HEAT INPUTS TO COTTON PLANTS

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INTRODUCTION

In recent years agricultural chemicals used for defoliation, weed control, and insect control have become closely regulated because of their potential for pollution of food, water, and the atmosphere. Pesticides, especially, have been the subject of much public clamor and emotion, but herbicides and chemical defoliants, like pesticides, also leave chemical residues.

Lykken (39) points out that under present conditions, fear of harm to man from pesticide residues is unwarranted. He admits the possibility of contamination is present, but believes the extent is below the level harmful to man or animals. Most pest-control chemicals degenerate to non-lethal substances after several days. However, long-term effects from pesticides have been reported (54), and as a result, some pesticides have been banned from the market (42). Therefore, valid arguments can be presented for investigating alternate control methods that will not leave chemical or other residues in any way harmful to man and his environment.

One alternative to chemicals is heat, and in order for this to become a more useful tool in agriculture, the effect and degree of sudden elevated temperatures in plants must be carefully examined. The uses of heat for pest control, cotton defoliation, and potato-vine desiccation have previously been shown to be effective (51).

Dorsey (10) investigated the use of flame to control weeds, insects, and disease in alfalfa. Also Maloy (40) reported using flame to control anthracnose, a fungus disease on alfalfa. Besides control of alfalfa pests, the use of heat has been investigated for the control of weeds in grain, sorghum, soybeans, and cotton (51).

Research was conducted at Oklahoma State University by Kent and Porterfield (29) on necessary exposure times and temperature levels to which cotton plants must be subjected in order for defoliation of the leaves to occur. However, no attempt was made to measure the quantity of heat a cotton leaf must absorb for defoliation to occur.

When heat is applied to a plant, whether the purpose be for weed, insect, or disease control or defoliation, thermal stresses in the plant result, and the response is an increase in the plant leaf temperature. This increase in leaf temperature depends upon the energy input to the leaf. The energy input is a function of the temperature gradient between the leaf and heat vehicle, the time the leaf is exposed to the heat vehicle, and the heat transfer coefficient, which is an inverse measure of resistance to heat flux between the leaf and heat vehicle. The heat transfer coefficient is a function of the air velocity, temperature, and physical and geometrical properties of the plant leaf and its immediate surroundings. The temperature level at which the heat vehicle must be maintained for a desired plant response is dependent primarily on the heat transfer efficiency between the heat vehicle and plant surface.

Limitations of the Study

The purpose of this research was to determine the heat absorbed by a cotton leaf and to relate the heat absorbed to leaf response. The study was limited to cotton plants, as some varieties of cotton require defoliation prior to harvest. Necessary research to support the objectives was also completed.

Objectives of the Research

1. Measure and formulate a mathematical expression to define leaf surface area, weight, and volume from the dimensions of the leaf.
2. Measure and define the capability of a plant to absorb heat relative to its physical characteristics and thermal properties.
3. Correlate the heat absorbed by the plant to the thermal properties of the heat vehicle.
4. Correlate the defoliation response of the plant to the heat absorbed.
5. Simulate the temperature response of a cotton leaf by using the results from objectives 1, 2, and 3.

CHAPTER II

LITERATURE REVIEW

This review of literature is not intended to be a comprehensive review of the subject of this research. Instead a brief synopsis of the topics pertinent to this investigation are reviewed. The main subjects discussed are defoliation and heat transfer between plants and their environment.

Effects of High Temperatures in Plants

Goodman and Wedding (19) reported that in the Imperial Valley cotton leaf temperatures were as high as 45.5°C when exposed to direct sunlight. Plants were, therefore, capable to some degree of physiological adjustment to high temperatures.

Degree of plant maturity may be a factor of heat resistance. Coffman (5) indicated that oat plants fifty days old were more resistant than were younger and, especially, older plants. Heyne and Laude, cited in (35), found that ten to fourteen-day old corn seedlings were more resistant to heat than older ones. Daniel (7) stated that plants became more resistant to heat penetration as they matured. Levitt (35) indicated that heat resistance was influenced by the water content of the plant. Both rapid and gradual dehydration of protoplasm often produced significant increases in heat resistance.

