	49	47	47	47	47	47
60	61	61	58	56	51	51	51	51	50	49	49	49	49	49
63	64	64	61	59	52	52	52	52	51	51	51	51	51	51
65	65	66	64	61	53	53	53	53	52	53	53	53	53	53
66	66	66	65	63	54	54	54	54	53	53	53	53	53	53
65	66	66	65	64	54	54	55	55	55	53	53	53	53	53
65	65	65	64	64	55	55	56	56	56	53	53	53	53	53
64	64	64	64	64	55	55	56	56	56	53	53	53	53	53
64	64	64	64	64	55	55	56	56	56	53	53	53	53	53