THERMAL DEFOLIATION OF COTTON

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Bachelor of Science

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1965

Submitted to the faculty of the Graduate
College of the Oklahoma State University
in partial fulfillment of the
requirements for the degree
of
MASTER OF SCIENCE
May, 1966

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PREFACE

The work reported in this thesis was conducted as a part of Regional Research Project 578, "Mechanized Cotton Harvesting in Oklahoma," of the Oklahoma Agricultural Experiment Station. One of the objectives of this project has been to investigate the feasibility of new cotton defoliation methods. This study was conducted to obtain information on the feasibility and practicality of thermal defoliation.

The author is grateful to Professor Jay G. Porterfield, the thesis adviser, for his counsel and encouragement throughout this study. Appreciation is also expressed to Assistant Professor David G. Batchelder for his assistance and suggestions in carrying out this research.

The financial assistance of the Natural Gas Processors Association and of Cities Service Gas Company is gratefully acknowledged.

Appreciation is also expressed to the personnel of the Oklahoma Cotton Research Station at Chickasha, Oklahoma for their assistance in the construction of the equipment and in conducting the tests. The assistance of the Agricultural Engineering Department draftsmen in the preparation of the illustrative materials contained in this thesis is also acknowledged.

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CHAPTER I

INTRODUCTION

With the advent of mechanical harvesting of cotton, defoliation has become an important preparatory operation. In order to insure top quality, clean cotton at the gin, the plants must be induced to shed their leaves prior to harvest to avoid an excessive amount of trash and leaf stain in the lint. Defoliation is probably a more important operation when cotton strippers are used than when cotton pickers are used since stripper harvesting is a non-selective operation. The cotton stripper removes open bolls as well as twigs, leaves, and green bolls whereas the spindle picker selects the open bolls.

The usual method of defoliation has been by means of chemicals, either spray or dust, or by merely waiting for frost to kill the plants. Chemical defoliants have the disadvantage of being unpredictable and inconsistent. There is also the possibility of an undesirable residue (31). Weather conditions and the plant's physiological condition appear to be the chief factors affecting the predictability of the defoliation process.

Super optimal temperatures have been shown to produce a defoliating effect (4, 38). It has been observed that subjecting cotton plants to a high temperature air stream for a short period of time results in some stimulus to the plant which causes some, or all, of the leaves to drop. Thermal defoliation has a distinct advantage over chemicals in that no potentially dangerous residue would be left on the leaves or fiber. However, excessive heat could possibly damage the lint.

The problem of thermal defoliation involves the transfer of heat from some medium, or heat sink, to the leaf in order to raise the leaf temperature to a lethal level. The heat transfer medium chosen was air which was heated considerably above the lethal temperature in order to obtain rapid heat transfer between the air and the plant. An efficient thermal defoliation operation in the field requires that the optimum amount of heat be transferred to the leaf in the shortest possible time. The optimum amount of heat is that amount necessary to cause defoliation and not desiccation, since defoliation is the desired result. Defoliation means the separation of the leaf and petiole from the stem. In the case of desiccation, an abscission layer does not form and the dried leaves remain on the plant. Thermal defoliation, when applied properly, does not kill the entire plant, only the leaves, and regrowth will sometimes occur.

The scope of this study was divided into two parts, a laboratory study, and a field study. For the laboratory study, small cotton plants were treated in a laboratory oven.

These plants were grown in individual containers, usually two plants per container, and treated five weeks after planting. The plants had grown about as much in that period of time as the one-quart containers would allow.

In contrast to the laboratory study, the field study was conducted using a self-propelled two-row thermal defoliation unit working in mature cotton under actual pre-harvest conditions.

CHAPTER II

OBJECTIVES AND HYPOTHESES

OBJECTIVES:

A. Determine the effect of four controllable factors on defoliation and leaf kill. The influencing factors chosen for study were air temperature, exposure time, air velocity, (as determined by the fan speed), and air absolute humidity.

B. Determine the optimum level and combination of these factors for maximum defoliation and leaf kill.

C. Establish a correlation, if any, between the laboratory results and the field results.

D. Investigate the defoliation response differences due to diurnal responses of the plant.

HYPOTHESES:

A. High temperature causes some response in plants resulting in their death or destruction. The leaf temperature can be raised to the lethal point by using a high temperature for a short time, or a lesser temperature for a longer time. The heat transfer to the leaf was believed to be influenced by the amount of air passing over the leaf and hence the air velocity as determined by the fan speed was believed to be an important factor. The literature review revealed some differences in opinion concerning the air humidity and heat transfer.

B. It was hypothesized that multiple regression techniques could be utilized to arrive at a prediction equation involving these four factors and possibly other information recorded at the time of the test.

C. Since the laboratory study was conducted using a rather small sample size and using immature plants, the results could conceivably differ from the field study using a large sample size and mature plants. It would be highly desirable to be able to apply the laboratory results to the field studies and thus eliminate the seasonal nature of the field investigations.

D. It was hypothesized that the plants would have a varying tolerance to high temperatures throughout the day. This could possibly be due to stomatal movement and photosynthesis activity.

CHAPTER III

REVIEW OF LITERATURE

This review of literature has not been restricted to previous investigations on thermal defoliation since such investigations are practically non-existent. The review of literature encompasses, in addition to a discussion of previous studies, the two general topics of high temperature effects on living plants, and heat transfer between the plant and the environment.

Previous Defoliation Studies

Interest in thermal defoliation was first initiated in 1950 when Nisbet (32) obtained a patent on an "apparatus for subjecting cotton plants and the like to hot gases". The idea was not pursued any further, however, until in more recent years.

Batchelder and Porterfield (4) in their work at Oklahoma State University have shown that thermal defoliation can be achieved, and have indicated that some optimum combination of temperature and exposure time may result in the maximum defoliation. The technique employed by Batchelder and Porterfield involved the use of high temperature air passing over the plants. The flame did not come in contact with the plant.

Reifschneider and Nunn (38) have investigated the use of infrared radiation for cotton defoliation and desiccation. Their results are in agreement with the Oklahoma State University study in that there appeared to be some optimum combination of temperature and exposure time which would cause maximum defoliation. Temperatures and/or exposure times above the optimum resulted in desiccation without defoliation.

High Temperature Effects on Living Plants

Most plant physiologists who have studied the effects of super optimal temperatures on living matter have reported the lethal temperature range to be between 113° F and 140° F depending upon the exposure time and the species (3, 11, 30, 34). Northen (34) reported that in most plants, protoplasmic activity cannot be maintained at temperatures much above 104° F. The rate of warming the plant is inversely proportional to the temperature rise required for thermal death (30). For example, if the exposure time is two minutes, the thermal death point may be 140° F, whereas the plant may be killed at 122° F if the exposure time is two hours. A similar observation was made by Collander (cited in 23) who indicated that the lethal temperature decreases by arithmetic progression when the duration of exposure is increased by geometric progression.

The thermal death point is reached suddenly. One of the early investigators of thermal death was Sachs (cited in 3) who in 1864 conducted experiments to determine the effect of high temperature on plants. Using an incubator to heat the leaves of tobacco, pumpkin, and mimosa, he found that all species could withstand temperatures of 106^{o} F to 124^{o} F without harm. However, when the plants were exposed to temperatures above 124^{o} F for over ten minutes, severe injury or death resulted. Immersion in water at 106^{o} F to 124^{o} F killed the plants however.

Belehradek (cited in 17) listed five general theories which may explain the mechanism of heat injury to protoplasm. These mechanisms are coagulation, heat destruction of enzymes, asphyxiation, intoxication and lipoid liberation.

The oldest and most widely accepted theory is coagulation of the proteins in the protoplasm. Baker (3) indicated that the reason for thermal death was the coagulation of the albuminous substances within the cells. This process is exothermic - heat is given off. The rate of the reaction does not follow the van't Hoff-Arrhenius Law that the speed of the chemical reaction is doubled for each 10^{o} C rise in temperature. Instead, the temperature coefficient of coagulation was observed to vary from 25 to 80, i.e., the speed of the reaction was increased by a factor of 25 to 80 for a 10^{o} C rise in temperature. Comparable very high temperature coefficients have been observed for heat coagulation of several proteins (11, 18). This similarity has led to the reasonable suggestion that death of cells at high temperatures results from coagulation of protoplasmic proteins.

There are two common objections to this theory (17). One, proteins usually require higher than lethal temperatures for coagulation; and two, the coagulative changes in the beginning are reversible in protoplasm but irreversible in proteins.

Heilbrunn (18) attempted to answer the question, "Does coagulation precede or follow death of the cell?" In the process of determining that coagulation occurs first, he noted that it was possible to obtain a light coagulation of the protoplasm and then by returning the cell to the original temperature, to induce a recovery. He was thus convinced that coagulation of the protoplasm was a reversible process. In contrast to Heilbrunn's views, Alexsandov (cited in 19) showed that temperatures high enough to injure the plants directly caused denaturation of proteins with an irreversible coagulation of the protoplasm.

In addition, Heilbrunn (cited in 17) noted that small concentrations of ether hastened the coagulation. He advanced the idea that coagulation depends primarily on the action of heat on fats and lipoids which are emulsified in all living matter. These fats are easily liquified at lethal temperatures and their liquification generally results in coagulation of the protoplasm. The coagulation occurs more rapidly as the temperature is increased. Ether in dilute solution increased the fluidity of protoplasm, whereas at slightly higher concentrations it caused coagulation. In experiments using wheat plants, Henckel (cited in 19) observed an opposite response caused by heat. He showed that a comparatively small increase in temperature caused increased heat resistance while a still higher temperature caused injury. Just before death of the cells due to high temperature, the protoplasmic viscosity fell sharply. Bukharin (7) reported that the viscosity of protoplasm continued to increase up to a temperature as high as 109°F.

Experiments with Spirogyra by Northen (34) indicated that the temperature at which the plants were growing greatly affected the time and temperature of coagulation. Less than one minute exposure using a water bath at 109°F was required to cause coagulation in 90 per cent of the cells tested that were collected from pond water at 45°F. In cells collected from pond water at 64°F, between six and twelve minutes were required to cause coagulation at 109°F in 90 per cent of the samples.

Northen (33) proposed a mechanism of heat death which is a combination of the lipoid liberation and protein coagulation theories of Belehradek. Protoplasm is composed of a network of protein and lipoid molecules. According to Northen, protoplasmic elasticity decreases preceding coagulation. The first effect of lethal temperatures is to liberate the lipoids from their combination with proteins in the protoplasmic network. This liberation loosens the structure and accounts for the observed decrease in protoplasmic elasticity. The liberated lipoid molecules fuse to form droplets, and the protein molecules, no longer separated in the network, fuse to form a coagulum. Northen suggested that the heat itself may cause the coagulation, or the heat working with the salts present in the interstices may cause the protein coagulation. When the network was destroyed, the solutions in the interstices formed vacuoles, and vacuolization is known to accompany heat death.

Iljin (20) emphasized the fact that cells having a large proportion of protoplasm and a small vacuole are least disturbed by desiccation and are protected against thermal injury. If the cell is large and the vacuole is correspondingly large, and if the cytoplasm membrane is very delicate, the destruction of the cell is made easy.

According to the hypothesis of Northen, conditions or substances which decrease elasticity should accelerate heat death. Anesthetics and mechanical injury decrease elasticity, and according to Belehradek (cited in 33) anesthetics, mechanical injury, and radiations hasten heat death.

Altergot (cited in 19) expressed another idea concerning heat death which can be classified as a mechanism of intoxication. According to this concept, high temperature disturbs metabolic processes and as a result injury and death follow. Plants are injured and killed by high temperature because of the decomposition of proteins with the release of ammonia. The ammonia, though beneficial to the plant when in the root zone, is toxic to the plant leaves.

Galston and Kaur (cited in 13, 14, 15) have conducted numerous experiments to determine the effect of various hormones on the heat coagulation of proteins. Pectin decreased the heat coagulation of many proteins, including the soluble proteins of pea stems, ovalbumin, and bovine serum albumin. Auxin induced a decrease in the heat coagubility of growing pea stem cells. This inducement was probably the result of the auxin causing a great increase in the soluble pectin content of the treated cells. Also, Galston indicated that increasing concentrations of 2, 4-D sharply reduced the quantity of heat coagulable proteins.

Yarwood (47) observed that when bean, cowpea, cucumber, fig, and tobacco leaves were heated 15-30 seconds at 122° F, 12-48 hours later they tolerated a temperature of 131° F up to three times as long for the same degree of heat injury as did leaves which were not previously heated. Altergot (1) reported that wheat plants that had been adapted to high temperatures withstood two hours heating up to 122° F and more, while those unprepared were completely killed at 118° F. Bukharin (7) found that growing cultivated plants became heat resistant if exposed to a temperature of 86° F for a short period of time. This acquired tolerance to heat was not observed by Sapper (cited in 26) however. He exposed plants to saturated air at temperatures of 104° F to 122° F for periods of one-half hour and found no increase in heat tolerance.

Yarwood (46) has defined translocated heat injury as the injury to unheated leaves which results when the other leaves of the same plant are heated. Yarwood noted that when individual attached leaves of bean and cowpea were heated in a water bath, adjacent leaves were damaged by some translocated stimulus with no apparent injury to the intravening tissue. Translocated injury was never apparent unless the heated leaf was severely injured, and usually not unless the heated leaf was killed. The translocated injury was first evident as loss of turgidity and change of color. Translocated injury was less on young plants than on those that had matured. Yarwood observed, but did not explain, the fact that abrasion of the heated leaf decreased translocation injury. Trials with peach and cucumber demonstrated that injury can be translocated to leaves which are not opposite to the heated leaves. Yarwood hypothesized that translocated heat injury is due to some translocated toxic chemical, although the translocation of chemicals is controversial. Koontz and Biddulph (cited in 46) found no translocation between twin bean leaves, but Jacobson and Yarwood (cited in 46) found translocation of carbon-14 and phosphorus-32. Doutt (cited in 46) indicated that vascular pathways do exist for such translocation.

In the above experiment, direct injury to the heated leaves increased with increased duration of heating. The relationship between exposure time and injury plots as a straight line on semi-log paper. The response to heating showed an ED 50 (dosage for 50 per cent injury) of about 500 seconds at 114° F, 75 seconds at 122° F, 16 seconds at 131° F, 3 seconds at 140° F, and 1 second at 149° F. The temperature coefficient was about 25 for this range. The dosage for translocated heat injury was about ten times that required for direct injury.

Altergot (1) listed several protective responses of plants to prolonged exposure to elevated temperatures. Among these were intensive photosynthesis, production of compounds that physiologically neutralize toxic ammonia, and formation of heat resistant embryonic tissue giving rise to repeated shoot growth.

Other investigators have observed a seasonal and diurnal cycle of heat resistance. Jameson (21) studied heat and desiccation resistance by heating samples of tree twig sections and grass crowns in water. The experiments were carried out under atmospheric conditions in the field, and the degree of injury was determined by a color change when the heated samples were chemically treated. Lethal temperatures were highest in winter and lowest in the late spring. Regressions were calculated for the lethal temperature values and other factors measured at the time samples were taken. Soil moisture and plant moisture were positively related to lethal temperatures, and air temperature, vapor pressure deficit and depression of wet-bulb thermometer were all negatively related, with depression of wet-bulb thermometer being the best indicator of resistance.

Laude (25) studied the diurnal cycle of heat resistance. Using corn, wheat, barley, sorghum, and alfalfa exposed for five hours at temperatures ranging from 122° F to 150° F, he found that the minimum resistance prevailed in the morning and the maximum resistance was attained about midday. Heat resistance increased when plants were exposed to light, and therefore photosynthetic production of organic material was suggested by Laude as an explanation for the increased resistance of plants to heat. Laude also suggested that perhaps a photochemical change or some other influence of light may be responsible for the increased resistance of plants to heat when they are exposed to light.

The stomata on the underside of leaves are light sensitive. They open when exposed to light, and close in the darkness. Curtis and Clark (11) reported that the guard cells of open stomata are more resistant than closed stomata, and suggested that the high sugar content of the guard cells of open stomata may be partly responsible for their increased heat resistance. In accord with this idea, was the finding of Altergot (1) that sugar protects the plasmic proteins sensitive to oxidative destruction.

To determine the heat activation of virus infections, Yarwood (44) compared the heat tolerance of healthy tissues to the tolerance of virus infected tissues. He observed that the tolerance of healthy tissue was less in the early morning than in the late afternoon. The diurnal difference in heat tolerance was attributed to the difference in the carbohydrate content of the leaves. Heat injury was found to be greatest when the leaves were heated in the early morning and then exposed to bright sunlight. On plants exposed to bright sunlight after heating, the upper epidermis was frequently killed, whereas the lower epidermis appeared unchanged. Orientation of the leaves with respect to the sun was important in determining the extent of the injury, with the greatest injury resulting when the leaves were oriented to receive maximum radiation.

The relative humidity of the air has been found to influence the heat resistance of plants. Working with cotton seedlings, Berkley (5) found that for a four hour exposure, the thermal death point in high humidity was 131° F and in low humidity it was 145° F. In low humidity, petioles, stems, and hypocotyls were the first to die. With high humidity, leaves and cotyledons were the first to die. The saturated atmosphere seemed to have an additional effect, that of smothering the plants. Berkley concluded that the lethal temperature depends upon the humidity of the air and the age of the plant.

Shirley (39) observed similar high temperature responses of conifer seedlings to varying relative humidity. Exposures were made in a water bath, in moist air, and in dry air. The plants were exposed for periods of two and five hours. High humidity was between 80 per cent and 94 per cent, and low humidity was generally less than 15 per cent. Five hour exposures caused death at lower temperatures than two hour exposures. The average lethal temperature for all species exposed for five hours to hot air of high relative humidity was about 124° F. The lethal temperature for the five hour exposure in moist air corresponded to the two hour exposure in water. For five hour exposures in dry air, the lethal temperature varied from 126° F for needles to 133° F for stems.

The cooling effect of transpiration is a much disputed topic. According to Berkley (5) and Shirley (39), the cooling effect of transpiration is of great value to plants in preventing overheating. On the contrary, Ansari and Loomis (2), Clum (8), and Watson (42) stated that the reduction in leaf temperatures as a result of transpiration was small. Berkley and Shirley based their conclusions on the fact that a higher temperature was required to kill plants in dry air. Their belief is that the greater resistance to heat in dry air is a result of the cooling effect of transpiration.

Watson (42) pointed out that neither transpiration nor thermal emission can be called the more important factor in the dissipation of heat. Factors to be considered in such a study are the transpiration rates, the water content of the leaves, and the rate of energy absorption. Curtis and Clark (11), Levitt (26), and Meyer, et. al. (30) all agree that tissues low in water content can endure higher temperatures than those with a high water content. According to Watson, the conclusion that all heat dissipation is through transpiration has led past investigators to overemphasize the importance of transpiration. For any given transpiration rate, the role of thermal emission becomes increasingly important with increase in temperature difference between the leaf and air.

The leaf's position has a marked influence on the rate of transpiration. Clum (8) and Konis (24) report that the maximum transpiration rates occur in horizontal leaves and any deflection from the horizontal leads to decreased transpiration with the greatest decreases occuring in vertical leaves.

Curtis (10) believes that much leaf temperature data has been misinterpreted. He stated that one of the most common mistakes found in the literature dealing with transpiration is the claim that a rise in air temperature increases transpiration because it lowers the relative humidity of the atmosphere, or increases its vapor pressure deficit. The change in relative humidity of the atmosphere around the leaf brought about by an increase in temperature has no tendency to increase transpiration unless the leaf also is heated. Heating of the leaf alone is responsible for the increased transpiration.

Wind has an influence on transpiration according to Martin and Clements (28). They reported that the transpiration rate increased rapidly with low wind velocity but approached a constant value of approximately 50 per cent increase at velocities of 15 to 16 miles per hour. The high initial rate of transpiration that took place at the onset of wind in the higher range of velocities apparently caused a reduction in the sap content of the leaves as was shown by their slightly wilted appearance.

Woolley (44) proposed three mechanisms by which wind influences transpiration. They are, (a) decrease in air pressure on the lee side of the leaf, causing increased evaporation on this side; (b) ventilation of intercellular spaces, caused by actual passage of air through amphistomatous leaves; and (c) bending of the leaves in the wind, causing compression of the intercellular spaces and consequent pumping of saturated air out of the stomata. Woolley concluded from theoretical considerations that none of these mechanisms could account for an appreciable amount of transpiration.

Heat Transfer Between the Plant and the Environment

The usual analysis of a heat transfer problem involves a consideration of conduction, convection (both free and forced), and radiation. In the case of a plant and its environment, the heat transferred by conduction from the leaves through the stem to the ground has been shown to be insignificant (43). However, Brown and Escombe (cited in 37) have indicated that heat is transferred in three ways: through conduction and convection in the form of sensible heat; through the evaporation of water in the form of latent heat; and by radiation.

In studies of heat transfer coefficients, the leaf is normally considered similar to a flat plate. McAdams (29) gives relationships for the heat transfer coefficients for heat leaving the upper surface of a horizontal plate (or leaf),

$$h = 0.27\left(\frac{t_L - t_{air}}{L}\right)^{\frac{1}{4}}$$

the heat leaving the lower surface of a horizontal plate,

$$h = 0.12 \left(\frac{t_L - t_{air}}{L} \right)^{1/4}$$

and the heat leaving one side of a vertical plate,

$$h = 0.29 \left(\frac{t_L - t_{air}}{L} \right)^{1/4}$$

where,

h = heat transfer coefficient, Btu/(hr ft^2 $^\circ$F)

t_L = temperature of the plate or leaf, $^\circ$F

t_{air} = temperature of the air, $^\circ$F

L = characteristic length, ft.

Wolpert (43) then used an average of McAdams' results, and since the heat is transferred from two sides of the leaf, he concluded that for natural convection from leaves,

$$h = 0.49 \left(\frac{t_L - t_{air}}{L} \right)^{1/4}$$

Gates (16) presents an equation of the same form relating the quantities when measured in the metric system. According to Gates, the heat lost by free convection from a horizontal plate or leaf in air is given by

$$Q_c = 6.0 \times 10^{-3} \quad \frac{\Delta T^{1.25}}{L^{0.25}} = h_c \quad \Delta T$$

where,

Q_c = heat flow rate, cal/(min. cm^2)

ΔT = difference in temperature between the leaf and air, $^\circ$C

L = characteristic length, cm.

This equation, like that of Wolpert, averages the situation for a warm upward-facing and a warm downward-facing surface.

Drake (12) obtained data on the heat transfer from an inclined flat plate in an air stream. His data may be represented by the equation,

$$\frac{Nu_x}{(Re_L)^{\frac{1}{2}}} = C\left(\frac{x}{L}\right)^n$$

or upon rewriting this equation as outlined by Wolpert (41),

$$h_x = C\left(\frac{X}{L}\right)^n\left(\frac{V\rho L}{\mu}\right)^{\frac{1}{2}}\ \frac{k}{X}$$

The average heat transfer coefficient is given by,

$$h = \frac{1}{L}\int_L h_x\ dx = \left(\frac{\rho}{\mu}\right)^{\frac{1}{2}} k\ \frac{C}{n}\left(\frac{V}{L}\right)^{\frac{1}{2}}$$

$$h = 1.3\ \frac{C}{n}\left(\frac{V}{L}\right)^{\frac{1}{2}}$$

where,

h_x = heat transfer coefficient at position x, Btu/(hr. ft^2 ^oF)

C = dimensionless parameter

n = dimensionless parameter

x = distance downstream from the leading edge of a surface exposed to a moving air stream, ft.

k = thermal conductivity of the air, Btu/(hr. ft. ^oF)

V = air velocity, mph

L = characteristic length, ft.

ρ = density of the air, lb_m/ft^3

μ = viscosity of the air, $lb_m/(hr\ ft)$

From Wolpert's data, the ratio C/n varies only slightly as the plate orientation varies from parallel to perpendicular to the air flow. Therefore, for forced convection,

$$h = (1.35 \pm 0.03)\left(\frac{V}{L}\right)^{\frac{1}{2}}$$

Brooks (6) presents a graph showing the temperature differences needed to provide the convective heat transfer from air to the leaf to balance a net radiation load of 10 Btu/(hr ft^2). The curve is a straight line between wind velocities from 1 to 20 miles per hour. In this range of velocities the temperature difference required for a heat transfer rate of 10 Btu/(hr ft^2) ranges from 3.0 °F at 1 mph to 0.7 °F at 20 mph.

The most comprehensive study of heat transfer by convection is that of Raschke (36). He utilized the boundary layer concept to explain the heat transfer rates. The boundary layer is of zero thickness at the windward edge of the leaf and increases as the air moves over the leaf. The thickness of the boundary layer decreases as the wind velocity increases as can be seen from the following equation assuming laminar flow;

$$\delta = 3.4\left(\frac{vx}{u}\right)^{\frac{1}{2}}$$

where,

δ = boundary layer thickness, cm

v = kinematic viscosity of the air, cm^2/sec

x = overflow distance, cm

u = wind velocity, cm/sec

The boundary layer deepens for turbulent flow. Heat flow through the laminar boundary layer is by conduction according to the law of heat conduction,

$$K = \frac{\lambda}{\delta}\,\theta$$

where,

K = heat flow rate, cal/min

λ = conductivity of the air in the boundary layer, cal/(min cm °C)

θ = temperature difference between the leaf and air, °C

Eckert (cited in 29) has indicated that the temperature distribution in the boundary layer is described better by a cubic parabola. As a result.

$$K = \frac{3\lambda}{2\delta}\,\theta$$

and the term $3\lambda/2\delta$ is equivalent to the heat transfer coefficient, h. Now it is apparent that the heat transfer coefficient is inversely proportional to the boundary layer thickness, and consequently the heat transfer coefficient increases with increasing wind velocity. Also the coefficient decreases as the distance from the windward edge increases and this results in a lower heat transfer coefficient for a large leaf. Combining the expressions for h and δ, the heat transfer coefficient h_x at any point on the upper surface of a leaf can be determined;

$$h_x = 0.44\,\lambda\left(\frac{u}{vx}\right)^{\frac{1}{2}}$$

The preceding discussion has been concerned only with laminar flow; however, the air circulation around a plant is normally of a turbulent nature. Numerous investigators cited by Raschke (29) have related the heat transfer coefficient to the wind velocity and leaf size by the following expression,

$$h = C\, x^{m}\, u^{n}$$

where,

C = shape factor of the leaf

m = dimensionless exponent

n = dimensionless exponent

x = leaf width, cm

u = wind velocity, cm/sec

Raschke indicated that appropriate average values for m and n are -0.3 and 0.5, respectively.

An absolute value of h depends upon knowledge of the constant (shape factor) in the preceding equation. In Canna leaves with a length-width ratio of 9:5, the constant is 0.0776 when the air moves across the leaf, and hence for a Canna leaf of width x,

$$h = 0.0776\, x^{-0.3}\, u^{0.5} \quad \text{cal/(min cm}^2\ {}^{\circ}\text{C)}.$$

When the wind moves over the leaf longitudinally, the shape factor was determined to be 0.0675.