Daniel (7) indicated that the effect of heat may reduce or stop the vital function of phloem elements. He also stated that in the leaves of corn, pigweed, and soybeans, chlorosis in vivo occurred at a temperature of 1°C below the occurrance of necrosis of the cell tissue.

Sapper, cited in (35), determined the maximum temperature that failed to produce visible injury by exposing plants to saturated air for one-half hour. Sapper found that for aquatic and shade plants, the maximum temperature was about 40°C and for xerophytes, about 50°C.

Webster (53) heated one cm length of petiole from cotton seedlings with distilled water at 45°C for fifteen minutes and reported only slight or no necrosis of the petiole.

Daniel et al. (8) subjected soybean plant tissue to a 1042°C flame for 130 msec. Visible effects of flame on the palisade parenchyma cells were that the chloroplasts, nuclei, and tonoplasts appeared to rupture, and leakage of the contents of the cytoplasm in the vacuole occurred. They also placed detached mature soybean leaves in a water bath in temperature increments from 47°C to 57°C for one minute. Little or no damage was observed with treatments at 53°C or less. At 54°C, approximately 40 percent of the palisade cells exhibited damage; at 55°C, approximately 50 percent of the palisade cells exhibited damage; and at 56°C and 57°C, approximately 90 percent of the cells exhibited disintegration of the chloroplasts and disruption of the vacuole.

Daniel (7) reported that injury to plant tissue at high temperatures depended not only on the maximum temperature reached, but also on the length of exposure time above a specified level.

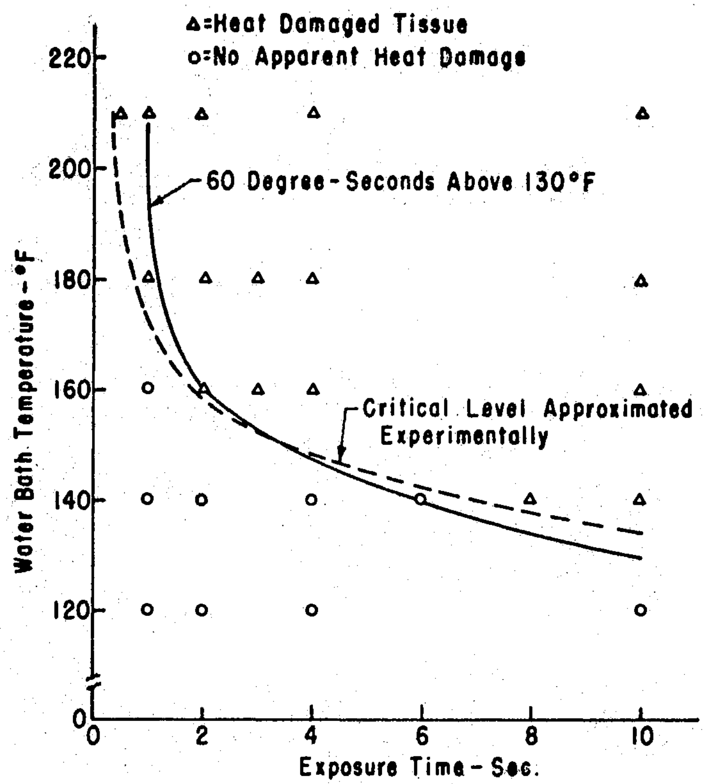


Figure 1. Effects of Temperature vs. Time on Cell Tissue of Corn Stems (52)

Thomas (52) submerged cell tissue of corn stems in a water bath at varying temperatures and exposure times. He illustrates in Figure 1 a level of heat damage depending on water bath temperature and exposure time. He also indicated that the critical product of exposure time and temperature was approximately 60 degree-seconds above 130^{o}F.

Daniel (7) summarized the cellular sequence of events at or near thermal death. He observed a critical swelling of chloroplasts, a reversible modification in the membranes of the chloroplasts, resulting in leakage of chlorophyll from the chloroplasts, and a reversible stoppage of cytoplasmic streaming. At thermal death there appeared to be a break-up or disorganization of the tonoplast, plasma membrane, and chloroplast membranes, followed by plasmolysis in some elodea cells with an irreversible stoppage of cytoplasmic streaming. He also indicated that 40 percent of the leaf cells in elodea leaves showed cellular disorganization at a temperature treatment resulting in the death of the whole leaf.