The second method of heat transfer as given by Brown and Escombe is through the evaporation of water in the form of latent heat. As reported by Keshin, et. al. (22) plant tissue contains three forms of water, the specific heats of which are different. Water in plants can be firmly bound (specific heat, 0.5 cal/gm °C), loosely bound (specific heat, 0.5 to 1.0 cal/gm °C), or it may exist as free water (specific heat, 1.0 cal/gm °C). Experiments have shown that the maximum amount of firmly and loosely bound water is observed in the leaves of mesophytes (32.46 per cent) and xerophytes (24.99 per cent). The bound water content of succulents is only 5.76 per cent and that of hydrophytes is 8.61 per cent. The specific heat of living leaves also depends upon the above classification. It is a minimum in xerophytes (0.709) and a maximum in the succulents (0.956). The values for mesophytes and hydrophytes are 0.820 and 0.908 respectively. Keshin lists values of the specific heat and bound water content of 14 species of mesophytes. The average of that tabulation are:

Total water content, per cent of leaf weight		84.20
Bound water content, per cent of leaf weight		28.02
Bound water content, per cent of total water content		32.46
Specific heat, cal/gm °C		
a. leaves	0.820	± 0.054
b. water in leaves	0.912	

As the air passes over the leaf, transpiration increases. Luikov (27) indicated that the boundary layer thickness increased with evaporation, and as indicated above, an increase in the boundary layer thickness results in a decrease in the heat transfer coefficient. With vapor condensation a different process takes place which leads to an increase in the heat transfer coefficient. Experiments on liquid evaporation from an open surface showed that heat transfer coefficients with evaporation, h_e, were greater than those without evaporation, h_o, under the same hydrodynamic and temperature conditions. This difference (h_e-h_o) increases with a decrease in relative humidity.

Isachenko (cited in 27) listed the following equation for evaluation of the Nusselt number for air flowing over a moist surface;

$$Nu = \frac{hx}{k} = 0.00455\ (Re)^{0.8}\left(\frac{Cp\ \Delta t}{r}\right)^{-0.4}$$

where,

h = heat transfer coefficient, cal/(min cm^2 ^oC)

x = characteristic length, cm

k = thermal conductivity of the air, cal/(min cm ^oC)

Re = Reynolds number, dimensionless

C_p = specific heat of air at constant pressure, cal/(gm^oC)

$\Delta t = t_a - t_b$

t_a = temperature of the moist air, ^oC

t_b = temperature of the adiabatic saturation state, ^oC

r = latent heat, cal/gm

The final mode of heat transfer is by radiation. The energy received by the plant from radiant sources, primarily the sun, is a function of the leaf absorptivity, reflectivity, and the transmissivity. The plant also loses heat by radiation in proportion to the emissivity of the leaf and the temperature difference between the leaf and air.

Shull (40) presents an appraisal of some work by Brown and Escombe. Brown and Escombe used the following equation to calculate the heating effects of absorbed radiation, on the supposition that there was no dissipation of energy by internal work;

$$\Delta t = \frac{Ra}{ms}$$

where,

Δt = change in temperature of the leaf, ^{o}C/min

R = total incident ratiation, cal/(min cm^2)

m = mass of 1 cm^2 of the leaf lamina, gm

a = coefficient of absorption of energy

s = specific heat of the leaf, cal/(gm ^{o}C).

Values used by Brown and Escombe for leaves of Helianthus Annuus were; R = 0.8, m = 0.020, a = 0.78, and s = 0.879. Shull used Brown and Escombe's values of R, a, and s with his own determination of m to compute Δt for 39 different species. However, Shull believes that a better value for R would be 0.55 cal/(min cm^2). Also, the coefficient of absorption needs to be corrected for reflection and the value of Ra should be reduced by the amount of energy used in photosynthesis. When these corrections are made, the values of Δt computed and tabulated by Shull are found to be about double the actual temperature rise.

Various attempts have been made to write an energy economy equation for plant leaves. One such approach has been presented by Waggoner and Shaw (41). The economy proposed is, (Energy from insolation) +

(Energy from respiration) = 2 (Energy consumed in transpiration)

+ (Energy consumed in photosynthesis)

+ (Energy exchange).

The energy from insolation (or radiation) was given as 0.60 and 0.15 cal/(min cm^2) (133 and 33 Btu/hr ft^2) for perpendicular and parallel leaves respectively. The energy from respiration as well as the energy consumed in photosynthesis was determined to be negligible. The value for twice the energy consumed by transpiration was 0.15 cal/(min cm^2) (33 Btu/hr ft^2). According to Brown and Wilson (cited in 41) the energy exchange, E, can be expressed as the product of the emissivity, H, and the temperature difference between the air and leaf, ΔT. The emissivity was expressed in terms of the wind velocity as,

$$H = 10^{-4} (119 + 1.74 V)$$

where V is the wind speed in meters per minute. Using Brown and Wilson's results, the economy equation becomes,

$$2E = 2H \Delta T = 2 \times 10^{-4} (119 + 1.74 V) \Delta T$$
$$+ \text{(Energy from insolation)}$$
$$-2 \text{(Energy consumed in transpiration)}.$$

Thermocouples were placed in the leaves by Waggoner and Shaw to determine the leaf temperature in an effort to check the validity of the proposed energy economy. The results obtained indicated that no appreciable error was introduced by considering photosynthesis to be negligible.

Perhaps the most comprehensive analysis of the energy economy of plants is that of Wolpert (43). He analyzed the situation for both thin leaves and thick leaves. Thin leaves are leaves whose top and bottom surfaces are at the same temperature. Heat is assumed to be absorbed by the plant from the sun's radiation. Dissipation of heat occurs through convection, re-radiation, evaporation, and chemical energy absorbed by photosynthesis. In equation form this is,

$$Q_{sun} = Q_{conv} + Q_{rr} + Q_{ev} + Q_{chem}$$

The energy received by the plant is dependent upon the angle of the leaf with respect to the sun's rays. For any position of the leaf around midday,

$$Q_{sun} = 120 \sin \theta \text{ Btu/hr ft}^2.$$

The convective heat transfer is determined by,

$$Q_{conv} = 2\, h\, (t_L - t_{air}).$$

Convection may be either forced or natural and the heat removed from smooth plant leaves by these methods is,

$$Q_{fc} = 2.70\left(\frac{V}{L}\right)^{1/2} (t_L - t_{air})$$

and

$$Q_{nc} = 0.49\left(\frac{t_L - t_{air}}{L}\right)^{1/4} (t_L - t_{air}).$$

The terms in these equations have been defined above in other citations from Wolpert. For leaves with significant leaf hair, the values above must be increased by the factor A_L'/A_L, where A_L' is the total area of leaf surface and hair surface and A_L is the area of the leaf surface without hair.

For a thin leaf,

$$Q_{rr} = 1.1\ \varepsilon_L\ (2t_L - t_{air} - t_g)$$

where ε_L is the emissivity of the leaf and t_g is the ground temperature in degrees Fahrenheit.

The heat transferred from the leaf by evaporation of water is,

$$Q_{ev} = h_{fg}\ W_w = 22\ W_w$$

where W_w is the water evaporation rate in gm/hr dm^2.

If a photosynthesis efficiency of two per cent is assumed then,

$$Q_{chem} = 5.6 \sin \theta .$$

Heat transfer from the leaf to the ground by conduction was neglected as well as the heat transfer by the mass movement of water. When all the above quantities are substituted into the general equation, the equation can be solved for the temperature difference between the leaf and air as shown below assuming the wind velocity is in excess of two or three miles per hour;

$$t_L - t_{air} = \frac{114 \sin \theta - 22\ W_w}{2.7 \left(\frac{A_L}{A_L}\right)\left(\frac{V}{L}\right)^{\frac{1}{2}} + 2.2\ \varepsilon_L}$$

This equation can be solved for the temperature difference when the variables θ, W_w, L, etc. are known and this temperature difference can then be used to calculate the amount of heat transferred by each of the four mechanisms. An analysis of these mechanisms by Wolpert indicated that the temperature of a typical plant leaf is controlled by convection if the leaf does not flap in the wind. Wolpert determined that 63 per cent of the heat removed is removed by convection. If the leaf flaps in the wind but has some water evaporation, the water evaporation is probably the controlling factor.

CHAPTER IV

APPARATUS AND EQUIPMENT

The two primary pieces of equipment used in this study, a laboratory defoliating oven and a field defoliation unit, were constructed at the Oklahoma Cotton Research Station.

Laboratory Equipment

The laboratory oven is illustrated in Figures 1, 2, 3, and 4. Schematic diagrams (Figures 5 and 6) further define the components and their arrangement. A 10 inch square air duct connected the oven chamber to a 12 inch diameter straight-blade centrifugal fan. The air was forced through the combustion area (Figure 5), where it was heated, prior to entering the plenum shown in Figure 6. From this 48 by 18 by 11 inch plenum above the oven chamber, the heated air was forced down the walls of the oven through a two inch passage. The air entered the oven chamber in a horizontal direction through a two inch opening near the base of the walls (Figure 2).

Heating of the air was accomplished by means of four Gotcher burners, equipped with two 2504 burner tips, connected to an LP gas supply as illustrated in Figure 3. Either two or all four of the burners could be used at once depending upon the temperature requirements. All four burners were

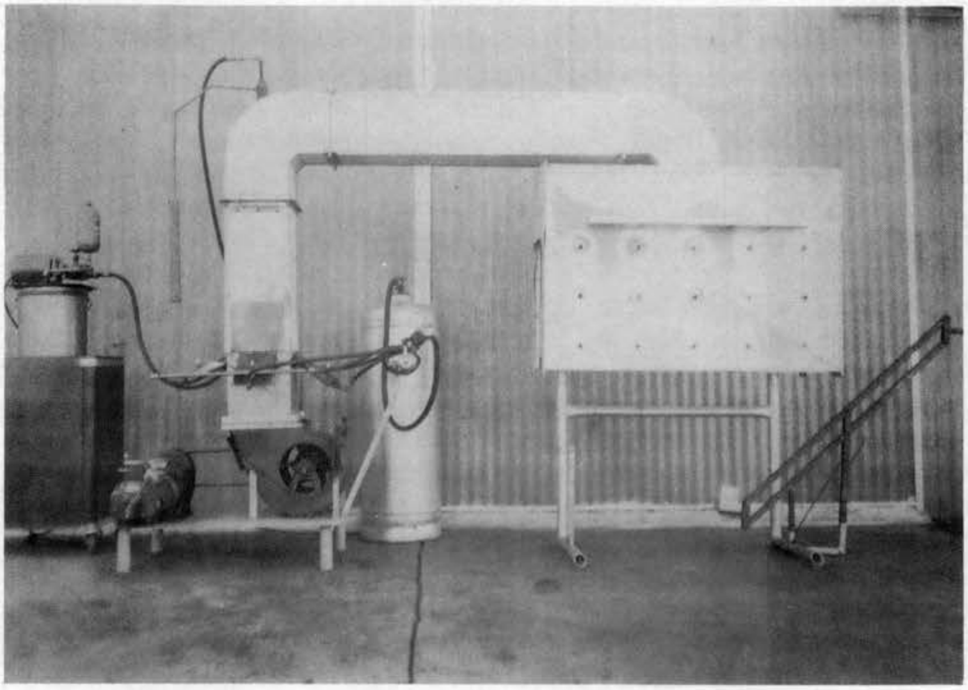

Figure 1. General View of the Laboratory Oven Showing all the Components

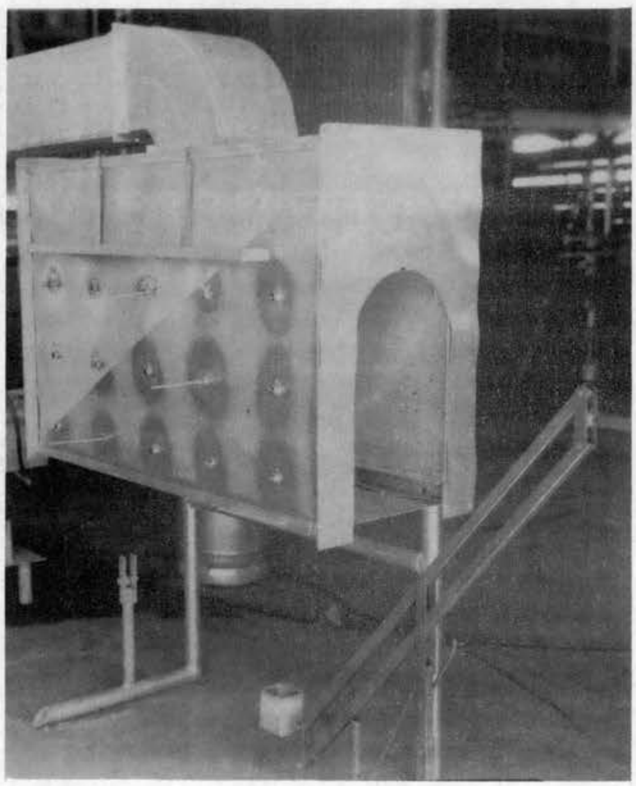

Figure 2. End View of the Laboratory Oven

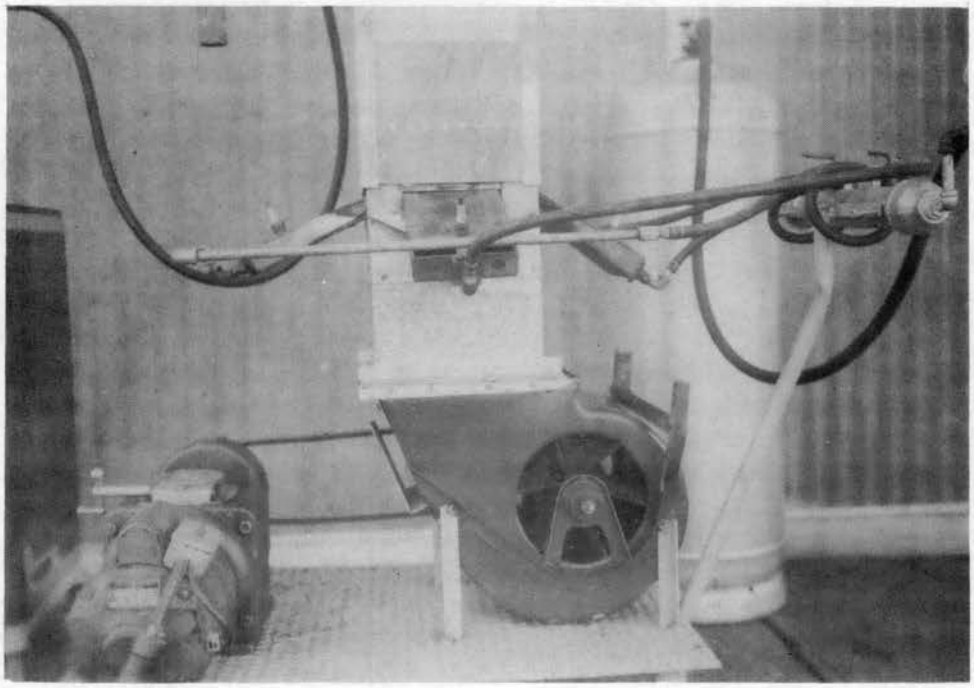

Figure 3. Fan and Burner Arrangement on the Laboratory Oven

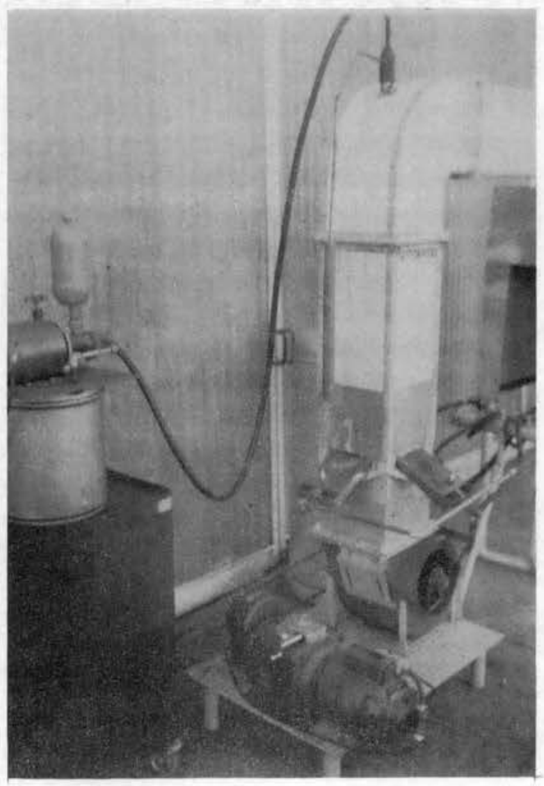

Figure 4. Spray System Used for Humidifying the Air

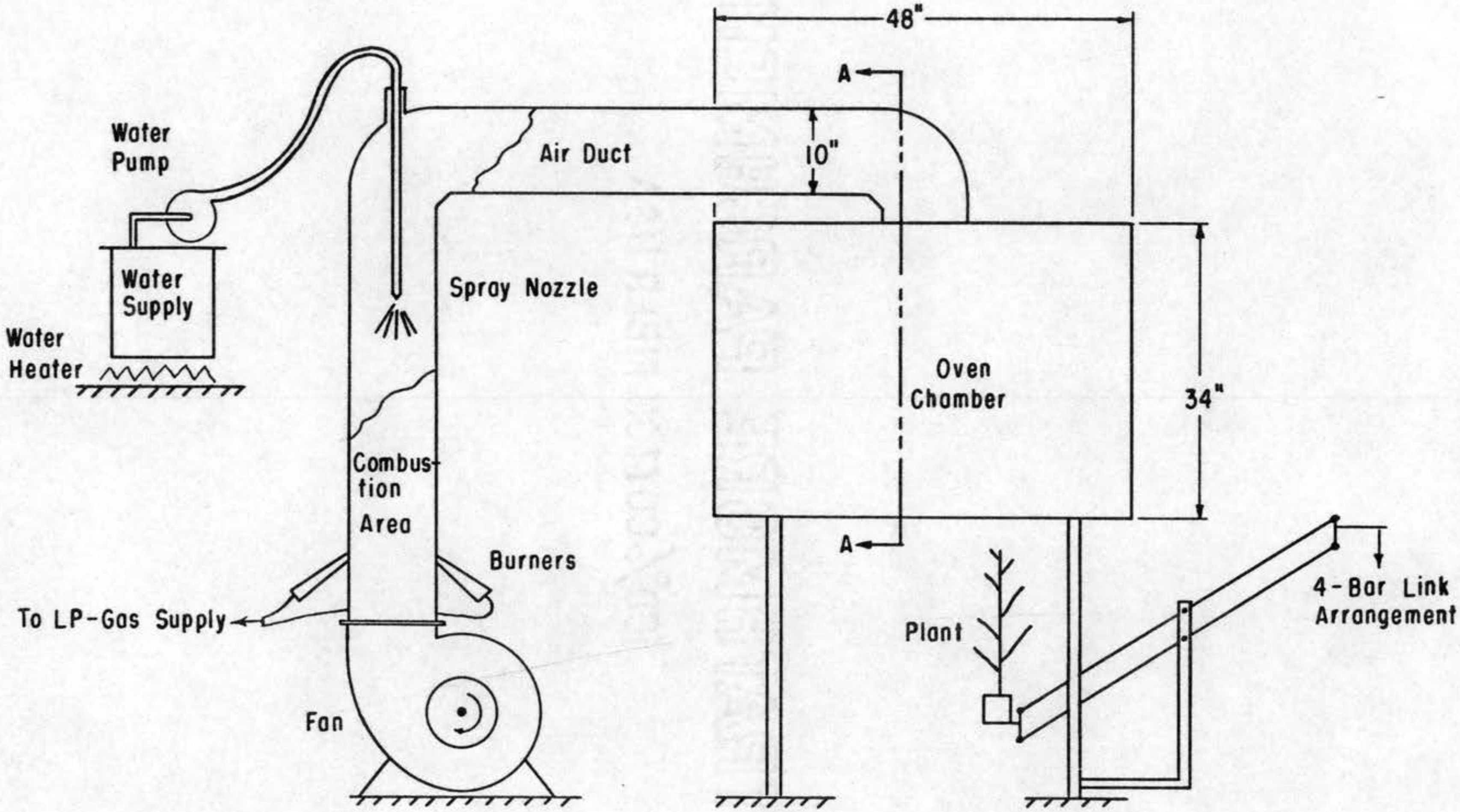

Figure 5. Schematic Diagram of the Laboratory Apparatus

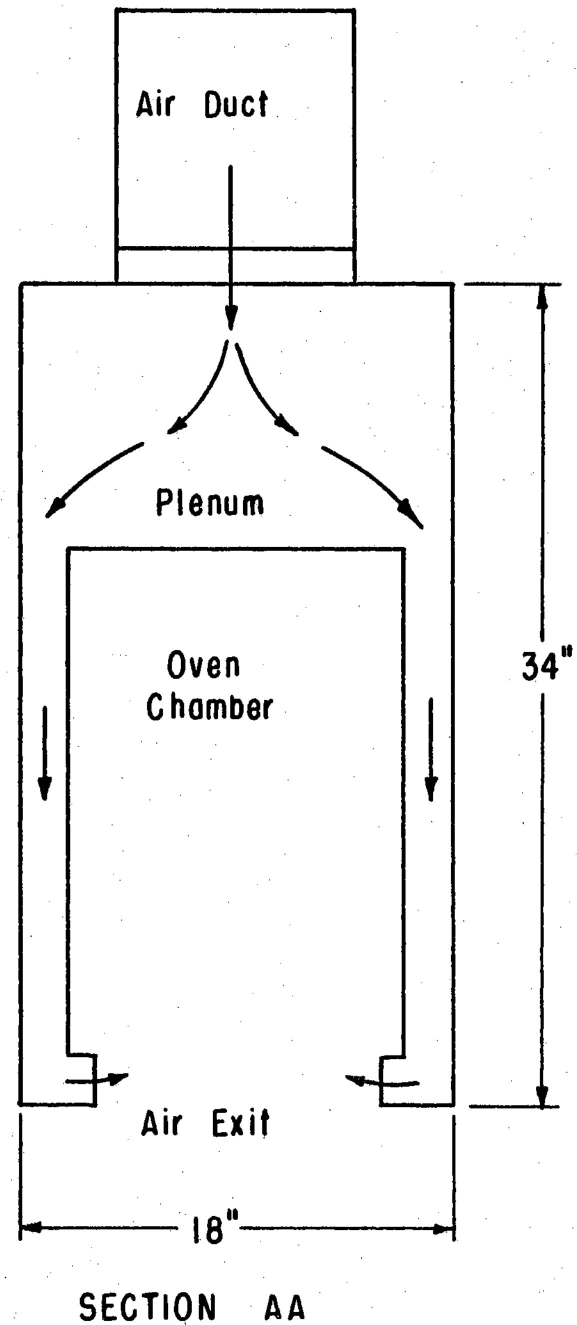

Figure 6. Cross Section of the Oven Chamber Showing the Air Flow Pattern

needed for the maximum temperatures and air flow rates used in this study.

The openings in the side of the oven chamber seen in Figures 1 and 2, were used for inserting thermometers to obtain a temperature profile, and to monitor the exposure temperature during the tests. Three mercury thermometers can be seen in Figure 2 protruding from the oven wall.

An initial attempt was made to control the exposure time by moving the plants, which were in individual containers, horizontally through the oven chamber. This was done using a drag chain, track, and a variable speed drive unit. The acceleration required for the short exposure time was such that the containers tended to overturn, and the plants were subjected to rather violent agitation. An alternative procedure was devised to control the exposure time. A four-bar link arrangement (Figures 2 and 5) was used to insert the plants into the oven in a vertical direction. This method proved to be quite satisfactory and since the region below the oven was heated only slightly, the plants were not subjected to excessive heat prior to being inserted into the oven chamber.

A one-fourth horsepower Graham variable speed drive unit was used for the driving mechanism on the fan. Consequently the fan speed could be readily changed as required by the various test conditions.

In order to change the humidity of the heated air, a cone type spray nozzle was extended into the air duct (Figures 4 and 5). Water could be pumped through the system under pressure up to 100 psi. In order to vaporize the maximum amount, the water was preheated to 180°-200°F prior to being sprayed into the air stream. The nozzle was calibrated twice throughout the six week period during which the laboratory study was being conducted.

Field Equipment

A two-row defoliating unit was used in the field. Figures 7, 8, 9, and 10 illustrate the main features of the field unit which was used in this investigation, but was not designed by the author. The duct work and hover system was mounted on a high clearance self-propelled tractor unit. The air flow pattern was essentially the same as in the laboratory oven, i.e., the hot air entered the oven chamber in a horizontal direction near the bottom of the chamber. Heating of the air was accomplished by two rows of eight burners each, located on each side of the unit near the top of the hovers (Figures 7 and 8).

The double doors at the front and rear of each hover (Figures 9 and 10) were spring loaded and opened by the passage of the plants through the heating chamber. The exposure time was controlled by the ground speed of the defoliation unit.

No attempt was made to humidify the air when using the field unit. Results from the laboratory study did not indicate that humidifying the air would make a significant difference in defoliation, and therefore humidifying

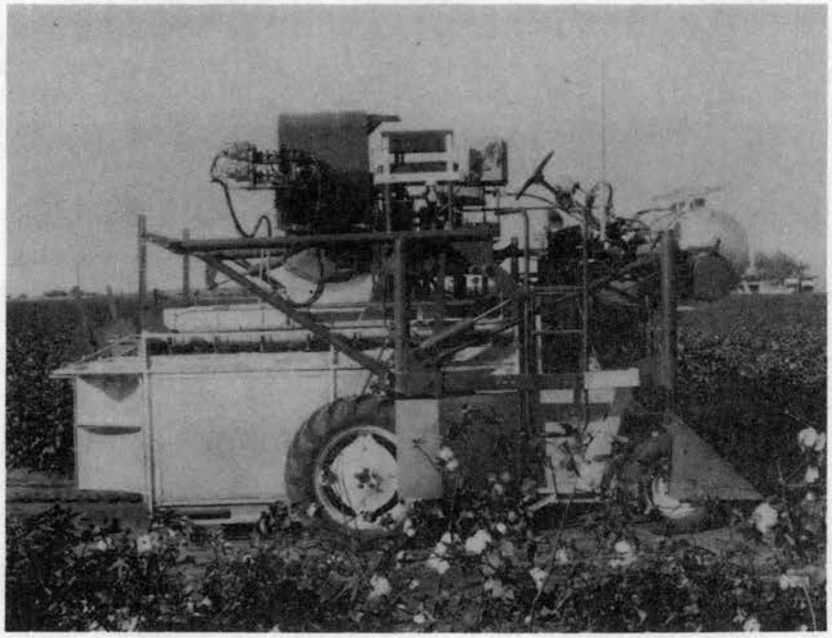

Figure 7. Right Side View of the Field Defoliation Unit

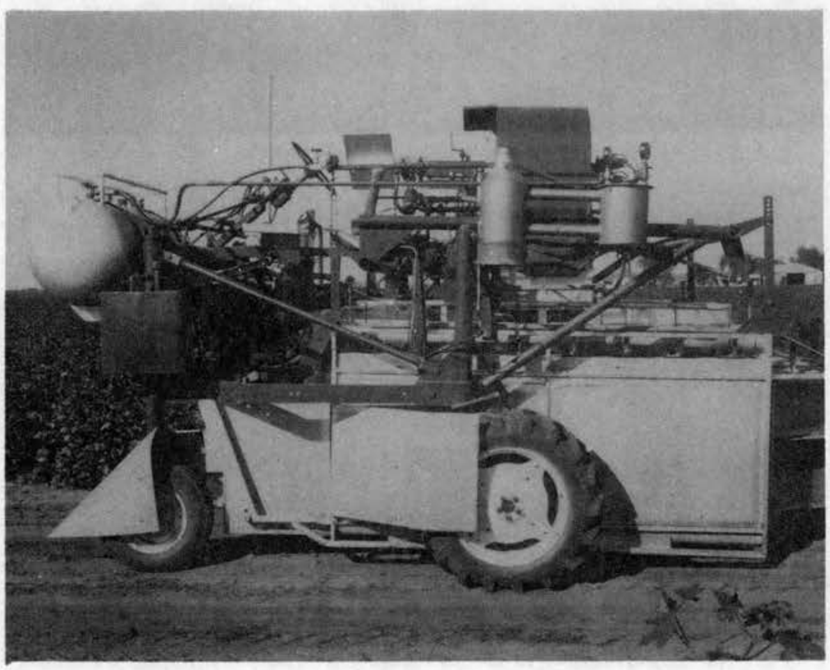

Figure 8. Left Side View of the Field Defoliation Unit

Figure 9. Front View of the Field Defoliation Unit

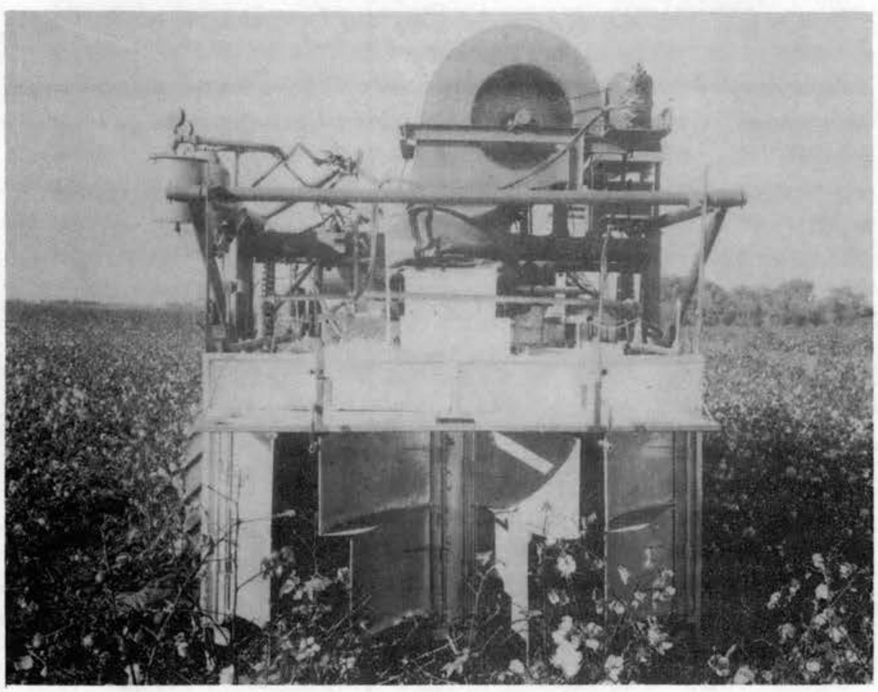

Figure 10. Rear View of the Field Defoliation Unit

equipment was not installed on the field unit.

A 22 inch forward-curved-blade fan was used for air circulation, and was equipped with a variable speed sheave arrangement for changing the fan speed, and consequently the air velocity.

The temperature was measured and monitored using thermocouples and a Leeds Northrop Model S Speedomax H indicating strip chart temperature recorder. This instrument was mounted on the defoliation unit (upper left in Figure 9), and was powered by a twelve volt wet cell battery.

CHAPTER V

METHODS AND PROCEDURE

Laboratory Study

Preliminary investigations were carried out in order to determine the range and capabilities of the fan and heating unit. With the variable drive unit used, a maximum fan speed of 1700 rpm was possible. A Dwyer pitot tube was used to measure the air velocity in the duct immediately downstream from the fan. The velocity was measured at room temperature and at 400°F with fan speeds of 750 rpm and 1300 rpm. At 1700 rpm a velocity measurement was made at 600°F as well as at room temperature and 400°F. The results of these velocity measurements are plotted in Figure 11. All preliminary investigation data is contained in Appendix A.

The velocity at the exit, near the base of the oven chamber, was considerably less than the velocities indicated by Figure 11 due to pressure and friction losses in the system. Using a velometer, an approximate exit velocity was determined for the case of unheated air. Due to the turbulent nature of the exit conditions, an accurate velocity measurement using a pitot tube was not possible. The exit velocities were estimated to be 655, 1130, and 1510 ft/min for the 750, 1300, and 1700 rpm fan speeds respectively.

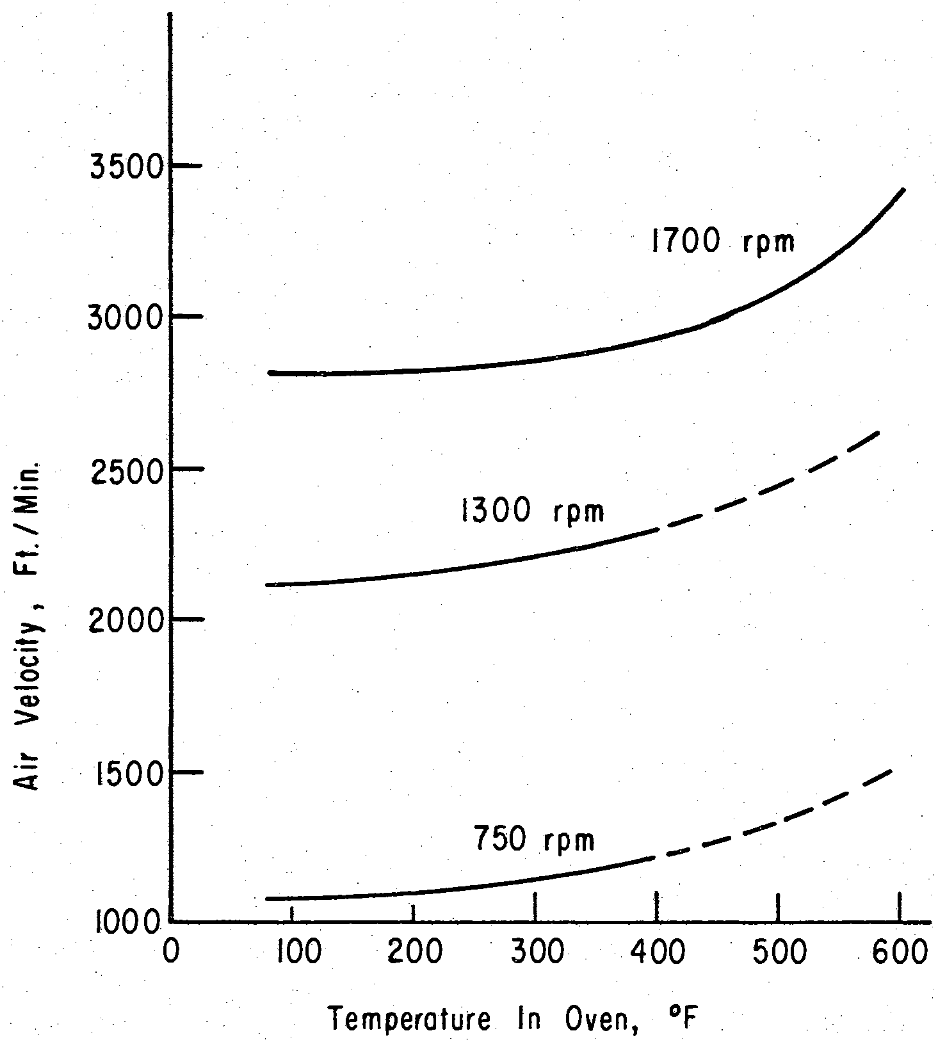

Figure 11. Air Velocity in the Air Duct as a Function of Oven Temperature for Various Fan Speeds

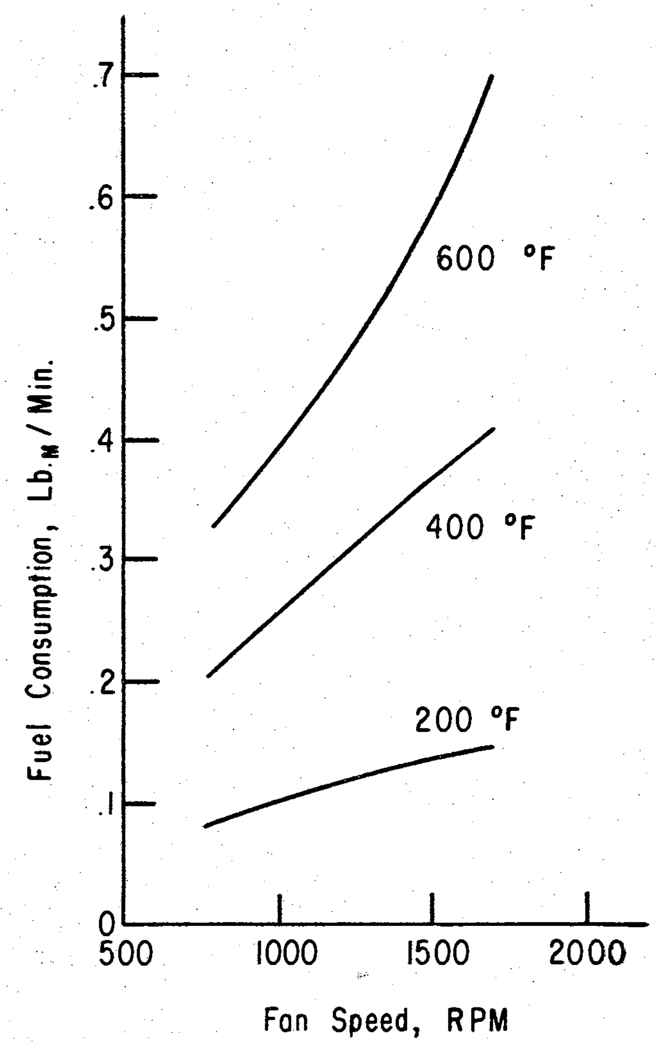

Figure 12. Fuel Consumption as a Function of Fan Speed for Various Temperatures

Four LP gas burners were used for heating the air. Preliminary investigations indicated that an oven temperature of $600^{\circ}F$ with a fan speed of 1300 rpm could be maintained using only two of the four burners. However, at $600^{\circ}F$ and 1700 rpm, all four burners were needed to maintain the high temperature. Fuel consumption data was obtained at various temperatures and fan speeds. This data is presented graphically in Figure 12. A temperature profile revealed that the maximum temperature difference indicated by three thermometers placed in the vicinity of the plant in the oven was $15^{\circ}F$.

It was desired to add as much water vapor to the heated air as possible since it was believed this would enable the investigator to detect any response differences if they should exist. The flow rates of four cone spray nozzles were determined as a function of pressure. These nozzles were then in turn mounted on the water injection apparatus in the hot air stream. To determine the maximum vaporization rate, the following procedure was used. At a given temperature and fan speed, the water pressure was continually increased until liquid was observed collecting on the sides of the duct. The pressure was then decreased slightly and if liquid ceased to collect on the duct walls, it was concluded that all the liquid spray was being vaporized. From the pressure settings, the vaporization rate in lb_m/min was determined for the particular temperature and fan speed setting. The maximum vaporization rates were

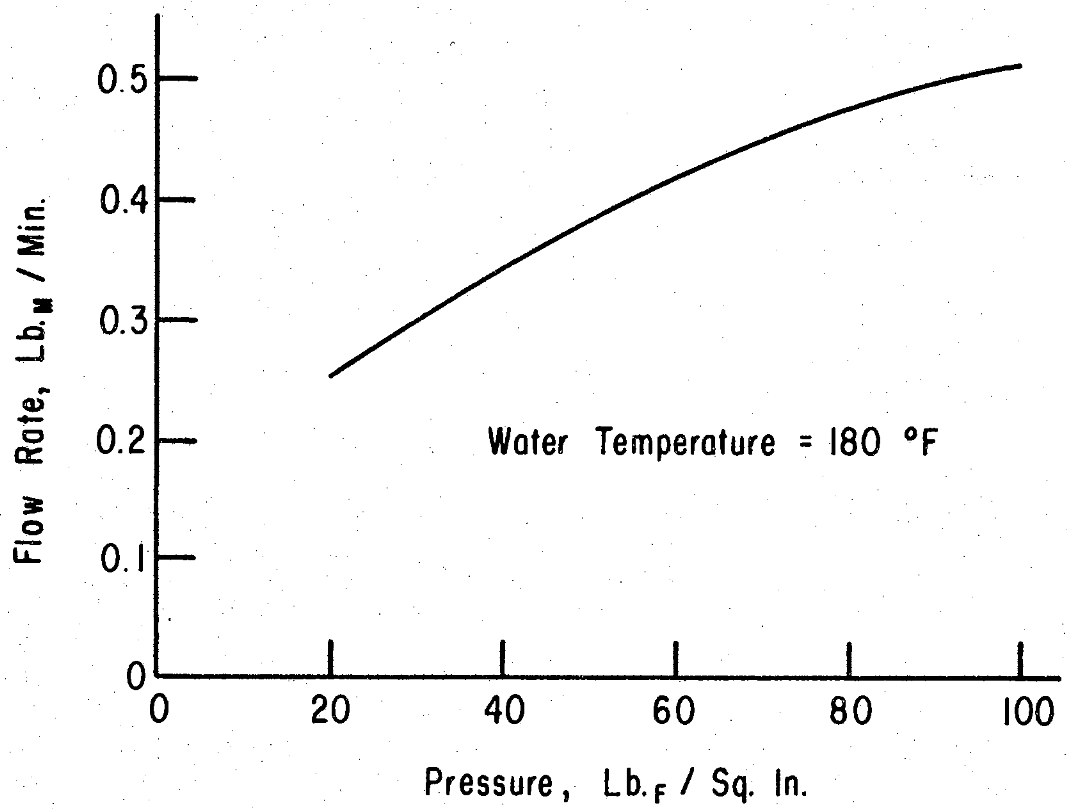

Figure 13. Flow Rate for Delevan Nozzle No. CS-3-70°

obtained using a Delavan CS-3-70° spray nozzle. Figure 13 depicts the vaporization rate as a function of pressure for this particular nozzle. In an effort to obtain the maximum vaporization rate, the water was heated to 180°F prior to being pumped through the spray system. In order to change the absolute humidity of the air by a constant amount, the water pressure had to be changed for each fan speed. Using pressure settings of 25, 48, and 100 psi at fan speeds of 750, 1300, and 1700 rpm respectively, the change in absolute humidity due to the water spray was determined to be 0.006 lb_m of water per lb_m of air. This is an increase in absolute humidity of 50 per cent at 95°F and 35 per cent relative humidity.

From the results of the preliminary investigation, the specific test conditions were chosen. Three levels of temperature, exposure time, and fan speed were selected. It was believed that the region of maximum response could be bracketed within these conditions. Two water pressure settings were chosen and it was assumed that any response differences due to humidity, if such differences existed, could be detected.

Temperatures of 200, 400 and 600°F were chosen for study. Earlier investigations had indicated that the maximum defoliation response would possibly lie within this temperature range. The three exposure times selected were one, three, and five seconds, and it was assumed that this selection of exposure times in conjunction with the selected temperatures would indicate an optimum temperature-time combination within the range.

The three fan speeds were selected somewhat arbitrarily since no information was available concerning air velocity, and consequently, fan speed. The lower limit on fan speed, 750 rpm, was influenced by the oxygen requirements for good combustion. The maximum speed, 1700 rpm, was determined by the horsepower limitations of the variable speed drive unit. An arbitrary intermediate value of 1300 rpm was also used.

Two moisture conditions were selected, those being (a) without spray, and (b) with spray. The maximum vaporization rate obtainable was used and resulted in an increase in absolute humidity due to spray of 0.006 lb_m of water per lb_m of air.

In the experimental design, all possible combinations of the three levels of temperature, three exposure times, three fan speeds, and two moisture conditions were used. There were 54 treatment combinations. The order in which the treatment combinations were applied to the plants was randomized for each replication. Randomization was believed to be necessary because of the change in plant response with time of day, the varying properties and conditions of the plants, and the changing ambient temperature and relative humidity. The design was a randomized complete block design with factorial treatment combinations (35).

However, the above design was used only on the first replication. Due to the randomized nature of the design, either a part of all of the factor levels had to be changed for each treatment. An excessive amount of time was required for the system to reach equilibrium after the temperature, fan speed, or humidity was changed. An attempt was made to conserve time and possibly improve the experimental technique by employing all three exposure times in succession for each combination of temperature, fan speed, and humidity.

Combinations of temperature, fan speed, and humidity were randomized and the three times were then randomized within each temperature-rpm-humidity combination. This design was a split-plot design. The main-plot consisted of a randomized block design with factorial treatment combinations. The sub-plots were exposure times. This design was used for replications two through six, and the first replication, although contained in Appendix B, was not used in the data analysis.

Analysis of a split-plot design enables the investigator to obtain more precise information on the sub-plot factor than on the main-plot factors. However, the average experimental error over all treatment comparisons is the same for the randomized block design and the split-plot design. As a result, there is no net gain in precision resulting from the use of the split-plot design (9). In this study, the split-plot design was used only for convenience.

The plants used for the laboratory study were grown in individual containers and were five weeks old when treated. Due to the limited root depth in the containers, the plants, in general, reached an average height of about 10.5 inches in five weeks and had an average of six well-developed leaves. In nearly all cases, there were two plants per container, and never more than three. The plants were grown in a somewhat protected environment, but not in a greenhouse. All replications were watered regularly.

Prior to treatment, the leaves in each container were counted and recorded along with the number of plants in the container and the plant height. The plant height was observed since it was believed to be an index of the general physiological condition of the plant. In addition, the plant height in conjunction with a vertical temperature gradient in the oven could combine to cause a varying defoliation and leaf kill with plant height. Ambient temperature and relative humidity conditions were also recorded before and after each replication. All treatments were applied near midday when the variation of the ambient atmospheric conditions would be at a minimum.

The treatments were applied in the randomized manner presented above. The temperature was controlled by the gas pressure. Fan speed was maintained by the variable speed drive unit, and the air humidity was varied by varying the water pressure. When these three variables were set as prescribed by the randomization procedure, and an equilibrium condition was attained, the plants were exposed for the proper time interval as timed by a stop watch. A complete replication was treated in one day and required approximately two hours. The six replications were spaced over a six week period.

Seven days following the treatment, the leaves remaining on the plants were counted again. Some difficulty was encountered in this process due to regrowth and in some cases it was difficult to determine if a leaf was present at the time of treatment, or had developed since the treatment was applied. The total number of leaves and the number of dead leaves on the plant were recorded. The latter item also involved a degree of judgment. Using this information, the per cent defoliation and the per cent leaf kill were determined.

Field Study

An analysis of the laboratory results indicated no significant difference in defoliation due to humidity variation or fan speed. However, two fan speeds were selected whose ratio corresponded to the ratio of the minimum and maximum fan speeds used for the laboratory study. The maximum fan speed on the field unit was governed by the horsepower limitations on the fan drive system. Since water addition appeared to be an insignificant factor, no provisions were made on the field unit to add water to the hot air. The exposure time was controlled by the ground speed of the unit. A maximum ground speed of 4.5 mph corresponded to an exposure time of 1.2 seconds. A ground speed of 5.5 mph which would correspond to the 1.0 second exposure time used in the laboratory study was beyond the capabilities of the field unit under the conditions encountered.

The particular factor levels used were as follows:

Temperature	-	200° F, 400° F, and 600° F
Exposure time	-	1.2 sec., 3.0 sec., and 5.0 sec.
(Ground speed)	-	4.5 mph, 1.8 mph, and 1.1 mph
Fan speed	-	250 rpm and 550 rpm

From previous demonstrations of the field unit at which time no data were collected, it appeared that a temperature of 600° F and a ground speed of 3 mph (exposure time of 1.8 sec.) would produce a substantial defoliation effect. Therefore, for the test designed to detect differences in response due to the time of day (hereinafter referred to as the hourly test) the temperature and exposure time were held constant at these values. A fan speed of 550 rpm was arbitrarily selected.

A random sampling of the field prior to treatment indicated that the average plant height was 32 inches, and the average plant width was 19 inches. There were an average of 32 leaves per plant and it was estimated that 70 per cent of the bolls were open. A stand count indicated approximately three plants per foot of row. The field tests were conducted on irrigated "Paymaster 202" cotton.

For the field tests designed in the same manner as the laboratory tests (hereinafter referred to as the laboratory correlation tests), all possible combinations of the three temperatures, three exposure times, and two fan speeds were used as treatment combinations. There were 18 of these treatment combinations. The treatments were applied at random to the previously marked plots. The design was blocked into rows in order that any difference in the effectiveness of the two rows of the defoliation unit could be detected. This design was a randomized complete block with factorial treatment combinations. Two observations were made per cell for a total of four observations per plot.

In the hourly test, the variables were the time of day and the associated ambient atmospheric conditions. A total of eight treatments were applied between dawn and dusk, and once again the design was blocked by rows. This was a randomized complete block design with subsampling. Two subsamples were taken in each cell for a total of four observations per plot.

All the plots for both the laboratory correlation study and the hourly tests were laid out in the same manner. The plots were two rows wide and approximately 90 feet long. No border rows were provided between the plots. A cleared area ten feet long separated the plots at the ends, and provided a location in which to stop the machine without danger of starting a fire in the field. It was believed that the plots would be long enough to establish a uniform ground speed and a uniform temperature as the defoliating unit moved through the field.

Two plants were selected at random from each row in each plot. These plants were marked and the number of leaves, plant height, plant width, and height to the low boll was recorded. The ambient air temperature and the relative humidity were recorded prior to applying the treatments.

For the laboratory correlation study, the temperature, fan speed, and ground speed were set as specified in the treatment randomization. The treatment combinations were applied as the machine moved through the field. All treatments were applied between 1:00 P.M. and 3:00 P.M. For the hourly test, the temperature and ground speed were held constant and treatments were applied hourly from 7:00 A.M. to 11:00 A.M. and at 1:00 P.M., 3:00 P.M., and 5:00 P.M. The treatments were applied hourly during the morning hours since it was theorized that the difference in response would be greatest during that period.

Fourteen days following the treatment, the leaves remaining on the marked plants were counted once again. As was stated earlier, for the laboratory study only seven days were allowed for the leaves to drop. The difference in time allowed for defoliation seemed to be justified since the immature plants exhibited a faster response and the regrowth occuring in 14 days on the immature plants seriously complicated the problem of counting the remaining leaves. Regrowth after 14 days was not a serious problem in the field study. The per cent defoliation and per cent leaf kill were computed in the same manner as for the laboratory study.

An additional test was conducted in conjunction with the laboratory correlation study. An attempt was made to determine the amount of moisture removed from the leaves as a result of the treatments. Leaf samples were taken immediately following the treatment and the moisture content was determined. An initial weight of the sample was obtained and then the sample was placed in a 200° F drying oven for 16 hours. The dry weight was obtained and the moisture content was computed. The results of this test are contained in Appendix D.

CHAPTER VI

PRESENTATION AND ANALYSIS OF DATA

The two attributes measured in this study were per cent defoliation and per cent leaf kill. Per cent leaf kill was always greater than or equal to per cent defoliation since the percentages were computed as follows:

$$\% \text{ Def.} = \frac{\left(\begin{array}{c}\text{No. leaves before}\\ \text{treatment}\end{array}\right) - \left(\begin{array}{c}\text{No. leaves after}\\ \text{treatment}\end{array}\right)}{\text{No. leaves before treatment}} \times 100$$

$$\% \text{ Kill} = \frac{\left(\begin{array}{c}\text{No. leaves}\\ \text{before}\\ \text{treatment}\end{array}\right) - \left(\begin{array}{c}\text{No. leaves}\\ \text{after}\\ \text{treatment}\end{array}\right) + \left(\begin{array}{c}\text{No. dead}\\ \text{leaves}\\ \text{remaining}\end{array}\right)}{\text{No. leaves before treatment}} \times 100$$

In order to determine which factors contributed significantly to defoliation and leaf kill, an analysis of variance was computed. A split-plot analysis of variance indicated that the main-plot error was no greater than the sub-plot error. The inverse ratio* (error (b) mean square/error (a) mean square) for the per cent defoliation analysis of five replications was 1.5 which approached significance at the 10 per cent level. The fact that error (a) was smaller than error (b) suggested that both were estimating the same parameter, and that the variance between main-plots was no greater than the variance between sub-plots within a main-plot. Since there is no net gain in precision from the use of a split-plot design, and since both error terms appeared to be estimating the same parameter, the errors were pooled. The analysis which resulted upon pooling the main-plot and sub-plot error terms was the same as if the design had been a randomized complete block with factorial treatment combinations. All analyses of variance presented in Appendix C and discussed on the following pages are of the randomized complete block types. All second and third order interactions were included in the experimental error term.

Table I contains a summary of the analysis of variance results for the laboratory study. Per cent defoliation significance levels are tabulated in columns 1, 2, 3, and 4 for each of the factors and factor combinations. These four columns represent an analysis involving (1), replications 2 and 3; (2), replications 2, 3, and 4; (3), replications 2, 3, 4, and 5; and (4), replications 2, 3, 4, 5, and 6. Each of these analyses of variance were computed in order to check the consistency of significance levels. Column 5 in Table I is the result of an analysis of variance on per cent leaf kill involving five replications. Only three significance levels are tabulated; 1 per cent, 5 per cent, and 10 per cent, although in some cases significance levels much less than 1 per cent were indicated. The error mean squares are also included in the table.