Defoliation

Natural Defoliation

Abscission of leaves is an active severance of living tissue and requires metabolic work. In leaves, the abscission zone is usually located at the base of the petiole next to the stem. In many instances the abscissed leaf may still be functional (47).

Hicks (24) stated that the initiation of abscission was associated with senescence (physiological aging) and was brought about by natural causes, nutrient deficiency, prolonged water stress, disease, insects, and frost. Carns (4) attributed abscission inhibition to petiole growth. Once growth ceased, degenerative changes occurred of which abscission was one result.

Addicott and Lynch (1) pointed out that deficiencies in nitrogen or any of the mineral nutrients could lead to leaf abscission. However, disease and injury also caused the abscission process to occur.

Rubinstein and Leopold (47) described abscission as "an event taking place at a zone of structural weakness in the cells of the petiole and consisting mainly of a hydrolysis of cell walls." Carnes (4) stated that there were few inter-cellular spaces and less fibrous material in the abscission zone at maturity. Separation was accomplished by the softening of cell walls and solubilization of some of the constituents.

Addicott and Lynch (1) attributed the critical phase of abscission to cell wall dissolution, and they reviewed three types of dissolution: 1) the middle lamella between two cell walls dissolving, with the primary cell walls remaining intact; 2) the middle lamella and primary cell walls between two layers of cells dissolving, leaving thin cellulose walls; and 3) entire cells of one or more layers dissolving. In some cases dissolution did not occur, and abscission appeared effected by physical stress.

Leinweber and Hall (34) reported that normal leaf separation in cotton was accompanied by cell division in the abscission zone, and the most reliable index of leaf-fall was the condition of the abscission zone. When a leaf was ready, the zone exhibited a narrow yellowish to hyaline band around the base of the petiole.

Laibach, cited in (4), was one of the first investigators who found evidence that an endogenous growth hormone was responsible for controlling abscission of leaves. LaRue, cited in (9), later demonstrated that synthetic auxins retarded abscission of coleus leaves.

Gawadi and Avery (18) and Hall (21) demonstrated that deblading of cotton started secondary cell division in the abscission zone prior to abscission of the petiole after approximately one week. Hall concluded that the leaf blade exerted some influence on abscission. When Hall (21) applied lanolin with a one percent indoleacetic acid (IAA), abscission was completely retarded in coleus.

Ethylene gas was demonstrated by Hall (21) to be very effective in inducing defoliation in cotton. However, when IAA was applied to the leaves before the ethylene treatment, defoliation was inhibited.

Hall concluded that the relative balance of ethylene to auxin in the petiole determines the amount and rate of abscission.

Addicott and Lynch (1) conducted a study in which they demonstrated that the auxin gradient across the abscission zone was an important factor. Application of IAA to the proximal or distal end of debladed bean leaf petioles effected the rate of abscission. Auxin retarded abscission when applied to the distal end and accelerated abscission when applied to the proximal side of the debladed petiole. They concluded that as long as the auxin concentration on the distal side of the abscission zone was higher than on the proximal side, abscission did not occur. However, abscission did occur when the gradient disappeared and was accelerated when the gradient was reversed.

Gaur and Leopold (17) did not agree with the auxin gradient theory. They maintained that auxins have the ability to promote abscission regardless of the site of application and showed that low concentrations of auxin promoted abscission, while higher concentrations inhibited abscission. They also maintained that the greater inhibition of abscission by distal compared to proximal application was due predominantly to the translocation of auxin in leaf petioles. A given application to the distal end would provide more auxin to the abscission zone than the same application to the proximal end. They concluded that the amount of auxin applied was the controlling factor in inhibition or stimulation of abscission and not the auxin gradient.