Table II is an analysis of variance summary for the field study. The significance levels of the various factors are shown for both per cent defoliation and per cent leaf kill. The error mean squares are included in this table also. In addition to the field data summary, Table II contains the results of an analysis of variance of laboratory data using the 18 treatment combinations employed in the field study. This analysis is based upon five replications.

TABLE I

ANALYSIS OF VARIANCE SUMMARY FOR LABORATORY DATA

	Significance Levels in Per cent				
Factor or Factor Combination	% Defoliation (1)	(2)	(3)	(4)	% Kill (5)
Replications	1	5	1	1	--
Temperature	1	1	1	1	1
time	1	1	1	1	1
RPM	--	--	--	--	--
Humidity	--	--	--	--	--
Temp x time	1	1	1	1	1
Humid x Temp	--	--	--	--	1
time x RPM	5	10	--	--	1
time x Humid	--	--	--	--	--
RPM x Humid	--	--	--	--	--
Error Mean Square	391.01	392.08	390.85	409.47	143.26

TABLE II

ANALYSIS OF VARIANCE SUMMARY FOR FIELD DATA AND LABORATORY DATA CORRESPONDING TO FIELD TREATMENTS

	Significance Levels in Per Cent			
Factor or	Field Data		Laboratory Data	
Factor Combination	% Def.	% Kill	% Def.	% Kill
Replications	--	--	10	--
Temperature	5	1	1	1
time	--	5	5	1
RPM	--	--	--	1
Temp x time	5	--	1	1
time x RPM	--	--	1	1
RPM x Temp	--	--	--	--
Error Mean Square	634.81	881.65	498.07	173.73

The average per cent defoliation and the average per cent leaf kill for each treatment in the laboratory study are included in Table III. The original data are contained in Appendix B. Also shown in Table III is the combination of factors that make up each treatment combination.

Field defoliation and leaf kill means are shown in Table IV. The treatment numbers in Table IV correspond to the treatment numbers in Table III; however, the maximum exposure time in the field was 1.2 seconds and not 1.0 seconds as in the laboratory study.

The analysis of variance indicated that temperature and time were the most significant factors affecting defoliation and leaf kill. Therefore the means of all temperature and time combinations, all temperatures, and all times were computed. These means for defoliation and kill are contained in Tables V and VI respectively. Data for both the laboratory study and the field study are included. Two columns of laboratory data are shown; all laboratory data, and partial laboratory data. The column labeled partial data contains means computed from the 18 treatment combinations employed in the field study. Note that the minimum exposure times for the laboratory study and the field study are different.

The data of Tables V and VI are plotted in Figures 14 and 15 respectively. In Figure 14, the per cent defoliation is plotted against temperature for each exposure time. Both the laboratory and field data have been included for comparison

TABLE III

AVERAGE PER CENT DEFOLIATION AND PER CENT LEAF KILL FOR LABORATORY DATA

Treat. No.	Temp. °F	Time Sec.	Fan RPM	Humid. Level	% Def.	% Kill	Treat. No.	Temp. °F	Time Sec.	Fan RPM	Humid. Level	% Def.	% Kill
1	200	1	750	Lo	10.32	10.32	28	400	3	1300	Hi	53.88	95.00
2	200	1	750	Hi	6.28	6.28	29	400	3	1700	Lo	42.02	100.00
3	200	1	1300	Lo	7.38	7.38	30	400	3	1700	Hi	37.50	100.00
4	200	1	1300	Hi	2.00	2.00	31	400	5	750	Lo	40.42	100.00
5	200	1	1700	Lo	8.08	8.08	32	400	5	750	Hi	47.98	100.00
6	200	1	1700	Hi	10.02	12.24	33	400	5	1300	Lo	24.12	100.00
7	200	3	750	Lo	3.42	9.42	34	400	5	1300	Hi	17.96	100.00
8	200	3	750	Hi	11.24	11.24	35	400	5	1700	Lo	16.46	100.00
9	200	3	1300	Lo	1.54	1.54	36	400	5	1700	Hi	1.66	100.00
10	200	3	1300	Hi	11.28	11.28	37	600	1	750	Lo	70.60	96.66
11	200	3	1700	Lo	4.74	10.90	38	600	1	750	Hi	57.86	96.18
12	200	3	1700	Hi	4.96	11.56	39	600	1	1300	Lo	32.98	100.00
13	200	5	750	Lo	9.48	12.68	40	600	1	1300	Hi	47.20	100.00
14	200	5	750	Hi	6.98	13.64	41	600	1	1700	Lo	42.98	100.00
15	200	5	1300	Lo	15.02	24.50	42	600	1	1700	Hi	36.56	100.00
16	200	5	1300	Hi	9.78	17.84	43	600	3	750	Lo	33.54	95.72
17	200	5	1700	Lo	14.70	40.70	44	600	3	750	Hi	21.68	98.00
18	200	5	1700	Hi	15.64	47.44	45	600	3	1300	Lo	12.72	100.00
19	400	1	750	Lo	20.52	57.88	46	600	3	1300	Hi	5.82	100.00
20	400	1	750	Hi	24.80	60.22	47	600	3	1700	Lo	16.88	100.00
21	400	1	1300	Lo	64.38	100.00	48	600	3	1700	Hi	18.00	100.00
22	400	1	1300	Hi	65.52	96.80	49	600	5	750	Lo	4.04	100.00
23	400	1	1700	Lo	52.42	92.50	50	600	5	750	Hi	12.10	100.00
24	400	1	1700	Hi	67.48	98.32	51	600	5	1300	Lo	17.70	100.00
25	400	3	750	Lo	59.20	98.56	52	600	5	1300	Hi	9.38	100.00
26	400	3	750	Hi	71.20	98.46	53	600	5	1700	Lo	13.82	100.00
27	400	3	1300	Lo	54.24	100.00	54	600	5	1700	Hi	15.34	100.00

TABLE IV

AVERAGE PER CENT DEFOLIATION AND PER CENT LEAF KILL FOR FIELD DATA

Treat No.	Temp °F	Time Sec.	Fan RPM	% Def.	% Kill
1	200	1.2	250	40.70	40.70
5	200	1.2	550	44.92	46.43
7	200	3	250	56.55	50.60
11	200	3	550	34.52	34.88
13	200	5	250	67.32	84.23
17	200	5	550	52.85	53.93
19	400	1.2	250	57.57	65.53
23	400	1.2	550	46.97	48.53
25	400	3	250	79.47	100.00
29	400	3	550	78.45	83.03
31	400	5	250	82.02	100.00
35	400	5	550	77.90	100.00
37	600	1.2	250	79.52	100.00
41	600	1.2	550	76.05	84.38
43	600	3	250	42.42	100.00
47	600	3	550	54.75	100.00
49	600	5	250	41.27	100.00
53	600	5	550	48.12	100.00

TABLE V

PER CENT DEFOLIATION MEANS FOR LABORATORY AND FIELD DATA

Temp °F	Time Sec.	All Lab Data *	Partial Lab Data **	Field Data
200	1 or 1.2	7.35	9.20	42.81
200	3	6.20	4.08	45.53
200	5	11.93	12.09	60.08
400	1 or 1.2	49.19	36.47	52.27
400	3	51.84	50.61	78.96
400	5	24.77	28.44	79.96
600	1 or 1.2	48.03	56.79	77.78
600	3	18.11	25.21	48.58
600	5	12.06	8.93	44.69

<u>OVERALL MEANS</u>

Temp °F	Time Sec.	All Lab Data *	Partial Lab Data **	Field Data
200		8.49	8.46	49.48
400		42.32	38.51	70.40
600		26.07	30.31	57.02
	1 or 1.2	34.85	34.15	57.62
	3	25.77	26.63	57.70
	5	16.25	16.48	61.58

*Average of Replications 2, 3, 4, 5, and 6.

**Average of the 18 treatment combinations used in the field test.

TABLE VI

PER CENT LEAF KILL MEANS FOR LABORATORY AND FIELD DATA

Temp °F	Time Sec.	All Lab Data *	Partial Lab Data **	Field Data
200	1 or 1.2	7.72	9.20	43.57
200	3	9.32	10.16	47.24
200	5	26.13	26.69	69.08
400	1 or 1.2	84.29	75.19	57.03
400	3	98.67	99.28	91.52
400	5	100.00	100.00	100.00
600	1 or 1.2	99.44	98.33	92.19
600	3	98.95	97.86	100.00
600	5	100.00	100.00	100.00

OVERALL MEANS

Temp °F	Time Sec.	All Lab Data *	Partial Lab Data**	Field Data
200		14.39	15.35	53.29
400		94.32	91.49	82.85
600		99.25	98.73	97.40
	1 or 1.2	63.60	60.91	64.26
	3	68.98	69.10	79.58
	5	75.38	75.56	89.69

*Average of replications 2, 3, 4, 5, and 6.

**Average of the 18 treatment combinations used in the field test.

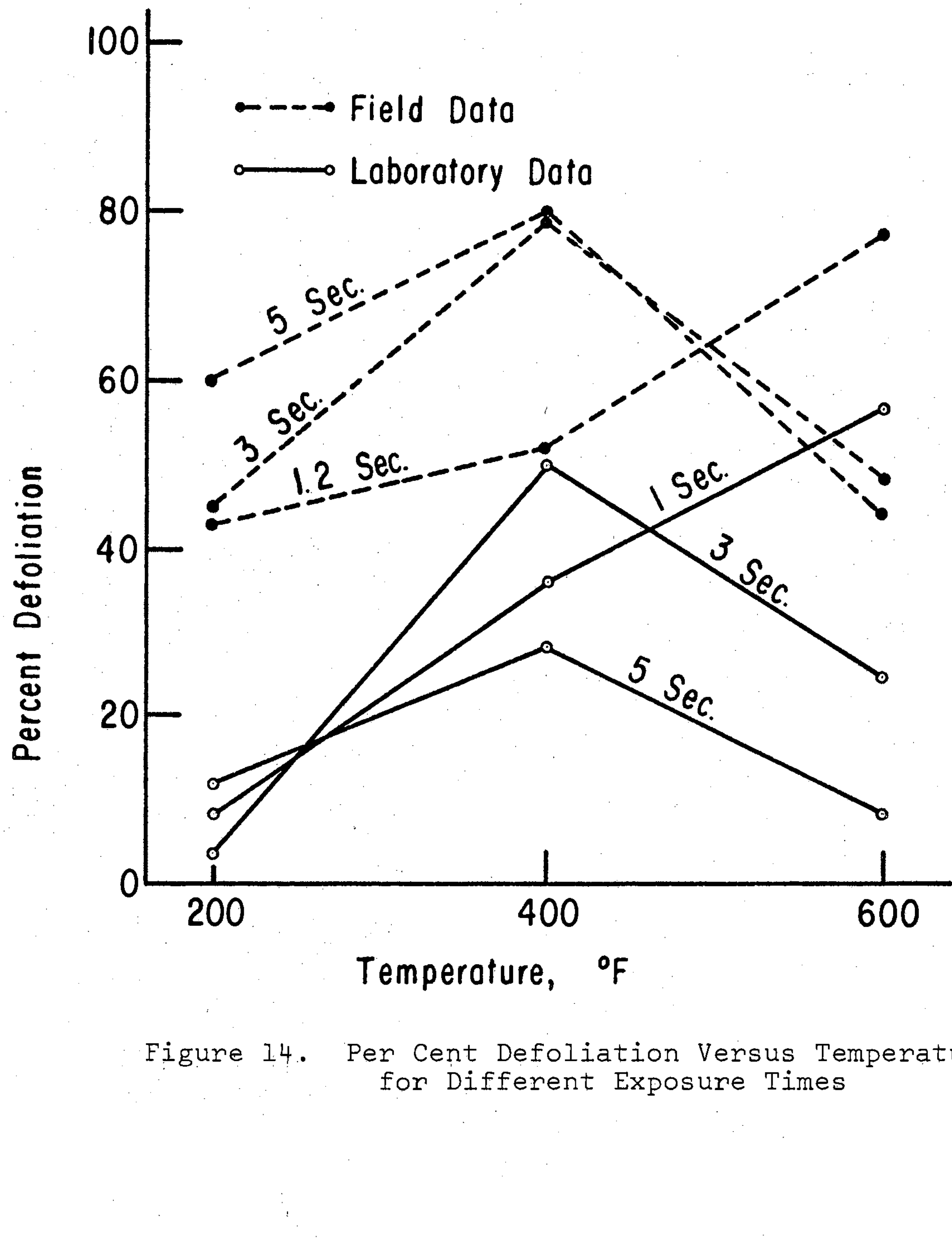

Figure 14. Per Cent Defoliation Versus Temperature for Different Exposure Times

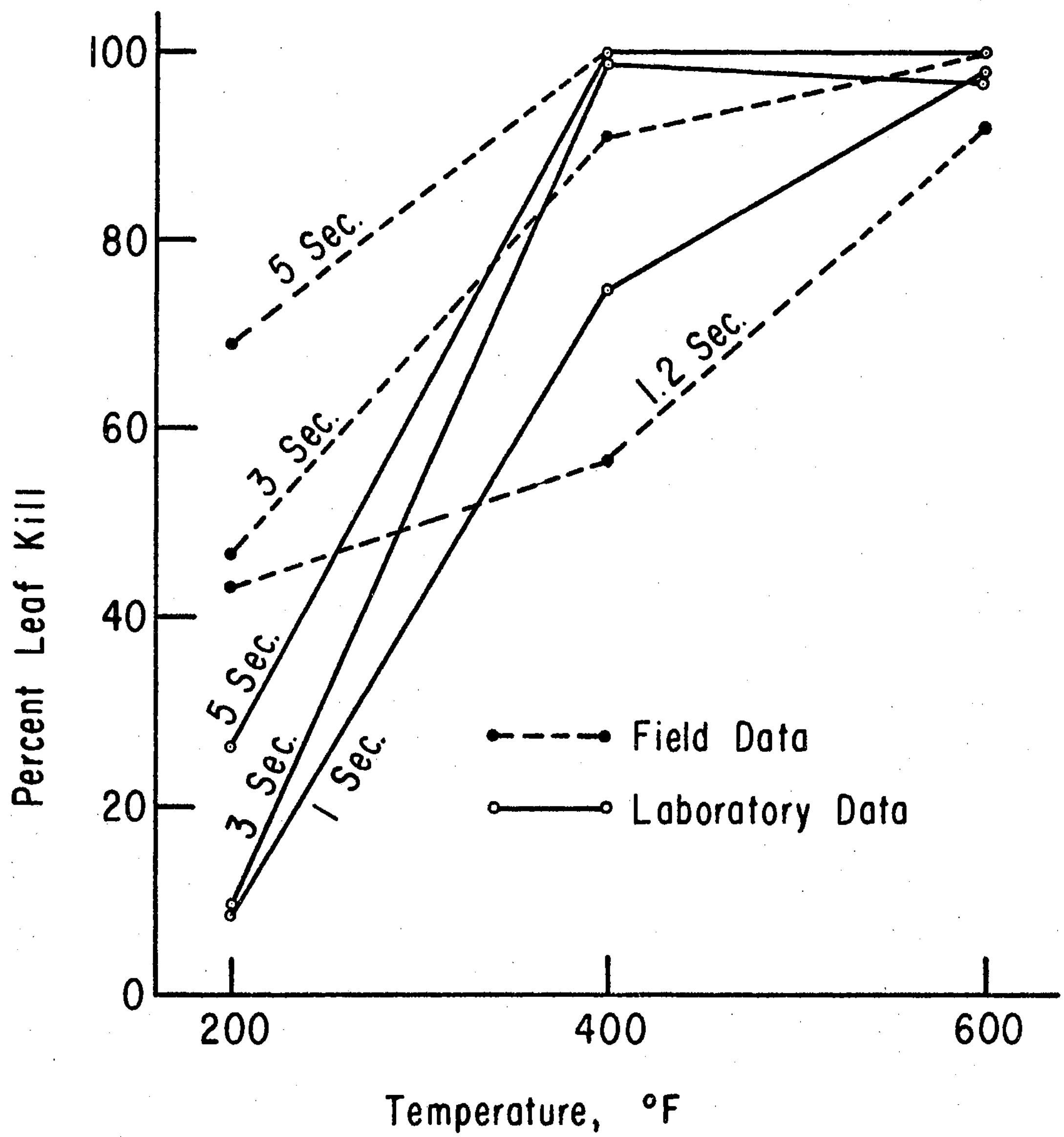

Figure 15. Per Cent Leaf Kill Versus Temperature for Different Exposure Times

purposes. Figure 15 is a plot of per cent leaf kill versus temperature for both laboratory and field data at the various exposure times.

Figures 14 and 15 give an indication of the interaction between temperature and exposure time. However, it is difficult to visualize the response at intermediate exposure times from these plots. A response which is a function of two variables can be represented by a response surface. The surface is obtained by plotting the variables on orthogonal axes and connecting the points of equal response. Interpolation is necessary, and in this analysis linear interpolation was used, although it is doubtful that the variation is linear.

Response surfaces for laboratory data are presented in Figures 16 and 17 for both per cent defoliation and per cent leaf kill as a function of temperature and time. Figures 18 and 19 are similar surfaces for the field data. For the laboratory data, only those treatment combinations corresponding to the field study were considered. In these figures, the response at each temperature-time combination is the average over all fan speeds and, in the case of the laboratory data, humidity levels. Additional response surfaces as a function of temperature and time for each fan speed were plotted, but are not included in this report. These additional surfaces were very similar to those presented here. The correlation coefficients indicated on each surface represent the correlation between the observed values of per cent defoliation or leaf kill, and the values calculated from a

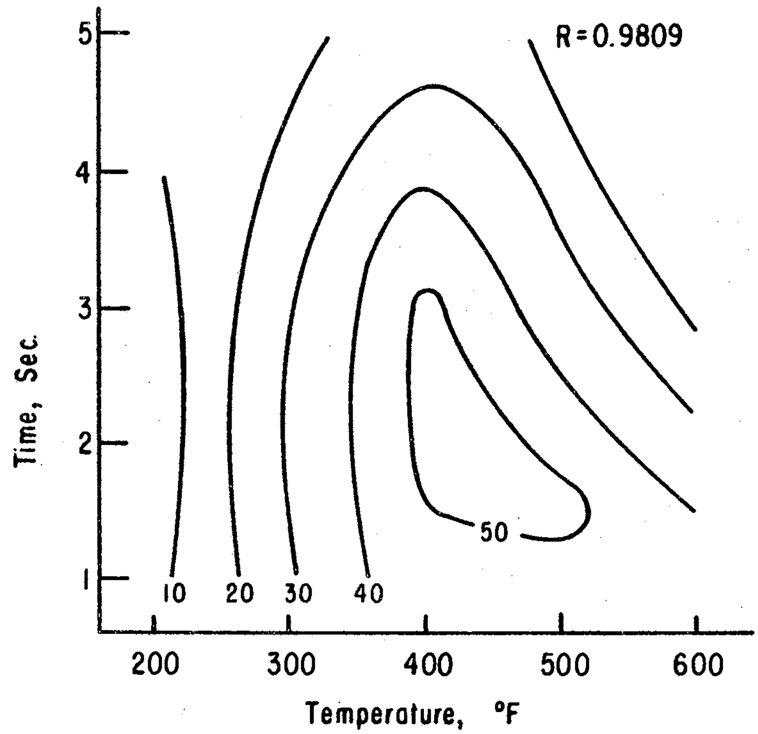

Figure 16. Per Cent Defoliation in the Laboratory as a Function of Temperature and Time

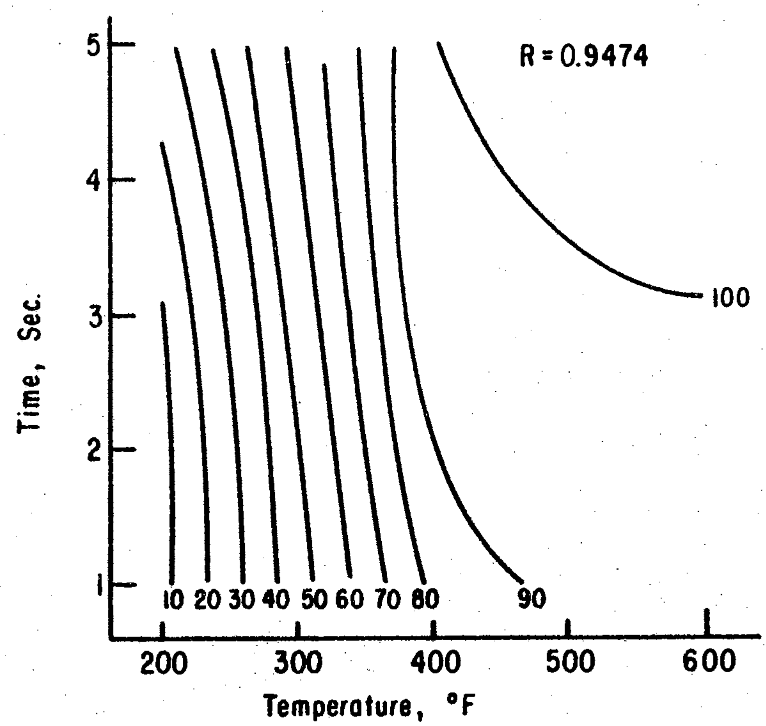

Figure 17. Per Cent Leaf Kill in the Laboratory as a Function of Temperature and Time

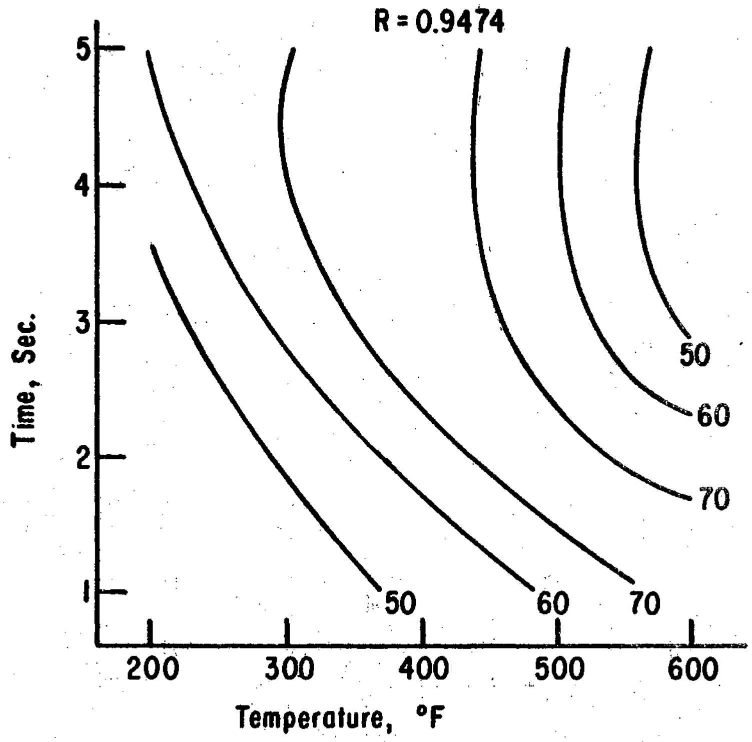

Figure 18. Per Cent Defoliation in the Field as a Function of Temperature and Time

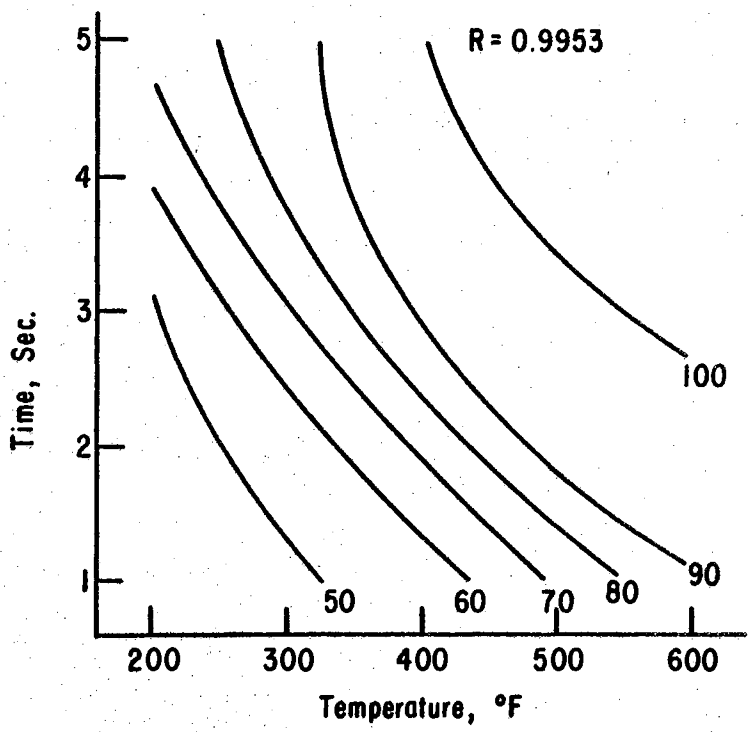

Figure 19. Per Cent Leaf Kill in the Field as a Function of Temperature and Time

prediction equation to be discussed later.

From the response surfaces, additional points were selected so that there would be 25 plotting points, one at each combination of five temperatures and five exposure times. A second degree polynomial was assumed to describe the relation between per cent defoliation, or per cent leaf kill, and temperature for each of the five exposure times. The points for the two and four second exposure times are admittedly rough estimates. A second degree curve was fitted by least squares methods to the points previously obtained. These families of curves corresponding to the surfaces presented earlier are illustrated in Figures 20, 21, 22, and 23.

The polynomial equations of these curves were utilized in obtaining a polynomial expression for the entire surface within the range of the temperature and time observed.

The families of curves discussed above are of the form

$$Y = a + bT + cT^2$$

where,

Y = the observed response in per cent

T = temperature in hundreds of degrees

a, b, and c = coefficients depending upon the exposure time.