Jacob, cited in (4), concluded that a leaf has its abscission time controlled by the auxin produced in the blade. When blade auxin production becomes low, stem auxin takes effect and abscission results. Addicott and Lynch (1) indicated there was a decrease in free auxin preceding abscission, and as leaves matured and approached abscission, there was a gradual decrease in diffusable auxin. Rubinstein and Leopold (47) reported that auxin effects might operate through mechanisms involving changes in membrane permeability, changes in pectic-enzyme activities, or changes in production of ethylene by petiole tissue.

Chemical Defoliation

Commercial defoliants are chemicals which accelerate leaf abscission. Addicott and Lynch (1) found chemical defoliants caused effects similar to injury of the blade and petiole without seriously affecting the abscission zone. Hall (21) concluded that the role of chemical defoliants was due in part to decreased activity of the cells of the leaf and thus eliminated or reduced IAA production. Hall also noted that commercial defoliants accelerated ethylene production in cotton leaves and that ethylene could destroy auxin.

Leinweber and Hall (34) found certain chemical defoliants induced different patterns of abscission. The commercial defoliant, Endothal, greatly accelerated leaf abscission, but the sequence of abscission was similar to that observed in natural senescence and abscission. Other defoliants, such as Shed-A-Leaf and amino triozole, induced leaf abscission without detectable cell division preceding separation. They noted that these defoliants stimulated rapid hydrolysis of walls across the abscission zone.

Hall and Lane (21) reviewed the physiological chemical pathway for defoliation. They maintained that after the defoliant was absorbed, metabolic processes of the leaf were temporarily inhibited, and localized tissue destruction occurred. These reactions lowered the auxin content and stimulated hydrolysis and respiratory enzymes, indicated by the accelerated oxygen uptake and carbon dioxide output. Soluble carbohydrates were oxidized under aerobic conditions, and increased aerobic respiration was favorable to ethylene production. This evolution of ethylene might have shifted the auxin-ethylene ratio in favor of ethylene, thus initiating the events leading to abscission. They concluded that the events probably accelerated respiration and production of ethylene in the petiole, thereby causing a loss of the auxin gradient across the abscission zone along with the dissolution of cells and cell-wall materials.

Leinweber and Hall (33) concluded that a successful cotton defoliant must produce a mild degree of physical or physiological injury with a corresponding stimulation of respiration. They also warned that extreme toxic or desiccant chemicals caused rapid death of the blade and petiole tissue with little or no abscission occuring.

Hall (22) pointed out that the results of chemical defoliants could be related to environmental conditions and the physiology of the plant. He stated when drought developed and became pronounced toward the end of the growing season, leaf abscission was retarded. Also, chemical defoliation was accelerated at light intensities in the 3000-foot candle range and 15°C to 35°C temperature range.

<u>Thermal</u> <u>Defoliation</u>

The effect of high temperatures causing the defoliation of plant organs has been observed for some time.

Lloyd (38) observed that the petals of Geranium Pyrenaicum were shed very rapidly when the laboratory temperature was over 40°C, and that a sudden change in temperature was more effective than a gradual change.

Kent and Porterfield (29) investigated the optimum temperatures and exposure times for defoliation and leaf kill on cotton. Their results indicated a maximum defoliation response for an air temperature of 400°F and exposure times of from three to five seconds, and for a 600°F air temperature with an exposure time of one second. Temperatures of 200°F showed no apparent response. They also presented an equation regressing percent defoliation on temperature and time.

Reifschneider and Tanner (46) investigated the use of infrared burners to successfully defoliate cotton. They reported maximum defoliation occurred at an exposure time of 1.9 seconds and an air temperature between 500°F and 600°F.

Hall (22) reported observations on degrees of frost killing. If first fall frosts were light, leaf blades indicated no external damage, but abscission was initiated, and defoliation resulted. If the first frost was a heavy or killing frost, the abscission zone and stem were killed and the leaves desiccated, but the bulk of the leaves remained attached.

Heat Transfer between the Plant and its Environment

The temperature of a plant leaf is an indication of its response to an energy input. The energy balance of a leaf is written as follows (13, 14, 45, 49):

$$R_s + R - R_1 \pm H \pm LE + B \pm S = 0 \qquad (1)$$

where:

R_s = Solar and scattered shortwave radiation.