For a given surface, an equation of the above form can be obtained for each exposure time. The coefficients will depend upon the exposure time and can be expressed as a function of time as follows:

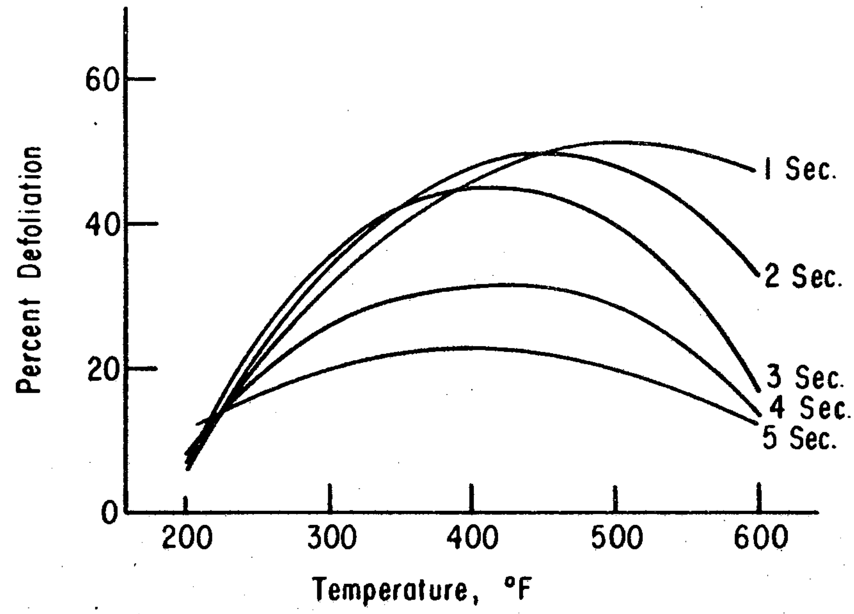

Figure 20. Per Cent Defoliation in the Laboratory Versus Temperature at each Exposure Time

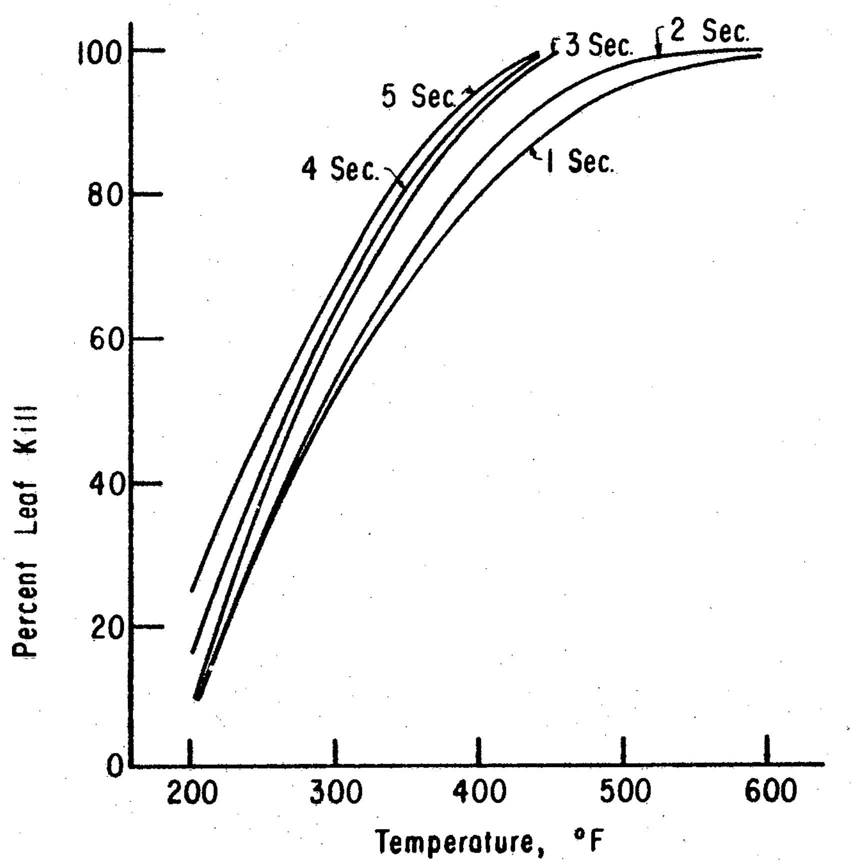

Figure 21. Per Cent Leaf Kill in the Laboratory Versus Temperature at each Exposure Time

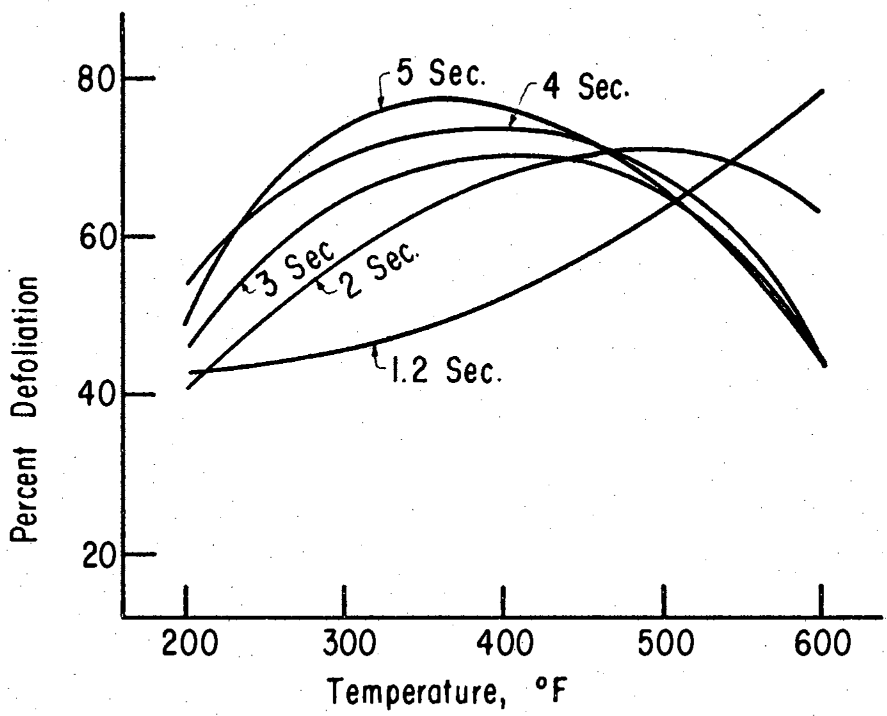

Figure 22. Per Cent Defoliation in the Field Versus Temperature at each Exposure Time

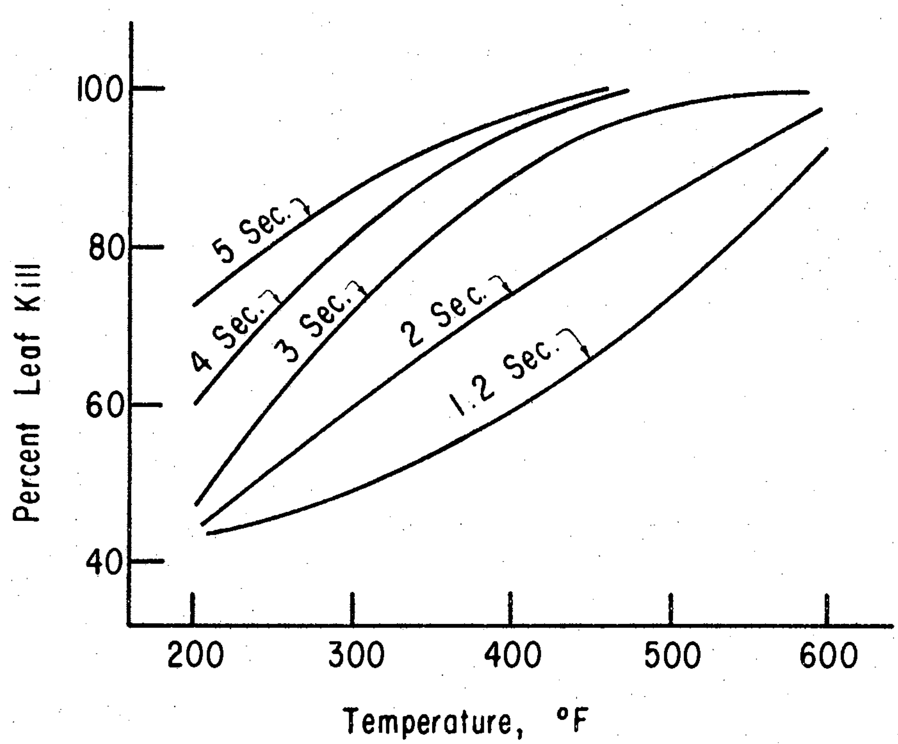

Figure 23. Per Cent Leaf Kill in the Field Versus Temperature at each Exposure Time

$$a = C_o + C_3t + C_4t^2$$

$$b = C_1 + C_5t + C_6t^2$$

$$c = C_2 + C_7t + C_8t^2$$

where,

t = exposure time in seconds

C_i = coefficients

By combining the above equations, a general expression for the response can be obtained,

$$Y = (C_o + C_3t + C_4t^2) + (C_1 + C_5t + C_6t^2)\ T + (C_2 + C_7t + C_8t^2)\ T^2$$

Expanding and rearranging, this becomes

$$Y = C_o + C_1T + C_2T^2 + C_3t + C_4t^2 + C_5Tt + C_6Tt^2 + C_7T^2t + C_8T^2t^2$$

This expression is quadratic in both temperature and time.

A general expression was derived in the above manner for each response surface. Table VII summarizes the coefficients required in the equation for the various test conditions. In Table VIII are listed the average algebraic deviation (per cent) and the average absolute deviation (per cent) from the observed value, and the correlation coefficient obtained when the equation is used for each test condition. The criteria of Table VIII were computed as follows:

$$\text{Average algebraic deviation} = \frac{\text{ALG SUM}}{\text{SUMY}} \times 100$$

TABLE VII

TABLE OF COEFFICIENTS FOR USE IN THE PREDICTION EQUATION

Test Condition:	C_0	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
Per Cent Defoliation:									
Lab Data									
750 RPM	142.8120	-89.6360	13.6160	-129.0851	17.2228	80.8402	-10.3957	-10.5385	1.2814
1700 RPM	-50.4880	38.3339	-3.2540	-37.2997	9.9042	21.3158	-5.6821	-3.1358	0.7421
All Data	-19.6480	15.3419	- .0660	-63.3257	12.6942	40.9877	-7.9942	-5.7545	1.0514
Field Data									
250 RPM	83.6467	-46.3823	8.8108	-63.0862	9.6069	54.7661	-7.4567	-8.5575	1.1228
550 RPM	208.1670	-100.5266	13.7178	-148.9830	21.1090	86.6456	-11.6071	-10.8387	1.3982
All Data	134.5056	67.1382	10.8384	-95.4764	13.7221	64.9321	-8.6464	-9.0569	1.1647
Per Cent Leaf Kill:									
Lab Data									
750 RPM	47.9680	-30.9820	6.6139	-103.9242	13.0957	67.2181	-8.2978	-8.4287	1.0392
1700 RPM	-108.2600	72.9159	-6.3520	-38.7200	9.5000	20.0445	-4.3314	-2.2971	0.4628
All Data	-79.4880	53.0679	-3.8800	-45.4600	8.0200	26.2367	-4.0992	-3.1350	0.4650
Field Data									
250 RPM	81.3021	-42.0608	7.6074	-66.8312	12.4643	52.1383	-8.0953	-6.8673	1.0057
550 RPM	192.5978	-85.1173	10.7379	-120.3448	15.3440	63.6587	-7.3383	-6.8037	0.7378
All Data	148.7021	-68.8525	9.7349	-105.2430	16.3103	63.1543	-8.8021	-7.3993	0.9881

TABLE VIII

PER CENT DEVIATION AND CORRELATION COEFFICIENTS FOR THE PREDICTION EQUATIONS OF TABLE VII

Test Condition	Average Algebraic Deviation, %	Average Absolute Deviation, %	Correlation Coefficient R
Per Cent Defoliation:			
Lab Data			
750 RPM	0.0647	9.0979	0.9806
1700 RPM	0.0707	7.8266	0.9833
All Data	-0.0162	7.9378	0.9809
Field Data			
250 RPM	-0.0222	3.5852	0.9727
550 RPM	-0.0651	5.2766	0.9926
All Data	-0.4875	4.5534	0.9474
Per Cent Leaf Kill:			
Lab Data			
750 RPM	-0.0060	3.7364	0.9944
1700 RPM	0.0226	4.5084	0.9928
All Data	0.0233	4.5391	0.9942
Field Data			
250 RPM	-0.0086	1.7813	0.9939
550 RPM	0.0477	2.5177	0.9949
All Data	0.0264	1.9566	0.9953

$$\text{Average absolute deviation} = \frac{\text{ABS SUM}}{\text{SUMY}} \times 100$$

$$R = \left(1 - \frac{\text{ESS}}{\text{EMS}}\right)^{\frac{1}{2}}$$

where,

ALG SUM = algebraic sum of the deviations of the calculated values from the observed values.

ABS SUM = absolute sum of the deviations of the calculated values from the observed values.

SUMY = sum of all observations.

ESS = sum of the squares of the deviations of the calculated values from the observed values.

EMS = sum of the squares of the deviations of the observed values from their mean.

In order to establish a correlation, if any, between the laboratory and the field results, the per cent defoliation in the field was plotted as a function of per cent defoliation in the laboratory as shown in Figure 24. Figure 25 is a similar plot for per cent leaf kill. Each point in these figures represents a treatment common to both the laboratory study and the field study. A second degree curve was fitted by least squares methods to the points and can be expressed by the polynomial shown where Y is the per cent defoliation or kill in the field, and X is the per cent defoliation or kill in the laboratory. The correlation coefficient is also indicated in the figures. Note that five treatments resulted in 100 per cent leaf kill in both the laboratory and field.

The treatment numbers of three of the points are indicated in Figures 24 and 25. If these three points are

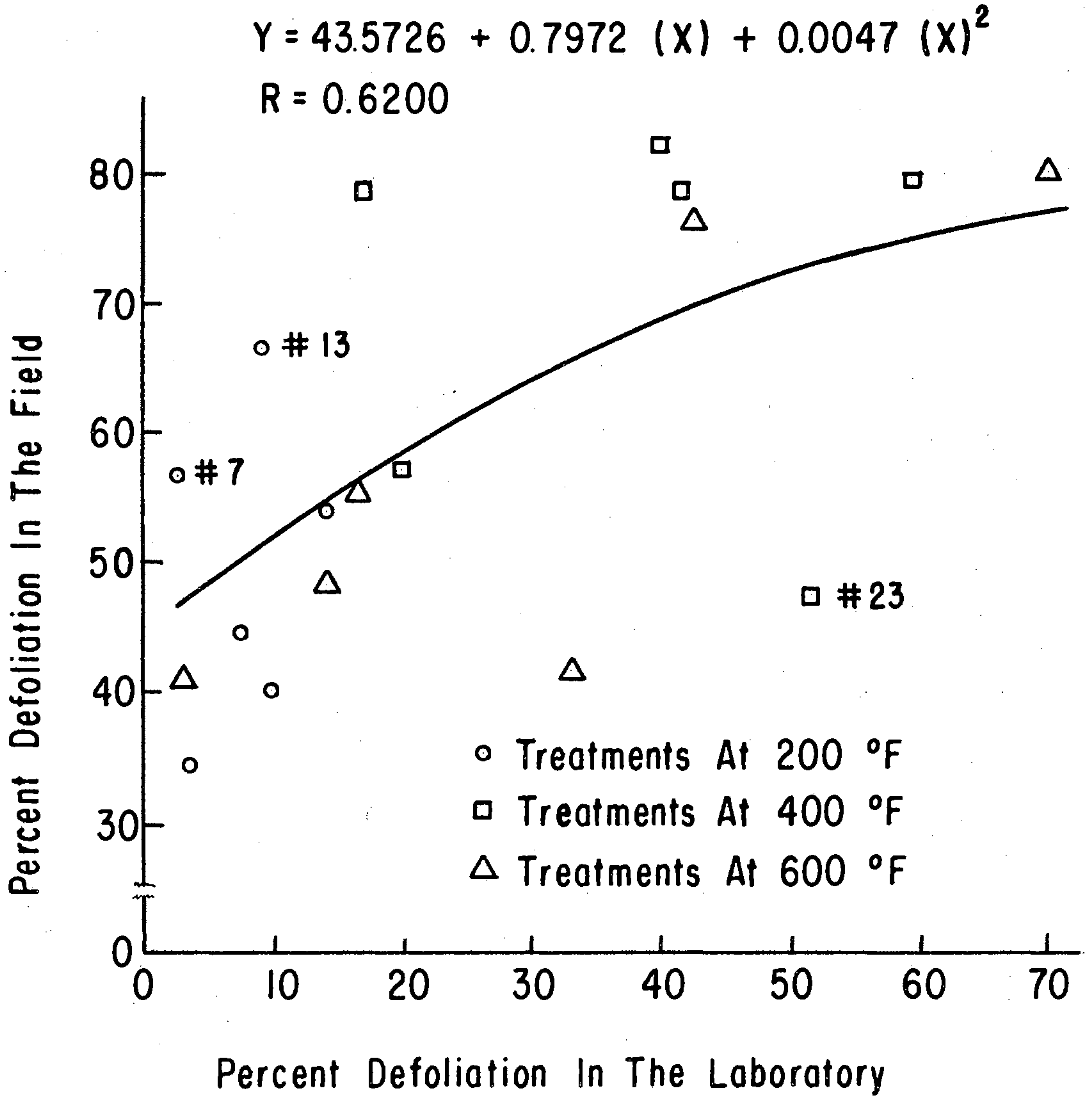

Figure 24. Relation Between Laboratory Defoliation and Field Defoliation When all Treatments are Considered

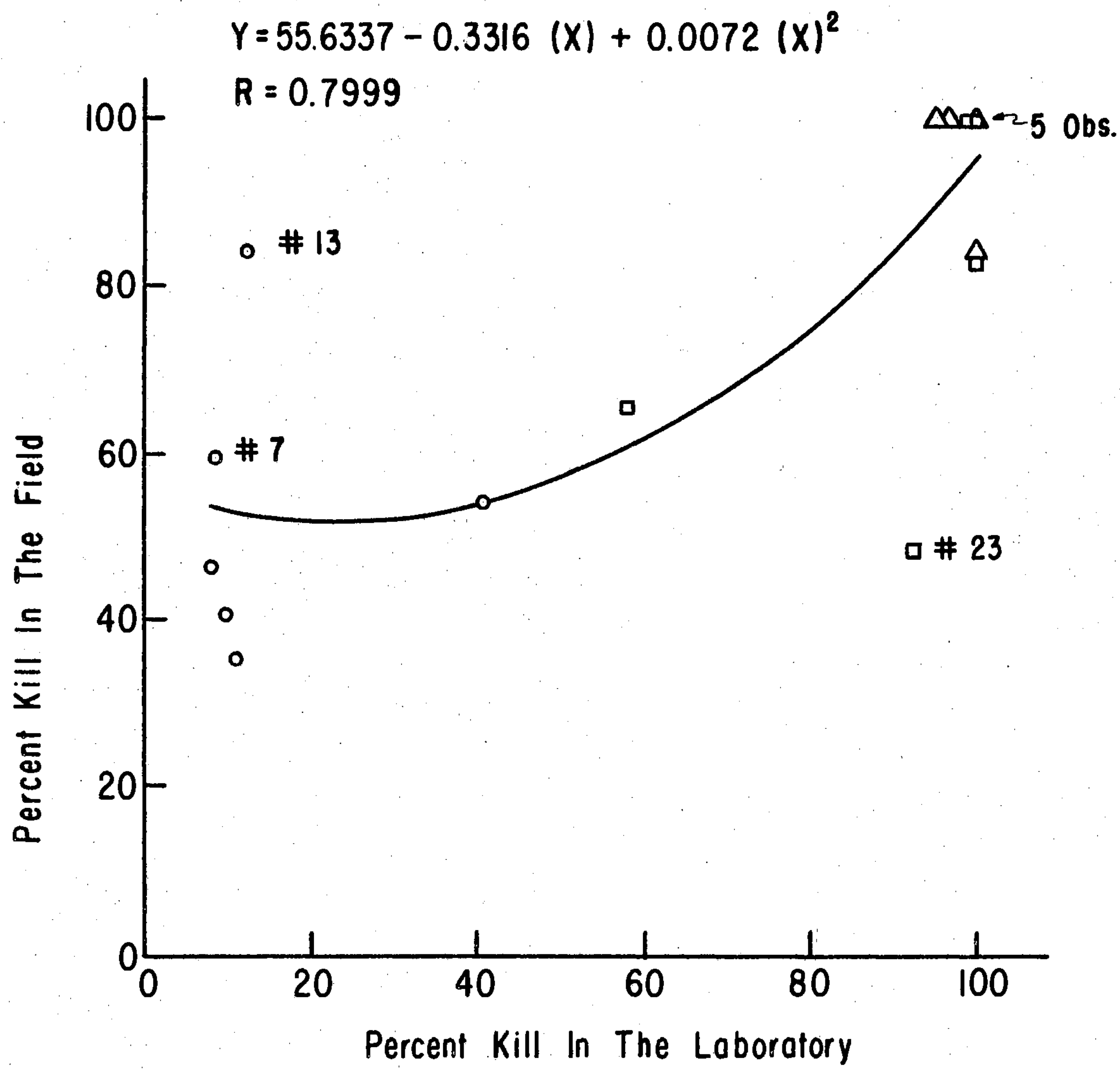

Figure 25. Relation Between Laboratory Leaf Kill and Field Leaf Kill When all Treatments are Considered

omitted, the relations shown in Figures 26 and 27 are obtained. A discussion of why this omission of data may be justified is necessary, and is included in Chapter VII.

The results of the hourly test are summarized in Table IX. The treatment numbers correspond to the hour of the treatment. In the table, the temperatures and relative humidities shown are those recorded at the time of the test. The original data from this experiment are included in Appendix B, and the complete analyses of variance are presented in Appendix C.

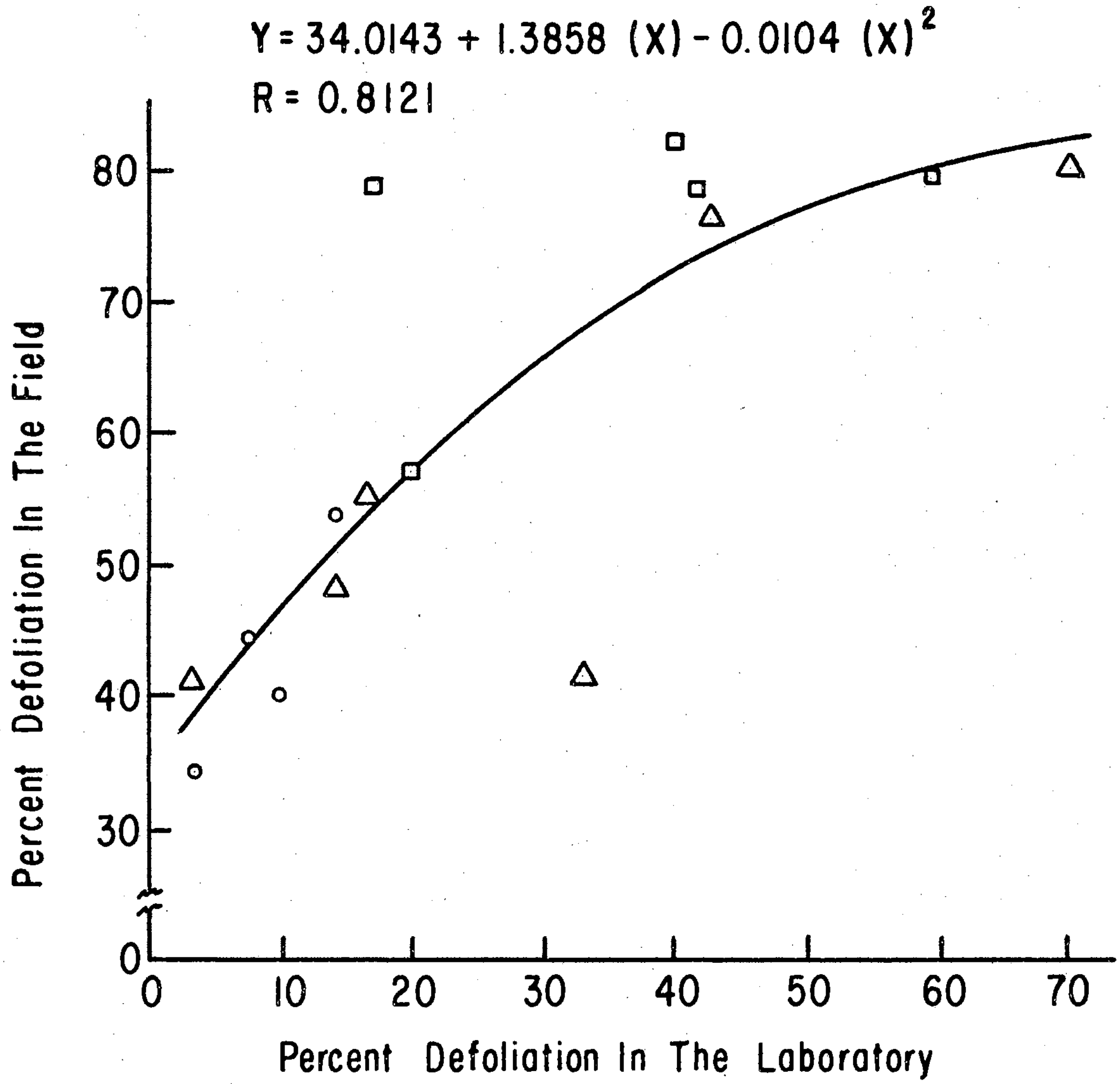

Figure 26. Relation Between Laboratory Defoliation and Field Defoliation When Treatments 7, 13, and 23 (Plots 18, 17, and 2) are Omitted

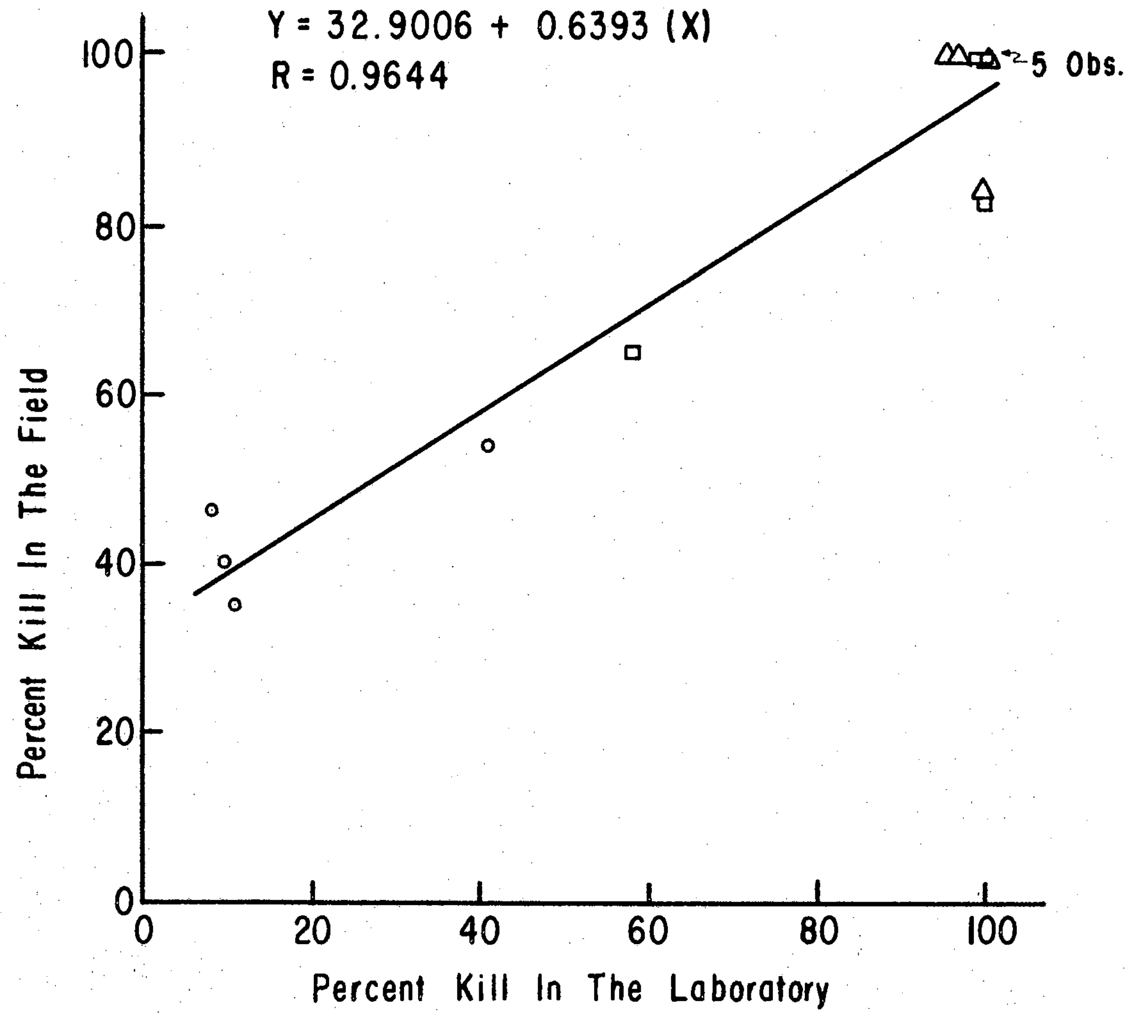

Figure 27. Relation Between Laboratory Leaf Kill and Field Leaf Kill When Treatments 7, 13, and 23 (Plots 18, 17, and 2) are Omitted

TABLE IX

AVERAGE PER CENT DEFOLIATION AND LEAF KILL FOR THE HOURLY TESTS

Treatment Conditions: Temperature = 600° F

Exposure Time = 1.8 Sec.