R = Longwave radiation emitted by ground, atmosphere, and surrounding vegetation.

R_1 = Reradiation at infrared lengths from the leaf surface.

H = Convection and conduction in the form of sensible heat.

L = Enthalpy of evaporation.

E = Evaporation or condensation of moisture in the leaf surface, including transpiration.

B = Chemical activity within the leaf through photosynthesis and other mechanisms

S = Transient term where the leaf is gaining or losing heat.

The sum of the energy terms in cal/cm^2-min must equal zero.

Energy will be considered positive if it flows toward the surface of the leaf and negative if it flows outward from the leaf. Raschke (45) indicated that photosynthesis rarely used more than two percent of the absorbed radiation, so the energy term, B, is ignored. Also for the steady state or equilibrium condition, the storage term, S, is zero. The energy balance can now be written as follows:

$$R_s + R \pm R_1 \pm H \pm LE = 0 \quad (2)$$

Radiation

Solar radiation, R_s, is the primary source of energy and is transmitted over a wide range of wavelengths. Figure 2 illustrates solar radiation from direct, overcast, and scattered sunlight and its variation with wavelength. The maximum intensity of direct sunlight is in the near infrared. Solar energy falls on the earth's atmosphere in a

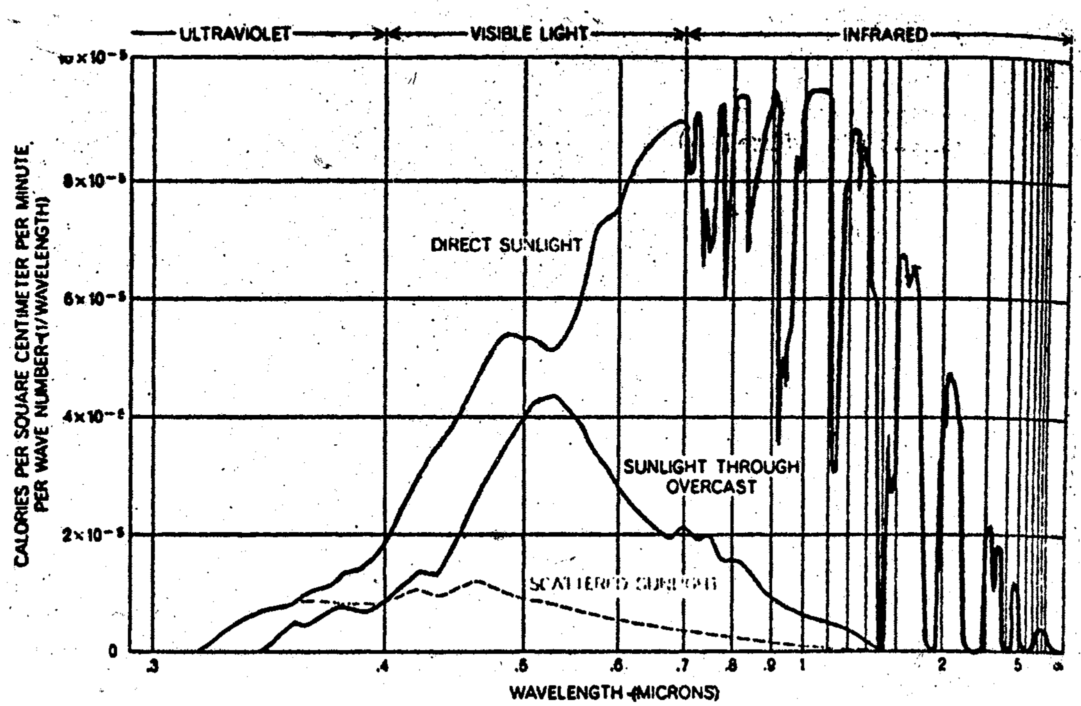


Figure 2. Intensity of Solar Radiation (13)

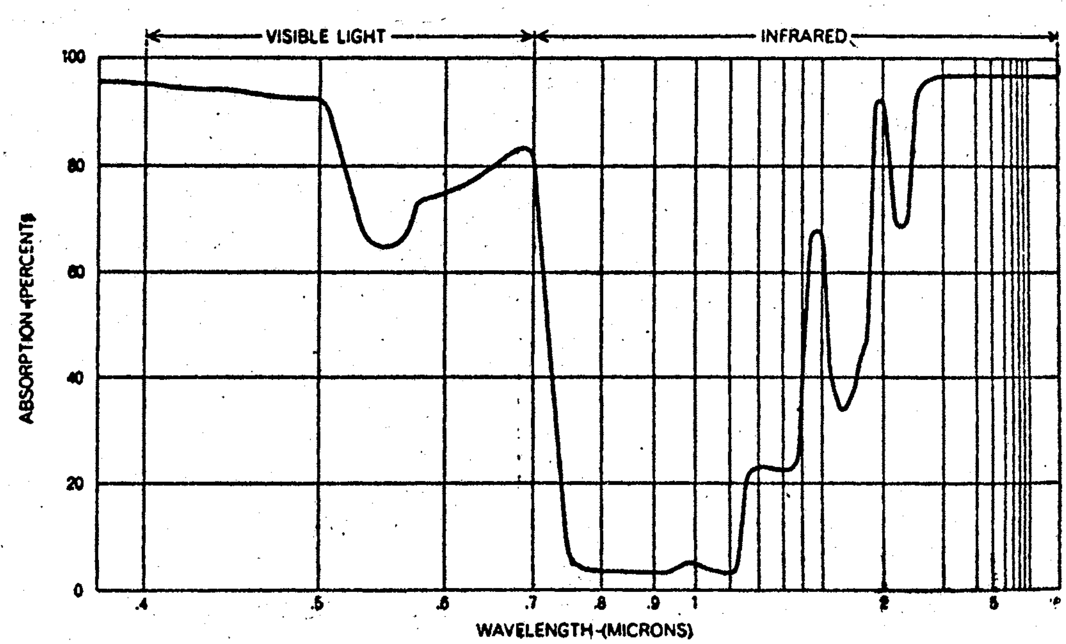


Figure 3. Absorption of Energy by a Leaf of the Poplar Populus Deltoids (7)

wide spectrum, but ozone in the upper atmosphere screens out the ultraviolet radiation of wavelengths less than 0.29 microns, and water vapor and carbon dioxide screen out infrared radiation at wavelengths greater than 22 microns. Gates (13) called the earth's atmosphere a "window" that allows only this narrow band of the spectrum to reach the earth's surface. The solar energy falling on the earth's atmosphere, called the solar constant, averages about two cal/cm^2-min. Because of this window, the earth's surface receives solar energy at a rate of between 1.2 to 1.4 cal/cm^2-min.

When radiant energy falls on a body, it will be absorbed, reflected, or transmitted through the body, which in mathematical form was written by Wiebelt (55) as:

$$\alpha + \rho + \tau = 1$$

where:

α = Absorptivity or fraction of the total energy absorbed.

ρ = Reflectivity or fraction of the total energy reflected.

τ = Transmissivity or fraction of total energy transmitted through the body.

The absorptivity, reflectivity, and transmissivity are dependent on the wavelength. The absorptivity of Populus Deltoides as a function of wavelength is illustrated in Figure 3. Where solar energy is highest, in the 0.7 to 1.2-micron range, absorptivity, α , is the smallest value which protects the plants from a high heat input.

Values for α, ρ , and τ for solar radiation on typical plant coverage are illustrated in Figure 4. Both Gates (13) and Wolpert (56) indicated that for longer wavelengths, a leaf acts more like a black body. Wolpert (56) plotted solar radiation per micron versus wave-

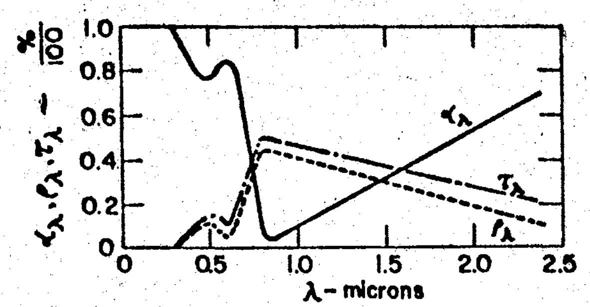


Figure 4. Absorptivity, Reflectivity, and Transmissivity for Solar Radiation on Typical Plant Coverage (26)