Fan Speed = 550 RPM

Treatment Number	Ambient Temp., °F	Relative Humidity	Per Cent Defoliation	Per Cent Leaf Kill
0700	45	92	45.55	47.47
0800	57	83	92.50	94.60
0900	65	62	92.10	97.82
1000	74	43	91.05	100.00
1100	79	41	63.70	100.00
1300	86	30	73.40	100.00
1500	86	30	86.87	100.00
1700	84	35	86.60	98.07

CHAPTER VII

DISCUSSION OF RESULTS

Of the four variables studied, temperature and exposure time appeared to be the most significant factors in thermal defoliation. Temperature and time were consistently significant at the 1 per cent level for both defoliation and leaf kill in the laboratory. In the field, temperature was significant at the 5 per cent level for defoliation and at the 1 per cent level for leaf kill. However, time was not a significant factor for defoliation in the field, but was significant at the 5 per cent level for leaf kill.

Fan speed was significant in only one case, that being for leaf kill in the laboratory, and in that one case was significant at the 1 per cent level. Fan speed was included as a variable on the assumption that fan speed would be an index of the air velocity in the vicinity of the plant. However, that assumption may not be valid due to the manner in which the hot air entered the oven chamber. Since the hot air entered horizontally from the sides of the oven chamber near the bottom, the velocity near the plant was due primarily to free convection and turbulence. Increasing the fan speed increased the exit velocity, and increased the turbulence near the plant, but may not have appreciably increased the net quantity of air passing over and through the plant. Thus the heat transfer from the air to the plant may not have been increased significantly by changing the fan speed.

Absolute humidity effects, as varied and controlled in this experiment, were consistently insignificant. The absolute humidity was increased up to 50 per cent of the original humidity (according to calculations) by the addition of water. This may not have been a large enough difference in absolute humidity to detect a difference in response. On the other hand, the increased moisture content may have produced compensating effects. Increasing the moisture content of the air increases the enthalpy, or heat content, and thus would increase the heat transfer from the air to the leaf. This would elevate the leaf temperature to a lethal level more rapidly and thus result in a higher response for the low exposure times. Conversely, moisture removal from the leaf may be a significant factor in thermal death. In that event, increasing the moisture content of the air would decrease the moisture gradient between the air and leaf, and thus decrease the moisture removal from the leaf, resulting in a lower response. Each of these effects may have operated to offset the other and as a result, no significant difference in humidity effects was detected.

The temperature and time interaction was significant at the 1 per cent level for all the laboratory work. In the field, this interaction was found to be significant (at the 5 per cent level) only for defoliation. The only other interaction of any significance was the time and rpm interaction for leaf kill in the laboratory, and it was significant at the 1 per cent level.

Examination of the laboratory data contained in Appendix B reveals that the response for any one treatment is highly variable for the different replications. The seven day period allowed for defoliation was selected arbitrarily, and perhaps a longer period would have resulted in a higher and more uniform response. As has been stated previously, regrowth presented a problem, and this problem intensified as the period allowed for defoliation was increased. The small sample size also contributed to the variation in the observations since the observations were in per cent based upon the number of leaves before treatment (sample size).

An insight into the optimum treatment for maximum defoliation and leaf kill can best be obtained from the response surfaces. Leaf kill appeared to be the more predictable, although defoliation is of primary concern. The discussion here will be concerned only with the surfaces representing the response as a function of temperature and time averaged over all fan speeds, i.e., Figures 16, 17, 18, and 19.

In general, defoliation cannot be achieved appreciably with a temperature of 200° F except for prolonged exposure times, and then only in field conditions. Higher temperatures require a shorter exposure time than the moderate temperatures to achieve the same response. Leaf kill reaches 100 per cent for three second exposures at 600° F in all cases. This response increases from a minimum with minimum exposure time and temperatures to a maximum at the maximum treatment conditions.

Figure 16, representing laboratory defoliation, indicates that the response peaked within the range of temperatures and times studied. A one to two second exposure at 400° F to 500° F resulted in a maximum defoliation of near 50 per cent.

The field defoliation shown in Figure 18 did not reach a peak as did the laboratory defoliation. The maximum response was obtained for a series of temperatures and times ranging from one second at 600° F to three to five seconds at 400° F. The response in this regime approached 80 per cent.

Leaf kill in the laboratory comprises Figure 17. This response increased steadily for all exposure times from a minimum at 200° F to over 90 per cent at 400° F. Between 400° F and 600° F the leaf kill was near 100 per cent. Leaf kill in the field (Figure 19) increases steadily from a minimum of 40 per cent at one second and 200° F to a maximum of 100 per cent at five seconds and 600° F.

These figures indicate that the same treatment will give a higher defoliation in the field than in the laboratory. At 400° F, the maximum defoliation in the field required a longer exposure time than in the laboratory. At 600° F, the maximum defoliation in both the field and laboratory was achieved using a one second exposure time.

A study of the plots of temperature means, Figures 14 and 15 indicated similar trends for the laboratory and field studies. Although the correlation is obviously not a one-to-one correspondence, the evidence presented in these two figures seemed to substantiate, rather than reject, the possibility of a laboratory-field correlation. For instance, defoliation continued to increase with temperature for the low exposure time for both the laboratory and field data. For the other exposure times, the defoliation response peaked between 200° F and 600° F. In both the laboratory and field studies, the per cent leaf kill continued to increase (up to 100 per cent) with temperature at all exposure times.

Figures 24 and 25 indicated a considerable scattering of the 18 points. However, upon closer analysis, it was noted that three of the points which did not readily satisfy the hypothesized correlation were common to both the per cent defoliation and the per cent leaf kill figures. These three treatments are indicated in Figures 24 and 25 and were omitted in Figures 26 and 27 for the reasons indicated below.

Consider first plot number 2 which received treatment number 23. For plot number 2, defoliation in the field appeared to be low, as did the per cent leaf kill. This suggested that the plants were not exposed to a sufficiently high temperature. One possibility is that an error could have been made in the temperature settings at the time of treatment. The assumption was made that any errors in the temperature or exposure time were probably made in the field rather than in the laboratory. This assumption seemed valid since the treatment conditions were set only once in the field, but were set five times (once for each replication) in the laboratory. On the average, the laboratory temperature settings and exposure times should have been more accurate.

Further examination of the original data and the plant measurements prior to treatment revealed that of the four observed plants in plot number 2, two had a low boll height of one inch. This implied that the low boll was lying on the ground, and that there were probably several low branches on these plants. The temperature near the ground in the center of the row would be lower, even though the heated air entered the oven chamber near the ground, since the hot air would rise rapidly. Therefore, the required application temperature probably was not reached.

Plots 17 and 18 were subjected to treatments 13 and 7 respectively. For these plots, the defoliation and leaf kill in the field appeared to be high. The correct treatment temperature was 200° F, but the results indicated that the actual temperature may have been too high. Refering to the field layout, an examination of the preceding and following treatments was made. Plots 17 and 18 were the last plots to be treated in the laboratory correlation study. The preceding treatment was at a temperature of 400° F and the following treatment was treatment number 1500 of the hourly test. Operator error probably entered here and resulted in plots 17 and 18 being subjected to an excessive temperature. It was necessary, according to the treatment schedule to apply treatment number 1500 at 3:00 P.M. In an attempt to stay on schedule, the machine temperature probably did not reach an equilibrium condition, and the required application temperature was exceeded.

In the opinion of the writer, the above discussion constitutes justification for the omission of the three treatments. The resulting correlations are shown in Figures 26 and 27 for per cent defoliation and per cent leaf kill respectively. The second degree curve of Figure 26 results in a correlation coefficient of 0.8121. This correlation indicates that field defoliation was consistently higher than laboratory defoliation, but the difference decreased as defoliation increased.

A correlation coefficient of 0.9644 was obtained when a linear function was plotted through the data points of Figure 27. Per cent kill in the field exceeds per cent kill in the laboratory for low response, but both approach 100 per cent under the maximum treatment conditions.

Table IX and the analyses of variance in Appendix C show that there is a high degree of variation in response with varying time of day. The treatment effects were significantly different at the 1 per cent level for both per cent defoliation and per cent leaf kill. A wide variation in ambient temperature and relative humidity was also noted, but the experimental design failed to provide a means of evaluating the effects of the time of day, ambient temperature, and relative humidity interactions. Therefore it is impossible to conclude which has the greatest effect on defoliation, although it is apparent that response did vary at different times of the day. The plants were covered with heavy dew at 7:00 A.M., but the dew was not visible at 9:00 A.M. The heavy dew probably protected the plants and caused the low response of the 7:00 treatment. The plants were exposed to bright sunshine throughout the day from sunrise at 6:35 A.M. until after the tests were completed.

The prediction equations outlined in Table VII can be used to compute the probable per cent defoliation or per cent leaf kill for any combination of temperature and exposure time between the limits of 200° F to 600° F and one to five seconds. These equations should not be extrapolated beyond this range. In some cases, the computed value of per cent leaf kill may exceed 100 per cent by as much as five per cent. This should create no problem however, since 100 per cent is obviously the maximum response. Comparable information about defoliation and leaf kill can be obtained from the families of curves shown in Figures 20, 21, 22, and 23.

Appendix E contains some information on the effect of plant height on defoliation and leaf kill. Plant height was believed to have an effect on the response due to the vertical temperature gradient within the oven chamber. The plant heights were sorted into groupings and considered "treatments" for this analysis. There were unequal sample sizes. The tables of means, analyses of variance, and multiple range tests are presented in the appendix.

A brief economic analysis of the field unit operation is presented in Appendix F. This analysis is concerned only with the fuel consumption required to heat the air, and does not consider any other cost factors. The analysis is based on an assumed fuel cost of $.08 per gallon and a field efficiency of 0.70. One way in which to reduce the operating costs per acre is to increase the field capacity. For commercial feasibility of thermal defoliation, the defoliating unit would probably need to be a four- or six-row machine.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

An investigation was conducted to determine the effects of air temperature, exposure time, air velocity, and absolute humidity on thermal defoliation of cotton. Both laboratory and field tests were conducted. Small cotton plants grown in greenhouse conditions were used in the laboratory study. Each of these plants was subjected to one of 54 different treatment combinations. The response was determined by counting the leaves before treatment and again seven days following the treatment. Per cent defoliation and per cent leaf kill were recorded. In contrast to the laboratory study, the field study involved the use of a self-propelled field defoliation unit working in mature cotton under actual pre-harvest conditions. Eighteen treatment combinations were used, and the response was measured 14 days following the treatments. Temperature and exposure time effects were highly significant, but absolute humidity and air velocity effects were not significant. Optimum treatment combinations for maximum defoliation and leaf kill were determined, and a correlation was established between the laboratory and field results. A polynomial expression was derived which can be used to predict the per cent defoliation or per cent leaf kill for all temperature and time combinations within the limits of this study.

Conclusions

1. Thermal defoliation of cotton is possible. Cotton plants can be induced to shed their leaves in a predictable manner by subjecting the plant to a super optimal temperature for a short period of time.
2. Temperatures from 400° F to 600° F result in the maximum response. A temperature of 200° F did not result in any significant response.
3. All exposure times studied resulted in significant response depending upon the exposure temperature. In general, an exposure time of two seconds at 500° F resulted in the maximum defoliation, although a unique optimum treatment was not evident from this study.
4. The effect of fan speed variation was not significant in defoliation.
5. The effect of absolute humidity on per cent defoliation and per cent leaf kill was not significant.
6. The defoliation response varies with the time of day. The individual effects of exposure to sunlight, ambient air temperature, and relative humidity were not determined.
7. Field results can be predicted with a limited degree of accuracy from laboratory tests. The correlation

coefficient for defoliation was 0.8121, and for leaf kill was 0.9644.

8. Thermal defoliation can be economically competitive with other means of defoliation. Fuel costs for the two-row unit used in this study were on the order of $2.00 per acre or less for satisfactory defoliation results.

Suggestions for Future Study

1. Different air flow patterns may have some merits. Since the upper and lower surfaces of leaves are different, perhaps the response would be different if the hot air was flowing downward over the leaf rather than upward. Air flow in a horizontal direction should be investigated as well. The air velocity could possibly be varied over a wider range if the air was forced past the plant in a horizontal direction.
2. Some lint damage from excessive temperatures was observed during the study. Ginning, fiber, and spinning tests are needed to determine the effects of thermal defoliation on the quality and grade of the lint.
3. Perhaps a better response could be obtained by using a different application technique. For example, would two exposures at 300° F be better than one exposure at 500° F? Shorter exposure times at higher temperatures than those reported here may be worthy of consideration.
4. With shorter exposure times, the control over the exposure time would be more critical. A more reliable,

dependable, and consistent method of controlling the exposure time is needed for the laboratory equipment.

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APPENDIX A

PRELIMINARY INVESTIGATION DATA

DATA SHEET A-I

AIR VELOCITY IN THE DUCT 3 FEET DOWNSTREAM FROM THE FAN—MEASUREMENTS MADE USING DWYER PITOT TUBE WITH UNHEATED AIR

Trial No. 1

Fan Speed RPM	Air Velocity ft./min.	Q ft^3/min.	Velocity at Exit (ft./min.) Measured	Computed
750	985	680	300	655
1300	1730	1180	700	1130
1700	2260	1570	---	1510

Trial No. 2

Fan Speed RPM	Air Velocity ft/min.	Q ft^3/min.
750	922	640
1300	1433	1000
1700	2020	1400

Measurements made using copper tube and water manometer.

Fan Speed RPM	H in. H_2O	Air Temp. ^oF	Air Velocity ft./min.	Q ft^3/min.
750	0.0767	85	1070	743
1300	0.283	85	2120	1470
1700	0.50	85	2820	1960
750	0.093	400	1220	846
1300	0.333	400	2300	1590
1700	0.534	400	2920	2030
1300	0.333	400	2300	1590
1700	0.733	600	3420	2380

DATA SHEET A-II

SPRAY NOZZLE CALIBRATION DATA

Nozzle flow rates of tap water in pounds per minute for various pressures.

Nozzle	Pressure, psi				
	30	40	60	80	100
Delavan - CS-1-70°			0.142	0.167	0.187
Delavan - CS-3-70°	0.14	0.280	0.333	0.375	0.430
Delavan - CS-5-70°			0.486	0.555	0.625
Delavan No. 23 swirl plate & orifice			1.0		
Tee Jet No. 3		0.417	0.50	0.577	0.654

Nozzle flow rates for the Delavan - CS-3-70° nozzle. Water temperature = 180° F

Pressure psi	Flow time min.	Mass of flow grams	Q lb_m/min.
25	1.5	105	0.276
40	1.5	125	0.327
50	1.5	143	0.375
60	1.5	152	0.399
75	1.5	174	0.457
80	1.5	175	0.460
92	1.5	187	0.490
100	1.5	201	0.528

DATA SHEET A-III

LABORATORY FUEL CONSUMPTION DATA
NO WATER ADDED

Temp. ^{o}F	Fan Speed RPM	Weight Consumed lb_m	Elapsed Time min.	Fuel Consumption lb_m/min.
200	750	1.0	12	0.0825
200	1300	1.4	11	0.127
200	1700	1.6	11	0.145
400	750	1.8	9	0.200
400	1300	3.2	10	0.320
400	1700	4.1	10	0.410
600	750	3.2	10	0.320
600	750	3.3	10	0.330
600	1300	5.0	10	0.500
600	1700	4.9	7	0.700

Temperature at time of calibration = 99^{o} F
Relative Humidity = 24%

APPENDIX B

ORIGINAL EXPERIMENTAL DATA

DATA SHEET B-I

LABORATORY DATA - REPLICATION NO. 1
AMBIENT TEMPERATURE = 91 DEG. F. RELATIVE HUMIDITY = 48 PERCENT
DATE OF TREATMENT - 06 29 65

TREAT NO.	TEMP DEG F	TIME SEC.	FAN RPM	WATER PRESS PSI.	PLANT HT. IN.	NO. PLANTS IN CONT.	NO. LEAVES BEFORE TREAT.	NO. LEAVES AFTER TREAT.	NO. DEAD LEAVES AFTER	PERCENT DEFOL-IATION	PERCENT KILL
1	200	1	750	0	9.0	2	7	11	0	0.0	0.0
2	200	1	750	25	10.0	1	8	8	2	0.0	25.0
3	200	1	1300	0	7.5	2	11	11	0	0.0	0.0
4	200	1	1300	48	9.0	2	10	11	0	0.0	0.0
5	200	1	1700	0	7.5	2	11	13	0	0.0	0.0
6	200	1	1700	100	8.5	2	12	11	0	8.3	8.3
7	200	3	750	0	9.0	2	11	12	0	0.0	0.0
8	200	3	750	25	8.0	2	12	11	0	8.3	8.3
9	200	3	1300	0	8.0	2	12	13	0	0.0	0.0
10	200	3	1300	48	8.0	2	9	9	0	0.0	0.0
11	200	3	1700	0	8.0	2	8	9	3	0.0	37.5
12	200	3	1700	100	9.5	2	11	10	0	9.1	9.1
13	200	5	750	0	9.0	2	8	9	0	0.0	0.0
14	200	5	750	25	9.0	2	10	10	0	0.0	0.0
15	200	5	1300	0	7.5	2	10	9	0	10.0	10.0
16	200	5	1300	48	8.5	2	8	9	0	0.0	0.0
17	200	5	1700	0	9.0	2	13	13	0	0.0	0.0
18	200	5	1700	100	8.5	2	8	7	7	12.5	100.0
19	400	1	750	0	8.5	2	8	2	1	75.0	87.5
20	400	1	750	25	7.5	2	9	12	1	0.0	11.1
21	400	1	1300	0	9.5	2	8	1	1	87.5	100.0
22	400	1	1300	48	8.0	2	10	10	3	0.0	30.0
23	400	1	1700	0	9.5	2	13	1	1	92.0	100.0
24	400	1	1700	100	8.5	2	10	10	7	0.0	70.0
25	400	3	750	0	9.0	2	10	10	6	0.0	60.0
26	400	3	750	25	10.0	2	9	1	1	89.0	100.0
27	400	3	1300	0	9.0	2	9	4	4	55.6	100.0
28	400	3	1300	48	9.0	2	10	10	10	0.0	100.0
29	400	3	1700	0	9.5	2	11	10	10	9.1	100.0
30	400	3	1700	100	9.0	2	9	1	1	89.0	100.0
31	400	5	750	0	9.0	2	8	5	5	37.5	100.0
32	400	5	750	25	9.5	2	8	3	3	62.5	100.0
33	400	5	1300	0	8.0	2	8	0	0	100.0	100.0
34	400	5	1300	48	8.5	2	10	7	7	30.0	100.0
35	400	5	1700	0	7.5	2	10	10	10	0.0	100.0
36	400	5	1700	100	9.0	2	13	11	11	15.4	100.0
37	600	1	750	0	9.0	2	10	2	2	80.0	100.0
38	600	1	750	25	9.5	2	10	5	4	50.0	90.0
39	600	1	1300	0	8.0	2	9	1	1	89.0	100.0
40	600	1	1300	48	10.0	2	10	0	0	100.0	100.0
41	600	1	1700	0	8.5	2	7	1	1	85.7	100.0
42	600	1	1700	100	8.5	2	10	3	3	70.0	100.0
43	600	3	750	0	9.0	2	11	11	11	0.0	100.0
44	600	3	750	25	8.5	2	8	7	7	12.5	100.0
45	600	3	1300	0	9.5	2	8	8	8	0.0	100.0
46	600	3	1300	48	9.0	2	11	11	11	0.0	100.0
47	600	3	1700	0	8.0	2	11	10	10	9.1	100.0
48	600	3	1700	100	9.5	2	10	9	9	10.0	100.0
49	600	5	750	0	7.0	2	10	9	9	10.0	100.0
50	600	5	750	25	9.0	2	9	7	7	22.2	100.0
51	600	5	1300	0	9.0	2	13	12	12	7.7	100.0
52	600	5	1300	48	10.0	2	11	9	9	18.1	100.0
53	600	5	1700	0	10.5	1	6	5	5	16.7	100.0
54	600	5	1700	100	9.0	2	10	8	8	20.0	100.0

DATA SHEET B-I (CONTINUED)

LABORATORY DATA - REPLICATION NO. 2
AMBIENT TEMPERATURE = 87 DEG. F. RELATIVE HUMIDITY = 64 PERCENT
DATE OF TREATMENT - 07 06 65

TREAT NO.	TEMP DEG F	TIME SEC.	FAN RPM	WATER PRESS PSI.	PLANT HT. IN.	NO. PLANTS IN CONT.	NO. LEAVES BEFORE TREAT.	NO. LEAVES AFTER TREAT.	NO. DEAD LEAVES AFTER	PERCENT DEFOL-IATION	PERCENT KILL
1	200	1	750	0	8.0	2	10	10	0	0.0	0.0
2	200	1	750	25	9.5	2	12	12	0	0.0	0.0
3	200	1	1300	0	8.0	1	9	8	0	11.1	11.1
4	200	1	1300	48	10.0	2	12	13	0	0.0	0.0
5	200	1	1700	0	9.0	2	12	11	0	8.3	8.3
6	200	1	1700	100	9.0	2	14	14	0	0.0	0.0
7	200	3	750	0	10.0	2	15	17	0	0.0	0.0
8	200	3	750	25	8.5	2	11	10	0	9.1	9.1
9	200	3	1300	0	8.5	2	12	13	0	0.0	0.0
10	200	3	1300	48	9.0	2	11	11	0	0.0	0.0
11	200	3	1700	0	10.0	2	13	12	3	7.7	30.8
12	200	3	1700	100	10.5	2	14	13	0	7.1	7.1
13	200	5	750	0	9.5	2	13	13	0	0.0	0.0
14	200	5	750	25	10.5	1	6	7	0	0.0	0.0
15	200	5	1300	0	8.0	2	13	12	4	7.7	38.5
16	200	5	1300	48	9.5	2	12	12	0	0.0	0.0
17	200	5	1700	0	8.0	2	13	14	4	0.0	30.8
18	200	5	1700	100	10.0	2	13	12	7	7.7	61.5
19	400	1	750	0	9.5	2	13	10	4	23.1	53.8
20	400	1	750	25	10.0	2	13	14	6	0.0	46.1
21	400	1	1300	0	10.0	2	12	8	8	33.3	100.0
22	400	1	1300	48	8.0	2	12	7	6	41.6	91.6
23	400	1	1700	0	8.0	2	8	8	5	0.0	62.5
24	400	1	1700	100	9.0	2	12	6	5	50.0	91.6
25	400	3	750	0	8.5	2	14	8	7	42.8	92.8
26	400	3	750	25	9.5	2	13	7	6	46.1	92.3
27	400	3	1300	0	11.0	1	7	2	2	71.5	100.0
28	400	3	1300	48	8.5	2	8	5	3	37.5	75.0
29	400	3	1700	0	10.0	2	10	4	4	60.0	100.0
30	400	3	1700	100	10.0	1	8	2	2	75.0	100.0
31	400	5	750	0	9.5	2	13	10	10	23.1	100.0
32	400	5	750	25	11.0	2	13	6	6	53.8	100.0
33	400	5	1300	0	9.5	2	12	8	8	33.3	100.0
34	400	5	1300	48	8.5	2	11	10	10	9.1	100.0
35	400	5	1700	0	9.0	2	14	11	11	20.4	100.0
36	400	5	1700	100	9.5	1	6	6	6	0.0	100.0
37	600	1	750	0	9.0	2	12	10	8	16.7	83.3
38	600	1	750	25	9.0	2	13	11	11	15.4	100.0
39	600	1	1300	0	10.0	2	11	2	2	81.8	100.0
40	600	1	1300	48	9.5	2	10	6	6	40.0	100.0
41	600	1	1700	0	10.0	2	13	2	2	84.6	100.0
42	600	1	1700	100	9.0	2	14	5	5	64.2	100.0
43	600	3	750	0	9.0	2	14	10	7	28.6	78.6
44	600	3	750	25	8.5	2	10	7	6	30.0	90.0
45	600	3	1300	0	9.5	2	13	12	12	7.7	100.0
46	600	3	1300	48	9.0	2	15	15	15	0.0	100.0
47	600	3	1700	0	10.0	2	12	10	10	16.7	100.0
48	600	3	1700	100	9.0	2	14	15	15	0.0	100.0
49	600	5	750	0	10.0	2	11	10	10	9.1	100.0
50	600	5	750	25	9.0	2	13	10	10	23.1	100.0
51	600	5	1300	0	9.0	2	14	13	13	7.1	100.0
52	600	5	1300	48	8.0	2	12	11	11	8.3	100.0
53	600	5	1700	0	9.0	2	13	11	11	15.4	100.0
54	600	5	1700	100	8.0	2	11	11	11	0.0	100.0

DATA SHEET B-I (CONTINUED)

LABORATORY DATA - REPLICATION NO. 3
AMBIENT TEMPERATURE = 96 DEG. F. RELATIVE HUMIDITY = 40 PERCENT
DATE OF TREATMENT - 07 13 65

TREAT NO.	TEMP DEG F	TIME SEC.	FAN RPM	WATER PRESS PSI.	PLANT HT. IN.	NO. PLANTS IN CONT.	NO. LEAVES BEFORE TREAT.	NO. LEAVES AFTER TREAT.	NO. DEAD LEAVES AFTER	PERCENT DEFOL-IATION	PERCENT KILL
1	200	1	750	0	10.0	2	13	10	0	23.0	23.0
2	200	1	750	25	10.5	2	12	13	0	0.0	0.0
3	200	1	1300	0	9.5	2	12	10	0	16.7	16.7
4	200	1	1300	48	10.5	2	10	9	0	10.0	10.0
5	200	1	1700	0	9.0	2	14	13	0	7.1	7.1
6	200	1	1700	100	10.5	2	13	9	0	30.7	30.7
7	200	3	750	0	11.0	2	14	13	0	7.1	7.1
8	200	3	750	25	11.0	2	15	14	0	6.7	6.7
9	200	3	1300	0	11.5	2	9	10	0	0.0	0.0
10	200	3	1300	48	10.0	2	12	8	0	33.3	33.3
11	200	3	1700	0	10.0	2	13	12	1	7.7	15.4
12	200	3	1700	100	9.5	2	13	12	0	7.7	7.7
13	200	5	750	0	7.5	2	13	9	1	30.7	38.4
14	200	5	750	25	10.5	2	11	10	0	9.1	9.1
15	200	5	1300	0	11.0	2	15	9	1	40.0	46.6
16	200	5	1300	48	10.0	2	11	10	0	9.1	9.1
17	200	5	1700	0	10.0	2	11	6	5	45.4	90.9
18	200	5	1700	100	11.0	2	12	10	5	16.7	58.3
19	400	1	750	0	9.5	2	12	12	6	0.0	50.0
20	400	1	750	25	8.5	2	11	10	1	9.1	18.2
21	400	1	1300	0	9.5	2	14	4	4	71.4	100.0
22	400	1	1300	48	10.0	2	13	4	3	69.3	92.4
23	400	1	1700	0	10.5	2	13	2	2	84.6	100.0
24	400	1	1700	100	9.0	2	13	4	4	69.1	100.0
25	400	3	750	0	9.0	2	11	7	7	36.4	100.0
26	400	3	750	25	9.5	2	11	8	8	27.3	100.0
27	400	3	1300	0	10.0	2	13	4	4	69.2	100.0
28	400	3	1300	48	10.0	2	12	5	5	58.3	100.0
29	400	3	1700	0	10.0	2	14	12	12	14.3	100.0
30	400	3	1700	100	10.0	2	14	6	6	57.1	100.0
31	400	5	750	0	9.0	2	12	3	3	75.0	100.0
32	400	5	750	25	9.5	2	13	4	4	69.2	100.0
33	400	5	1300	0	10.0	2	10	4	4	60.0	100.0
34	400	5	1300	48	11.0	2	13	9	9	30.7	100.0
35	400	5	1700	0	11.5	2	12	11	11	8.3	100.0
36	400	5	1700	100	10.5	2	12	11	11	8.3	100.0
37	600	1	750	0	8.5	2	12	0	0	100.0	100.0
38	600	1	750	25	10.0	2	13	3	3	76.8	100.0
39	600	1	1300	0	10.5	2	13	12	12	7.7	100.0
40	600	1	1300	48	9.5	2	14	5	5	64.2	100.0
41	600	1	1700	0	10.0	2	11	4	4	63.6	100.0
42	600	1	1700	100	10.0	2	12	6	6	50.0	100.0
43	600	3	750	0	10.5	2	12	3	3	75.0	100.0
44	600	3	750	25	9.5	2	13	10	10	23.1	100.0
45	600	3	1300	0	10.5	2	15	10	10	33.3	100.0
46	600	3	1300	48	9.5	2	14	11	11	21.4	100.0
47	600	3	1700	0	9.5	2	14	13	13	7.1	100.0
48	600	3	1700	100	9.5	2	12	8	8	33.3	100.0
49	600	5	750	0	10.0	2	12	12	12	0.0	100.0
50	600	5	750	25	9.5	2	14	12	12	14.3	100.0
51	600	5	1300	0	11.0	2	13	12	12	7.7	100.0
52	600	5	1300	48	10.0	2	12	11	11	8.3	100.0
53	600	5	1700	0	10.0	2	9	11	11	0.0	100.0
54	600	5	1700	100	10.0	2	10	9	9	10.0	100.0

DATA SHEET B-I (CONTINUED)

LABORATORY DATA - REPLICATION NO. 4

AMBIENT TEMPERATURE = 94 DEG. F. RELATIVE HUMIDITY = 42 PERCENT

DATE OF TREATMENT - 07 20 65

TREAT NO.	TEMP DEG F	TIME SEC.	FAN RPM	WATER PRESS PSI.	PLANT HT. IN.	NO. PLANTS IN CONT.	NO. LEAVES BEFORE TREAT.	NO. LEAVES AFTER TREAT.	NO. DEAD LEAVES AFTER	PERCENT DEFOL-IATION	PERCENT KILL
1	200	1	750	0	13.0	1	7	5	0	28.6	28.6
2	200	1	750	25	13.0	2	14	13	0	7.7	7.7
3	200	1	1300	0	13.0	2	12	12	0	0.0	0.0
4	200	1	1300	48	11.5	2	10	10	0	0.0	0.0
5	200	1	1700	0	11.5	2	11	11	0	0.0	0.0
6	200	1	1700	100	9.5	2	12	12	0	0.0	0.0
7	200	3	750	0	11.0	2	12	12	0	0.0	0.0
8	200	3	750	25	12.0	2	13	11	0	15.4	15.4
9	200	3	1300	0	12.0	2	11	11	0	0.0	0.0
10	200	3	1300	48	10.0	2	12	12	0	0.0	0.0
11	200	3	1700	0	12.5	2	13	13	0	0.0	0.0
12	200	3	1700	100	13.0	2	12	12	0	0.0	0.0
13	200	5	750	0	12.0	3	14	14	0	0.0	0.0
14	200	5	750	25	11.5	2	12	12	4	0.0	33.3
15	200	5	1300	0	12.0	2	11	10	0	9.1	9.1
16	200	5	1300	48	10.5	2	13	10	2	23.1	38.4
17	200	5	1700	0	14.5	2	11	10	5	9.9	54.5
18	200	5	1700	100	12.0	2	12	11	0	8.3	8.3
19	400	1	750	0	12.0	2	11	10	6	9.1	63.6
20	400	1	750	25	12.0	2	11	9	7	18.2	81.8
21	400	1	1300	0	13.0	1	7	3	3	57.2	100.0
22	400	1	1300	48	15.0	1	8	2	2	75.0	100.0
23	400	1	1700	0	12.5	2	12	5	5	58.2	100.0
24	400	1	1700	100	12.5	2	10	4	4	60.0	100.0
25	400	3	750	0	10.0	2	11	3	3	72.7	100.0
26	400	3	750	25	11.0	2	11	1	1	90.9	100.0
27	400	3	1300	0	11.0	2	13	6	6	53.8	100.0
28	400	3	1300	48	13.5	2	14	6	6	57.1	100.0
29	400	3	1700	0	13.5	1	7	1	1	85.8	100.0
30	400	3	1700	100	11.0	2	13	11	11	15.4	100.0
31	400	5	750	0	11.5	2	11	2	2	81.8	100.0
32	400	5	750	25	11.5	2	10	6	6	40.0	100.0
33	400	5	1300	0	13.0	2	13	13	13	0.0	100.0
34	400	5	1300	48	14.0	2	12	11	11	8.3	100.0
35	400	5	1700	0	13.0	2	13	9	9	44.5	100.0
36	400	5	1700	100	10.5	2	11	11	11	0.0	100.0
37	600	1	750	0	11.5	2	11	2	2	81.8	100.0
38	600	1	750	25	12.0	2	10	3	2	70.0	90.0
39	600	1	1300	0	13.5	2	12	6	6	50.0	100.0
40	600	1	1300	48	11.0	2	11	3	3	72.7	100.0
41	600	1	1700	0	12.5	1	6	5	5	16.7	100.0
42	600	1	1700	100	11.5	2	11	7	7	36.4	100.0
43	600	3	750	0	12.5	1	9	6	6	33.3	100.0
44	600	3	750	25	11.5	1	7	5	5	28.6	100.0
45	600	3	1300	0	11.5	3	17	16	16	5.9	100.0
46	600	3	1300	48	11.5	2	11	11	11	0.0	100.0
47	600	3	1700	0	13.0	2	12	9	9	33.3	100.0
48	600	3	1700	100	11.5	1	5	3	3	40.0	100.0
49	600	5	750	0	11.0	2	9	8	8	11.1	100.0
50	600	5	750	25	10.5	3	13	12	12	7.7	100.0
51	600	5	1300	0	13.0	1	6	6	6	0.0	100.0
52	600	5	1300	48	11.0	2	13	12	12	7.7	100.0
53	600	5	1700	0	12.0	2	10	7	7	30.0	100.0
54	600	5	1700	100	10.0	2	12	10	10	16.7	100.0

DATA SHEET B-1 (CONTINUED)

LABORATORY DATA - REPLICATION NO. 5
AMBIENT TEMPERATURE = 97.5 DEG. F. RELATIVE HUMIDITY = 37.5 PERCENT
DATE OF TREATMENT - 07 27 65

TREAT NO.	TEMP DEG F	TIME SEC.	FAN RPM	WATER PRESS PSI.	PLANT HT. IN.	NO. PLANTS IN CONT.	NO. LEAVES BEFORE TREAT.	NO. LEAVES AFTER TREAT.	NO. DEAD LEAVES AFTER	PERCENT DEFOL-IATION	PERCENT KILL
1	200	1	750	0	13.0	2	11	11	0	0.0	0.0
2	200	1	750	25	11.5	2	12	11	0	8.3	8.3
3	200	1	1300	0	11.0	2	10	10	0	0.0	0.0
4	200	1	1300	48	12.0	2	12	12	0	0.0	0.0
5	200	1	1700	0	12.0	2	13	13	0	0.0	0.0
6	200	1	1700	100	12.5	2	10	9	1	11.1	22.2
7	200	3	750	0	12.0	2	10	9	3	10.0	40.0
8	200	3	750	25	12.5	2	10	11	0	0.0	0.0
9	200	3	1300	0	13.0	2	10	10	0	0.0	0.0
10	200	3	1300	48	12.0	2	9	9	0	0.0	0.0
11	200	3	1700	0	12.5	2	12	12	0	0.0	0.0
12	200	3	1700	100	11.5	2	9	9	3	0.0	33.3
13	200	5	750	0	11.5	2	12	10	1	16.7	25.0
14	200	5	750	25	10.5	2	12	10	0	16.7	16.7
15	200	5	1300	0	10.5	2	10	9	1	10.0	20.0
16	200	5	1300	48	12.0	2	10	10	0	0.0	0.0
17	200	5	1700	0	12.0	2	11	10	0	9.1	9.1
18	200	5	1700	100	11.0	2	11	7	7	36.4	100.0
19	400	1	750	0	12.5	2	12	9	4	25.0	58.4
20	400	1	750	25	11.5	1	10	2	0	80.0	80.0
21	400	1	1300	0	13.0	2	10	2	2	80.0	100.0
22	400	1	1300	48	12.0	2	10	5	5	50.0	100.0
23	400	1	1700	0	10.0	2	8	5	5	37.5	100.0
24	400	1	1700	100	11.5	2	12	5	5	58.3	100.0
25	400	3	750	0	11.0	2	12	5	5	58.4	100.0
26	400	3	750	25	11.5	2	12	1	1	91.7	100.0
27	400	3	1300	0	11.0	2	12	10	10	16.7	100.0
28	400	3	1300	48	13.0	2	13	9	9	30.8	100.0
29	400	3	1700	0	13.5	1	7	7	7	0.0	100.0
30	400	3	1700	100	11.5	2	10	11	11	0.0	100.0
31	400	5	750	0	11.5	2	9	7	7	22.2	100.0
32	400	5	750	25	10.0	2	13	10	10	15.4	100.0
33	400	5	1300	0	10.5	2	11	8	8	27.3	100.0
34	400	5	1300	48	10.0	2	12	9	9	25.0	100.0
35	400	5	1700	0	11.0	2	10	10	10	0.0	100.0
36	400	5	1700	100	11.5	2	11	11	11	0.0	100.0
37	600	1	750	0	11.5	2	11	4	4	63.6	100.0
38	600	1	750	25	10.5	2	11	6	6	45.4	100.0
39	600	1	1300	0	12.0	2	9	8	8	11.1	100.0
40	600	1	1300	48	10.5	2	11	10	10	9.1	100.0
41	600	1	1700	0	13.0	2	12	10	10	16.7	100.0
42	600	1	1700	100	12.0	2	11	10	10	9.1	100.0
43	600	3	750	0	12.5	2	13	12	12	7.7	100.0
44	600	3	750	25	10.5	2	12	10	10	16.7	100.0
45	600	3	1300	0	11.0	2	12	10	10	16.7	100.0
46	600	3	1300	48	12.0	2	13	12	12	7.7	100.0
47	600	3	1700	0	13.5	2	11	10	10	9.1	100.0
48	600	3	1700	100	12.0	2	12	10	10	16.7	100.0
49	600	5	750	0	13.0	2	10	11	11	0.0	100.0
50	600	5	750	25	10.5	2	13	11	11	15.4	100.0
51	600	5	1300	0	11.0	2	13	11	11	15.4	100.0
52	600	5	1300	48	14.0	1	7	6	6	14.3	100.0
53	600	5	1700	0	12.0	2	13	11	11	15.4	100.0
54	600	5	1700	100	12.5	2	12	9	9	25.0	100.0

DATA SHEET B-I (CONTINUED)

LABORATORY DATA - REPLICATION NO. 6

AMBIENT TEMPERATURE = 91 DEG. F. RELATIVE HUMIDITY = 32 PERCENT

DATE OF TREATMENT - 08 03 65

TREAT NO.	TEMP DEG F	TIME SEC.	FAN RPM	WATER PRESS PSI.	PLANT HT. IN.	NO. PLANTS IN CONT.	NO. LEAVES BEFORE TREAT.	NO. LEAVES AFTER TREAT.	NO. DEAD LEAVES AFTER	PERCENT DEFOL-IATION	PERCENT KILL
1	200	1	750	0	8.5	2	11	11	0	0.0	0.0
2	200	1	750	25	10.5	2	13	11	0	15.4	15.4
3	200	1	1300	0	9.0	2	11	10	0	9.1	9.1
4	200	1	1300	48	9.0	2	11	11	0	0.0	0.0
5	200	1	1700	0	8.5	2	12	9	0	25.0	25.0
6	200	1	1700	100	9.0	2	12	11	0	8.3	8.3
7	200	3	750	0	10.0	2	8	8	0	0.0	0.0
8	200	3	750	25	8.0	2	12	9	0	25.0	25.0
9	200	3	1300	0	10.0	2	13	12	0	7.7	7.7
10	200	3	1300	48	10.0	2	13	10	0	23.1	23.1
11	200	3	1700	0	10.0	2	12	11	0	8.3	8.3
12	200	3	1700	100	8.5	2	10	9	0	10.0	10.0
13	200	5	750	0	9.5	2	11	11	0	0.0	0.0
14	200	5	750	25	7.5	2	11	10	0	9.1	9.1
15	200	5	1300	0	9.0	2	12	11	0	8.3	8.3
16	200	5	1300	48	10.5	2	12	10	3	16.7	41.7
17	200	5	1700	0	10.0	2	11	10	1	9.1	18.2
18	200	5	1700	100	8.0	2	11	10	0	9.1	9.1
19	400	1	750	0	10.5	2	11	6	2	45.4	63.6
20	400	1	750	25	10.0	2	12	10	7	16.7	75.0
21	400	1	1300	0	10.5	2	10	2	2	80.0	100.0
22	400	1	1300	48	10.0	2	12	1	1	91.7	100.0
23	400	1	1700	0	10.5	2	11	2	2	81.8	100.0
24	400	1	1700	100	9.5	2	15	0	0	100.0	100.0
25	400	3	750	0	10.0	1	7	1	1	85.7	100.0
26	400	3	750	25	9.5	2	11	0	0	100.0	100.0
27	400	3	1300	0	9.5	2	10	4	4	60.0	100.0
28	400	3	1300	48	11.0	1	7	1	1	85.7	100.0
29	400	3	1700	0	8.5	2	12	6	6	50.0	100.0
30	400	3	1700	100	11.0	2	10	6	6	40.0	100.0
31	400	5	750	0	10.5	2	12	12	12	0.0	100.0
32	400	5	750	25	8.5	2	13	5	5	61.5	100.0
33	400	5	1300	0	10.0	2	15	15	15	0.0	100.0
34	400	5	1300	48	10.0	2	12	10	10	16.7	100.0
35	400	5	1700	0	10.5	2	11	10	10	9.1	100.0
36	400	5	1700	100	11.0	1	7	8	8	0.0	100.0
37	600	1	750	0	9.5	2	11	1	1	90.9	100.0
38	600	1	750	25	8.0	2	11	2	1	81.7	90.9
39	600	1	1300	0	10.0	2	14	12	12	14.3	100.0
40	600	1	1300	48	10.0	2	12	6	6	50.0	100.0
41	600	1	1700	0	9.5	2	12	8	8	33.3	100.0
42	600	1	1700	100	9.5	2	13	10	10	23.1	100.0
43	600	3	750	0	10.5	2	13	10	10	23.1	100.0
44	600	3	750	25	8.0	2	10	9	9	10.0	100.0
45	600	3	1300	0	9.5	2	11	11	11	0.0	100.0
46	600	3	1300	48	10.5	2	12	12	12	0.0	100.0
47	600	3	1700	0	11.0	2	11	9	9	18.2	100.0
48	600	3	1700	100	10.5	2	12	12	12	0.0	100.0
49	600	5	750	0	12.0	2	12	13	13	0.0	100.0
50	600	5	750	25	9.0	2	11	11	11	0.0	100.0
51	600	5	1300	0	9.5	2	12	5	5	58.3	100.0
52	600	5	1300	48	9.5	2	12	11	11	8.3	100.0
53	600	5	1700	0	10.0	2	12	11	11	8.3	100.0
54	600	5	1700	100	9.0	2	12	9	9	25.0	100.0

DATA SHEET B-II

ORIGINAL FIELD DATA
LABORATORY CORRELATION TEST

AMBIENT TEMPERATURE = 86 DEG. F. RELATIVE HUMIDITY = 30 PERCENT
COTTON VARIETY - PAYMASTER 202 (IRRIGATED) 65 PERCENT OPEN COTTON
DATE OF TREATMENT - 10 08 65

TREAT NO.	PLOT NO.	PLANT NO.	PLANT HT. IN.	PLANT WIDTH IN.	LOW BOLL IN.	NO. LEAVES BEFORE TREAT.	NO. LEAVES AFTER TREAT.	NO. DEAD LEAVES AFTER	PERCENT DEFOL-IATION	PERCENT LEAF KILL
1	16	1	28	13	11	26	12	0	53.8	53.8
		2				34	14	0	58.8	58.8
		3	36	31	4	37	36	0	2.8	2.8
		4				19	10	0	47.4	47.4
5	14	1	36	28	6	54	32	2	40.8	44.5
		2				19	6	0	68.5	68.5
		3	34	25	3	41	22	1	46.4	48.7
		4				50	38	0	24.0	24.0
7	18	1	28	33	14	63	33	0	47.6	47.6
		2				45	29	3	35.6	42.2
		3	31	14	6	50	16	1	68.0	70.0
		4				28	7	1	75.0	78.6
11	15	1	36	20	10	43	15	1	65.1	66.5
		2				42	16	0	62.0	62.0
		3	24	14	2	32	30	0	3.8	3.8
		4				98	91	0	7.2	7.2
13	17	1	31	18	10	28	6	0	78.5	78.5
		2				32	10	10	68.8	100.0
		3	33	13	18	24	10	0	58.4	58.4
		4				22	8	8	63.6	100.0
17	13	1	32	13	17	28	13	0	53.6	53.6
		2				33	12	0	63.6	63.6
		3	37	23	6	40	9	1	77.5	80.0
		4				54	45	1	16.7	18.5
19	7	1	37	21	8	46	21	0	54.4	54.4
		2				18	11	0	38.9	38.9
		3	33	17	3	23	3	3	87.0	100.0
		4				32	16	6	50.0	68.8
23	2	1	28	12	1	16	7	1	56.3	62.5
		2				48	30	0	37.5	37.5
		3	40	20	1	27	16	0	33.3	33.3
		4				51	20	0	60.8	60.8
25	8	1	34	30	3	44	9	9	79.5	100.0
		2				10	5	5	50.0	100.0
		3	36	18	8	29	2	2	93.0	100.0
		4				21	1	1	95.4	100.0
29	1	1	29	14	10	10	0	0	100.0	100.0
		2				9	3	3	66.7	100.0
		3	39	26	9	52	8	3	84.6	90.4
		4				32	12	4	62.5	75.0

DATA SHEET B-II (CONTINUED)

TREAT NO.	PLOT NO.	PLANT NO.	PLANT HT. IN.	PLANT WIDTH IN.	LOW BOLL IN.	NO. LEAVES BEFORE TREAT.	NO. LEAVES AFTER TREAT.	NO. DEAD LEAVES AFTER	PERCENT DEFOL- IATION	PERCENT LEAF KILL
31	9	1	28	13	5	42	5	5	88.1	100.0
		2				35	8	8	77.2	100.0
		3	37	27	1	49	7	7	85.8	100.0
		4				26	6	6	77.0	100.0
35	3	1	23	10	5	9	6	6	33.3	100.0
		2				14	1	1	92.8	100.0
		3	27	16	6	30	1	1	96.6	100.0
		4				54	6	6	88.9	100.0
37	11	1	38	17	14	28	2	2	92.8	100.0
		2				50	1	1	98.0	100.0
		3	43	23	1	59	38	38	35.6	100.0
		4				12	1	1	91.7	100.0
41	5	1	18	9	5	18	3	3	83.4	100.0
		2				13	1	1	92.3	100.0
		3	30	18	10	55	34	0	37.5	37.5
		4				22	2	2	91.0	100.0
43	12	1	31	22	1	40	25	25	37.5	100.0
		2				41	26	26	36.6	100.0
		3	38	19	5	19	11	11	42.2	100.0
		4				30	14	14	53.4	100.0
47	6	1	36	27	4	55	51	51	7.3	100.0
		2				20	3	3	85.0	100.0
		3	35	15	3	35	14	14	60.0	100.0
		4				32	12	12	66.7	100.0
49	10	1	37	13	11	28	14	14	50.0	100.0
		2				54	27	27	50.0	100.0
		3	33	25	2	9	7	7	22.2	100.0
		4				14	8	8	42.9	100.0
53	4	1	21	12	5	11	9	9	18.2	100.0
		2				7	5	5	28.6	100.0
		3	37	16	5	61	16	16	73.8	100.0
		4				32	9	9	71.9	100.0

DATA SHEET B-III

ORIGINAL FIELD DATA
HOURLY TEST

TREATMENT TEMPERATURE = 600 DEG. F. GROUND SPEED = 3 MPH
DATE OF TREATMENT - 10 08 65

TREAT NO.	AMB. TEMP. DEG F	PERCENT REL. HUMID.	PLANT NO.	PLANT HT. IN.	PLANT WIDTH IN.	LOW BOLL IN.	NO. LEAVES BEFORE TREAT.	NO. LEAVES AFTER TREAT.	NO. DEAD LEAVES AFTER	PERCENT DEFOL-IATION	PERCENT LEAF KILL
0700	45	92	1	31	13	10	44	26	0	40.9	40.9
			2				46	22	0	52.2	52.2
			3	35	18	1	33	15	0	54.5	54.5
			4				26	17	2	34.6	42.3
0800	57	83	1	32	20	6	30	2	0	93.4	93.4
			2				20	3	0	85.0	85.0
			3	38	28	13	20	0	0	100.0	100.0
			4				12	1	1	91.6	100.0
0900	65	62	1	29	26	10	28	0	0	100.0	100.0
			2				23	4	4	82.6	100.0
			3	26	21	4	18	1	1	94.5	100.0
			4				23	2	0	91.3	91.3
1000	74	43	1	20	12	4	15	3	3	80.0	100.0
			2				12	1	1	91.7	100.0
			3	28	17	13	29	1	1	96.5	100.0
			4				50	2	2	96.0	100.0
1100	79	41	1	25	9	10	15	8	8	46.7	100.0
			2				25	6	6	76.0	100.0
			3	31	20	10	26	9	9	65.4	100.0
			4				12	4	4	66.7	100.0
1300	86	30	1	36	17	8	23	8	8	65.2	100.0
			2				29	9	9	69.0	100.0
			3	26	22	4	32	10	10	68.8	100.0
			4				53	5	5	90.6	100.0
1500	86	30	1	37	27	5	32	2	2	93.8	100.0
			2				43	14	14	67.5	100.0
			3	31	22	8	13	1	1	92.3	100.0
			4				33	2	2	93.9	100.0
1700	84	35	1	42	22	21	37	2	2	94.6	100.0
			2				41	10	10	95.6	100.0
			3	28	12	6	31	5	5	83.9	100.0
			4				13	1	0	92.3	92.3

APPENDIX C

ANALYSES OF VARIANCE AND MULTIPLE RANGE TESTS

DATA SHEET C-I

ANALYSIS OF VARIANCE FOR PER CENT DEFOLIATION IN THE LABORATORY

Replications 2 and 3

Source of Variation	df	SS	MS	F
Total	107	74,365.17		
Reps	1	3,183.93	3,183.93	8.14**
Temp	2	16,547.34	8,273.67	21.16**
time	2	4,399.24	2,199.62	5.63**
RPM	2	134.06	67.03	<1
Humidity	1	237.63	237.63	<1
Temp x time	4	11,518.47	2,879.61	7.36**
Temp x RPM	4	2,144.09	536.02	1.37
Humid x Temp	2	63.68	31.84	<1
time x RPM	4	3,985.17	996.29	2.55*
time x Humid	2	126.01	63.01	<1
RPM x Humid	2	354.02	177.01	<1
Error	81	31,671.53	391.01	

*Significant at $\alpha = 0.05$
**Significant at $\alpha = 0.01$

DATA SHEET C-I (continued)