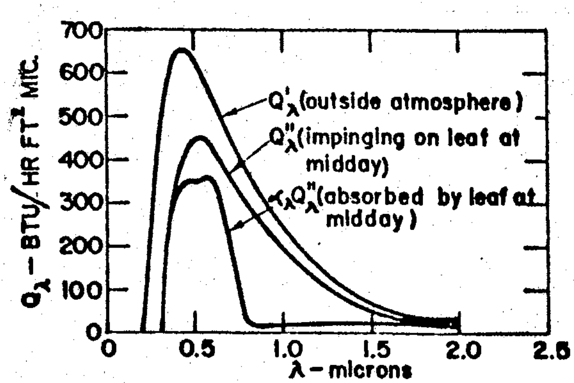


Figure 5. Available Energy for a Typical Plant Leaf from Solar Radiation (26)

length, Figure 5. He showed the solar energy hitting the outside atmosphere, Q'_{λ} , the solar energy impinging on a leaf at midday, Q''_{λ} , and the energy absorbed by a leaf at midday, $\alpha_{\lambda} Q''_{\lambda}$. The energy absorbed by the leaf was calculated by summing the area under the $\alpha_{\lambda} Q''_{\lambda}$ curve as follows:

$$Q_{absorbed} = \int_{0.3}^{2.0} \alpha_{\lambda} Q''_{\lambda} \, d\lambda \simeq 0.543 \text{ cal/min-cm}^2$$

Wolpert's data indicated that less than one half of the solar energy striking a leaf's surface will be absorbed with the remainder being reflected or transmitted through the leaf. The absorption of solar energy is dependent on the absorptivity, α , of the leaf, which will be a function of the leaf's physical, surface, and color properties along with leaf orientation.

Thermal radiation from a black body is calculated from the Stefan-Boltzman law as follows:

$$Q = \sigma T^4 \tag{3}$$

where:

Q = Radiant energy, cal/cm^2-min.

σ = Stephan-Boltzman constant, 0.8123 $(10)^{-10}$ cal/cm^2-min-K^4.

T = Absolute temperature, $^{\circ}$K.

For non-black bodies, the emissivity, ε , is introduced which is a ratio of the energy emitted from a non-black body to that emitted from a black body at the same temperature. Equation 3 for a non-black body then becomes:

$$Q = \varepsilon \sigma T^4 \tag{4}$$

Wiebelt (54) reviewed Kirchoff's Law of Radiation and showed that for an isothermal enclosure the absorptivity, α , equals the emissivity, ε , shown as:

$$\alpha = \varepsilon$$

The leaves of a plant are continuously exchanging long and short wave radiation with the atmosphere and adjacent soil and plant surfaces. The net radiation, R_n, can be written as:

$$R_n = \alpha_s R_s + \alpha_l R - \varepsilon_l R_l \quad (5)$$

where:

α_s = Fraction of incident short wave radiation absorbed.

α_l = Fraction of incident long wave radiation absorbed.

ε_l = Fraction of long wave radiation emitted.

Slatyer (49) gave values for the short wave absorptance, α_s, to be 0.5 to 0.8, and for long wave radiation, the absorptivity, α_l, and emissivity, ε_l, were approximately 0.97.

Convection

Two forms of convection heat transfer can occur, these being natural or free convection and forced convection. Natural or free convection occurs whenever the flow of air is created solely by density gradients, and forced convection occurs when the air flow is caused by bulk air movement or some external force field. In reviewing heat transfer between the leaf and environment, the concepts of conduction and convection are included under the single mode, convection.

The rate at which heat is transferred from an object by convection is:

$$H = h_c A (T_A - T_L) = h_c A \Delta T \quad (6)$$

where:

H = Heat energy, cal/min.

h_c = Convection coefficient, cal/cm^2-min-^{o}C.

A = Surface area, cm^2.