Replications 2, 3, and 4

Source of Variation	df	SS	MS	F
Total	161	117,181.00		
Reps	2	3,215.80	1,607.90	4.10*
Temp	2	30,757.48	15,378.74	39.22**
time	2	7,674.25	3,837.13	9.79**
RPM	2	115.24	57.62	<1
Humidity	1	337.42	337.42	<1
Temp x time	4	16,861.72	4,215.43	10.75**
Temp x RPM	4	1,823.04	455.76	1.16
Humid x Temp	2	35.06	17.53	<1
time x RPM	4	3,467.71	866.93	2.21
time x Humid	2	308.94	154.47	<1
RPM x Humid	2	45.46	22.73	<1
Error	134	52,538.88	392.08	

*Significant at $\alpha = 0.05$
**Significant at $\alpha = 0.01$

DATA SHEET C-I (continued)

Replications 2, 3, 4, and 5

Source of Variation	df	SS	MS	F
Total	215	146,260.14		
Reps	3	5,289.84	1,763.28	4.51**
Temp	2	37,141.88	18,570.94	47.51**
time	2	9,138.45	4,569.22	11.69**
RPM	2	941.58	470.79	1.20
Humidity	1	65.89	65.89	<1
Temp x time	4	15,393.58	3,848.39	9.85**
Temp x RPM	4	2,524.53	631.13	1.61
Humid x Temp	2	7.20	3.60	<1
time x RPM	4	2,351.43	587.86	1.50
time x Humid	2	253.92	126.96	<1
RPM x Humid	2	62.43	31.21	<1
Error	187	73,089.41	390.85	

**Significant at $\alpha = 0.01$

DATA SHEET C-I (continued)

Replications 2, 3, 4, 5, and 6

Source of Variation	df	SS	MS	F
Total	269	200,040.73		
Reps	4	5,952.37	1,488.09	3.63**
Temp	2	51,520.51	25,760.25	62.91**
time	2	15,570.98	7,785.49	19.01**
RPM	2	1,215.01	607.50	1.48
Humidity	1	1.21	1.21	<1
Temp x time	4	21,321.27	5,330.32	13.01**
Temp x RPM	4	3,098.89	774.72	1.89
Humid x Temp	2	184.46	92.23	<1
time x RPM	4	2,730.42	682.60	1.67
time x Humid	2	131.13	65.56	<1
RPM x Humid	2	40.66	20.33	<1
Error	240	98,273.82	409.47	

**Significant at $\alpha = 0.01$

DATA SHEET C-II

ANALYSIS OF VARIANCE FOR PER CENT LEAF KILL
IN THE LABORATORY

Replications 2, 3, 4, 5, and 6

Source of Variation	df	SS	MS	F
Total	269	462,690.50		
Reps	4	1,051.00	262.75	1.83
Temp	2	408,431.80	204,215.90	1,425.49**
time	2	6,254.10	3,127.05	21.83**
RPM	2	3,431.30	1,715.65	11.97**
Humidity	1	8.60	8.60	<1
Temp x time	4	4,570.20	1,142.55	7.98**
Temp x RPM	4	2,378.30	594.57	4.15**
Humid x Temp	2	10.10	5.05	<1
time x RPM	4	2,047.40	511.85	3.57**
time x Humid	2	16.50	8.25	<1
RPM x Humid	2	108.10	54.05	<1
Error	240	34,383.10	143.26	

**Significant at $\alpha = 0.01$

DATA SHEET C-III

ANALYSIS OF VARIANCE FOR PER CENT DEFOLIATION IN THE LABORATORY—
18 TREATMENT COMBINATIONS USED IN THE FIELD

Replications 2, 3, 4, 5, and 6

Source of Variation	df	SS	MS	F
Total	89	70,755.08		
Reps	4	4,126.75	1,031.69	2.07
Temp	2	14,477.55	7,238.78	14.53**
time	2	4,716.16	2,358.08	4.73*
RPM	1	432.08	432.08	1
Temp x time	4	9,975.75	2,493.94	5.01**
RPM x Temp	2	646.35	323.17	1
time x RPM	2	519.58	259.79	1
Error	72	35,860.86	498.07	

*Significant at α = 0.05
**Significant at α = 0.01

DUNCAN'S MULTIPLE RANGE TEST
Per Cent Defoliation

Treat:	7	49	11	5	13	1	53	17	35	47	19	43	31	29	41	23	35	37
Mean:	3.4	4.0	4.7	8.1	9.5	10.3	13.8	14.7	16.5	16.9	20.5	33.5	40.4	42.	43.	52.4	59.2	70.6

Interpretation of the Range Test:
Any two means not underscored by the same line are significantly different at the 5 per cent level of significance. Any two means underscored by the same line are not significantly different at the 5 per cent level of significance.

DATA SHEET C-IV

ANALYSIS OF VARIANCE FOR PER CENT LEAF KILL IN THE LABORATORY — 18 TREATMENT COMBINATIONS USED IN THE FIELD

Replications 2, 3, 4, 5, and 6

Source of Variation	df	SS	MS	F
Total	89	149,631.29		
Reps	4	1,042.83	260.71	1.50
Temp	2	128,019.39	64,009.69	368.44**
time	2	3,237.22	1,618.61	9.32**
RPM	1	1,397.89	1,397.89	8.05**
Temp x time	4	2,709.58	677.39	3.90**
RPM x Temp	2	353.38	176.69	1.02
time x RPM	2	362.84	181.42	1.04
Error	72	12,508.16	173.73	

**Significant at α = 0.01

DUNCAN'S MULTIPLE RANGE TEST
Per Cent Leaf Kill

Treat:	5	7	1	11	13	17	19	23	43	37	25	29	31	35	41	47	49	53
Mean:	8.1	9.4	10.3	10.9	12.7	40.7	57.9	92.5	95.7	96.7	98.6	100	100	100	100	100	100	100

Note: See page 119 for interpretation of the Multiple Range Test.

DATA SHEET C-V

ANALYSIS OF VARIANCE FOR PER CENT DEFOLIATION IN THE FIELD

Source of Variation	df	SS	MS	F
Total	71	45,647.77		
Rows	1	96.84	96.84	<1
Temp	2	5,388.09	2,694.05	4.24*
time	2	246.29	123.15	<1
RPM	1	232.21	232.15	<1
Tem x time	4	10,313.43	2,578.36	4.06
RPM x Temp	2	791.93	395.96	<1
time x RPM	2	1.19	.60	<1
Experimental Error	21	13,331.09	634.81	
Sampling Error	36	15,246.70	423.52	

*Significant at $\alpha = 0.05$

DUNCAN'S MULTIPLE RANGE TEST
Per Cent Defoliation

Treat:	11	1	49	43	5	23	53	17	47	7	19	13	41	35	29	37	25	31
Mean:	34.5	40.7	41.3	42.4	45.	47.	48.	52.8	54.7	56.6	57.6	67.3	76.1	78.	78.4	79.5	79.5	82.

Note: See page 119 for interpretation of the Multiple Range Test.

DATA SHEET C-VI

ANALYSIS OF VARIANCE FOR PER CENT LEAF KILL IN THE FIELD

Source of Variation	df	SS	MS	F
Total	71	57,590.54		
Rows	1	524.87	524.87	<1
Temp	2	24,242.62	12,121.31	13.75**
time	2	7,871.08	3,935.54	4.46*
RPM	1	2,173.59	2,173.59	2.47
Temp x time	4	3,786.56	946.64	1.07
RPM x Temp	2	379.03	189.51	<1
time x RPM	2	80.14	40.07	<1
Experimental Error	21	18,514.65	881.65	
Sampling Error	36	8,628.74	239.69	

*Significant at $\alpha = 0.05$
**Significant at $\alpha = 0.01$

DUNCAN'S MULTIPLE RANGE TEST
Per Cent Leaf Kill

Treat:	11	1	5	23	17	7	19	29	13	41	25	31	35	37	43	47	49	53
Mean:	34.9	40.7	46.4	48.5	53.9	59.6	65.5	83.0	84.2	84.4	100	100	100	100	100	100	100	100

Note: See page 119 for interpretation of the Multiple Range Test.

DATA SHEET C-VII

ANALYSIS OF VARIANCE FOR PER CENT DEFOLIATION VERSUS TIME OF DAY

Source of Variation	df	SS	MS	F
Total	31	10,311.19		
Rows	1	304,43	304.43	
Time of day	7	8,012.74	1,144.68	40.33**
Experimental Error	7	198.70	28.39	
Sampling Error	16	1,795.32	112.21	

**Significant at $\alpha = 0.01$

DUNCAN'S MULTIPLE RANGE TEST
Per Cent Defoliation

Treatment:	0700	1100	1300	1700	1500	1000	0900	0800
Mean:	45.5	63.7	73.4	86.6	86.9	91.1	92.1	92.5

Note: See page 119 for interpretation of the Multiple Range Test.

DATA SHEET C-VIII

ANALYSIS OF VARIANCE FOR PER CENT LEAF KILL VERSUS TIME OF DAY

Source of Variation	df	SS	MS	F
Total	31	9,657.18		
Rows	1	2.46	2.46	
Time of day	7	9,262.32	1,323.19	61.19**
Experimental Error	7	151.36	21.62	
Sampling Error	16	241.04	15.06	

**Significant at $\alpha = 0.01$

DUNCAN'S MULTIPLE RANGE TEST
Per Cent Leaf Kill

Treatment:	0700	0800	0900	1700	1000	1100	1300	1500
Mean:	<u>47.5</u>	<u>94.6</u>	<u>97.8</u>	<u>98.1</u>	<u>100.0</u>	<u>100.0</u>	<u>100.0</u>	<u>100.0</u>

Note: See page 119 for interpretation of the Multiple Range Test.

APPENDIX D

LEAF MOISTURE DATA AND ANALYSIS

DATA SHEET D-I

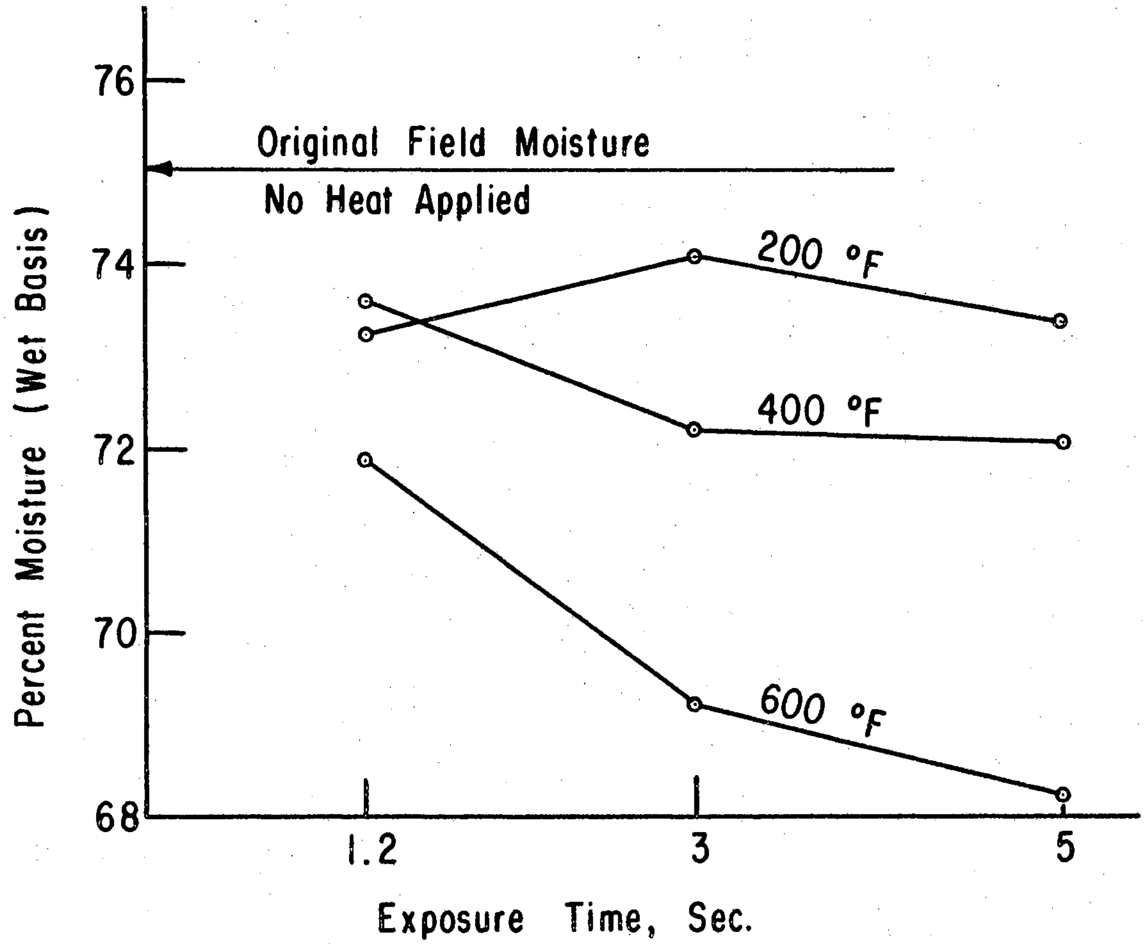
CHANGE IN MOISTURE CONTENT OF LEAVES
IMMEDIATELY FOLLOWING TREATMENT

Plot Number	Treatment Temp. °F	Exposure Time Sec.	Initial Weight Grams	Final Wt. Grams	% Moisture (Wet Basis)
Control	—	—	35.89	9.23	74.28
1	400	3	47.40	13.15	72.26
2	400	1.2	32.40	8.53	73.67
3	400	5	35.30	10.00	71.67
4	600	5	40.12	12.74	68.24
5	600	1.2	31.92	8.99	71.84
6	600	3	41.45	12.76	69.22
13	200	5	39.00	10.39	73.36
14	200	1.2	36.84	9.86	73.24
15	200	3	48.68	12.58	74.16

Fan Speed = 550 RPM

DATA SHEET D-II

LEAF MOISTURE VERSUS EXPOSURE TIME
FOR VARIOUS TEMPERATURES



APPENDIX E

PLANT HEIGHT DATA AND ANALYSIS

DATA SHEET E-I

LABORATORY DATA SUMMARY FOR PLANT HEIGHT VERSUS RESPONSE

Plant Height inches	Number of Observations	% Defoliation		% Leaf Kill	
		Total	Mean	Total	Mean
7.5	8	69.8	8.7	268.6	33.6
8.0	20	400.9	20.0	1035.3	51.8
8.5	22	578.1	26.3	1385.9	63.0
9.0	42	770.5	18.3	2754.6	65.6
9.5	41	1323.2	32.3	3219.6	78.5
10.0	53	1737.3	32.8	3959.8	74.7
10.5	32	725.4	22.7	2252.7	70.4
11.0	26	773.3	29.7	2118.7	81.5
11.5	23	663.6	28.9	1679.6	73.0
12.0	22	289.2	13.1	1117.3	50.8
12.5	11	237.0	21.5	680.6	61.9
13.0	15	298.8	19.9	936.3	62.4
13.5	5	202.0	40.4	500.0	100.0
14.0	4	107.5	26.9	354.5	88.6

ANALYSIS OF VARIANCE FOR RESPONSE VERSUS PLANT HEIGHT IN THE LABORATORY

Per Cent Defoliation:

Source of Variation	df	SS	MS	F
Total	323	262,920.46		
Plant Height	13	8,938.73	687.60	<1
Error	310	253,981.73	819.30	

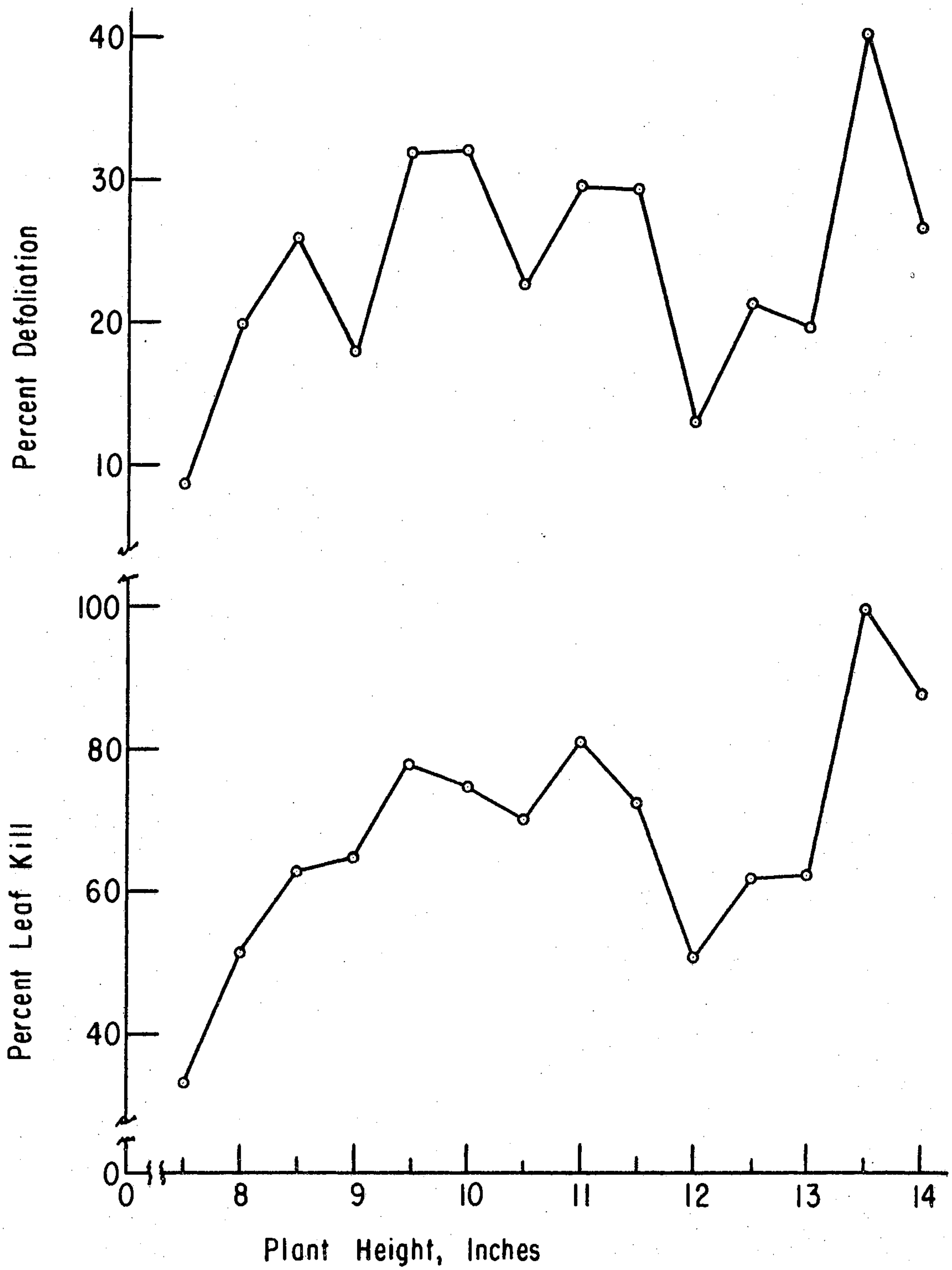
Per Cent Leaf Kill:

Source of Variation	df	SS	MS	F
Total	323	567,958.70		
Plant Height	13	42,030.14	3,233.09	1.91*
Error	310		1,696.54	

*Significant at $\alpha = 0.05$.

DATA SHEET E-II

PER CENT DEFOLIATION AND PER CENT LEAF KILL IN
THE LABORATORY VERSUS PLANT HEIGHT



DATA SHEET E-III

FIELD DATA SUMMARY FOR PLANT HEIGHT VERSUS RESPONSE

Plant Height inches	Number Observations	% Defoliation Total	% Defoliation Mean	% Leaf Kill Total	% Leaf Kill Mean
≤21	2	101.6	50.8	200.0	100.0
22-24	2	37.1	18.6	103.8	51.9
25-27	1	96.6	96.6	100.0	100.0
28-30	7	425.5	60.8	501.4	71.6
31-33	7	405.2	57.9	560.4	80.1
34-36	8	394.9	49.4	562.5	70.3
37-39	7	518.9	74.1	624.8	89.3
>39	2	68.9	34.4	133.3	66.7

ANALYSIS OF VARIANCE FOR RESPONSE VERSUS PLANT HEIGHT IN THE FIELD

Per Cent Defoliation:

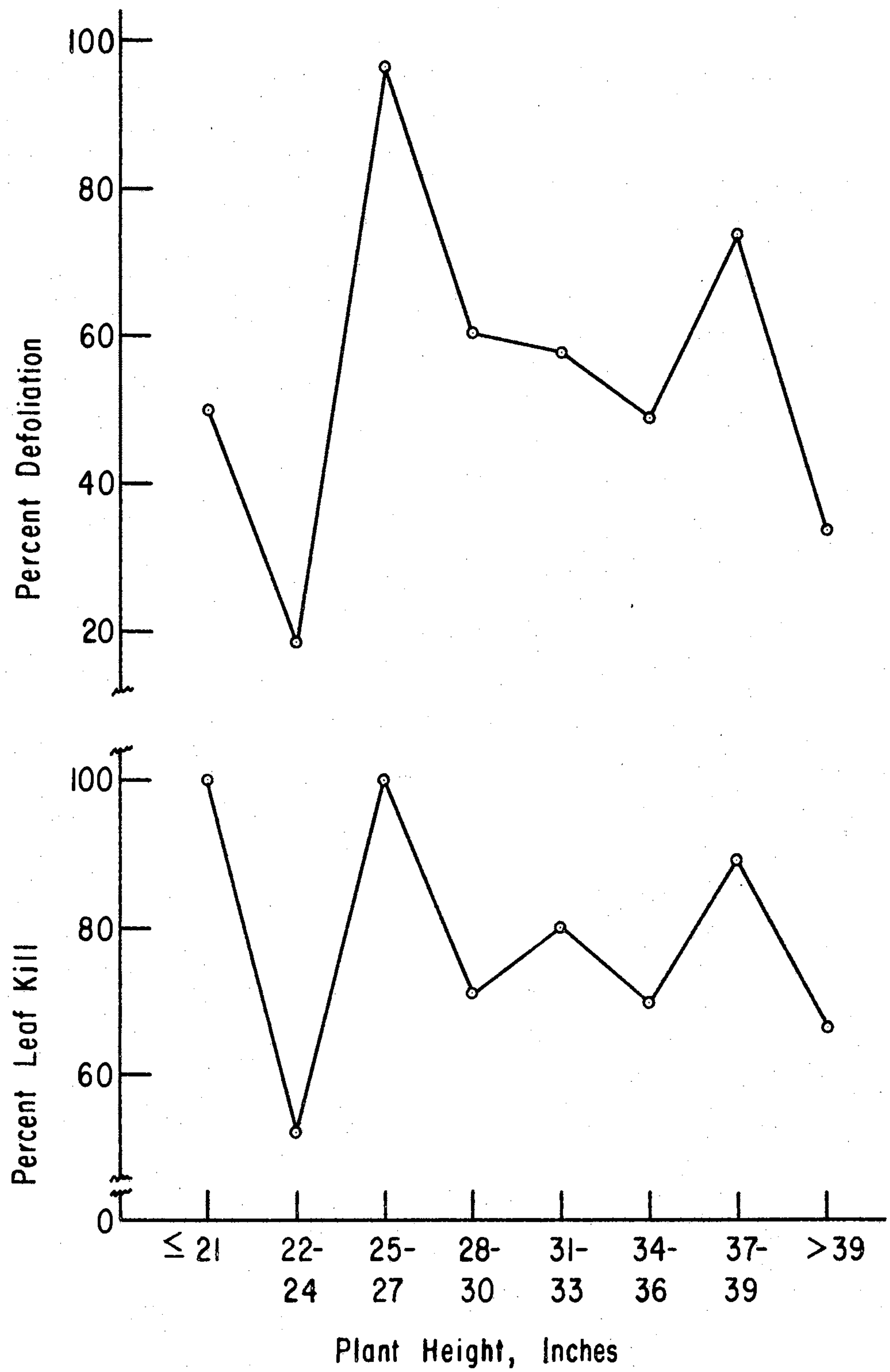
Source of Variation	df	SS	MS	F
Total	35	26,074.97		
Plant Height	7	8,244.71	1,177.82	1.85
Error	28	17,830.26	636.79	

Per Cent Leaf Kill:

Source of Variation	df	SS	MS	F
Total	35	29,604.16		
Plant Height	7	4,717.71	673.96	<1
Error	28	24,886.45	888.80	

DATA SHEET E-IV

PER CENT DEFOLIATION AND PER CENT LEAF KILL IN THE FIELD VERSUS PLANT HEIGHT



APPENDIX F

ECONOMIC ANALYSIS OF FIELD UNIT OPERATION

DATA SHEET F-I

FIELD UNIT FUEL COST AT $.08 PER GALLON
ESTIMATED FIELD EFFICIENCY = 70 PER CENT

Temp.	Fan Speed	Ground Speed	Fuel Press.	Fuel Rate	Fuel Rate	Fuel Cost	Field Capacity	Fuel Cost	Defoliation	Leaf Kill
^{o}F	RPM	MPH	psi	lb_m/min	gal/hr	$/Hr	Ac/Hr	$/Ac	Per Cent	Per Cent
200	250	4.5	1	1.0	14.2	1.13	2.54	.44	40.7	40.7
	550	4.5	3	1.3	18.4	1.47	2.54	.57	44.9	46.4
	250	1.8	1	1.0	14.2	1.13	1.01	1.11	56.6	59.6
	550	1.8	3	1.3	18.4	1.47	1.01	1.44	34.5	34.9
	250	1.1	1	1.0	14.2	1.13	.62	1.82	67.3	84.2
	550	1.1	3	1.3	18.4	1.47	.62	2.36	52.8	53.9
400	250	4.5	6	1.6	22.7	1.81	2.54	.71	51.6	65.5
	550	4.5	9	1.9	26.9	2.15	2.54	.84	46.9	48.5
	250	1.8	6	1.6	22.7	1.81	1.01	1.79	79.5	100.1
	550	1.8	9	1.9	26.9	2.15	1.01	2.11	78.5	83.1
	250	1.1	6	1.6	22.7	1.81	.62	2.92	82.0	100.0
	550	1.1	9	1.9	26.9	2.15	.62	3.46	77.9	100.0
600	250	4.5	22	3.3	46.8	3.74	2.54	1.47	79.5	100.0
	550	4.5	25	3.6	51.0	4.08	2.54	1.60	76.0	84.4
	250	1.8	22	3.3	46.8	3.74	1.01	3.69	42.4	100.0
	550	1.8	25	3.6	51.0	4.08	1.01	4.03	54.7	100.0
	250	1.1	22	3.3	46.8	3.74	.62	6.00	41.3	100.0
	550	1.1	25	3.6	51.0	4.08	.62	6.56	48.1	100.0

VITA

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Master of Science

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