ΔT = Temperature difference between the air and leaf, ^oC.

Salisbury and Ross (48) defined a boundary layer to be "a transfer zone of gas or liquid in contact with an object in which the temperature, vapor pressure or velocity of the fluid is influenced by the object." Beyond the boundary layer, there is no influence of the object upon the fluid. At a leaf air interface, across which an air stream is moving, the velocity increases with distance from the leaf until it is indistinguishable from the medium. The transition zone in which the velocity increases is called the boundary layer. Likewise, with heat transfer there is a transition zone for temperature difference between the leaf surface and air. The thickness of the thermal boundary layer is not sharply defined, but approximated as an effective thickness across a temperature gradient equal to that which would have to exist to give the same total gradient and is illustrated in Figure 6, thus:

$$\frac{dT}{dx} = \frac{T_A - T_L}{d} = \frac{\Delta T}{d} \qquad (7)$$

where:

dT = Temperature gradient, $^oC/cm$.

d = Effective thickness of the boundary layer, cm.

ΔT = Temperature difference between the bulk air and leaf, ^oC.

Heat is transferred across the boundary layer by conduction and is removed by convective motion of the bulk medium. The rate of heat transfer across this boundary layer can be represented by Fourier's one dimensional heat flow equation:

$$H = -k\ A\ \frac{(T_A - T_L)}{d} = k\ A\ \frac{(T_L - T_A)}{d} = \frac{kA}{d}\ \Delta T \qquad (8)$$

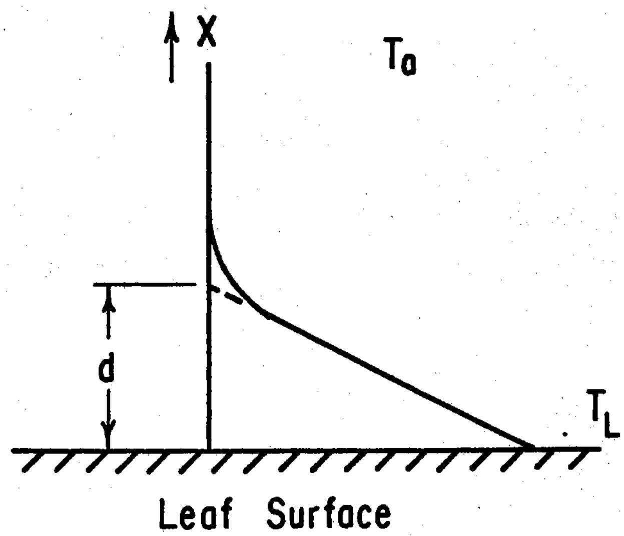


Figure 6. Temperature Boundary Layer for a Leaf

where:

k = Thermal conductivity of air, cal/cm^2-min-^{o}C

Δ T = Difference between leaf and air temperature, ^{o}C

and the other terms are as previously defined.

Some researchers (32, 36, 45, 49) defined the convection coefficient in terms of an equivalent diffusion resistance, r_a. Slatyer (49) introduced the convective heat transfer coefficient as h_c, as:

$$h_c = k/d \tag{9}$$

and defined a diffusive resistance, r_a, to heat transfer across the boundary layer as follows:

$$r_a = \frac{c_p \rho_a}{h_c} \tag{10}$$

where:

r_a = Diffusive resistance, sec/cm.

c_p = Specific heat of air at constant pressure, cal/g-^{o}C.

ρ_a = Density of air, g/cm^3.

and the other terms are as previously defined. Solving for k/d from Equations 8 and 9 and substituting into Equation 6 the following equation for convective heat transfer is obtained:

$$H = h_c\ A\ (T_L - T_A) = \frac{C_p\ \rho_a}{r_a}\ A\ (T_L - T_A) \qquad (11)$$

Values for h_c, d and r_a are all averaged values as the thickness of the boundary layer increases in the downwind direction. Therefore sensible heat flow, H, is also an averaged value.

Convection coefficients have been determined for flat horizontal plate's oriented with a warm side facing up and down as a vertically orientated plate for natural convection. Gates (15 and 16) reviewed semi-empirical convection coefficients for natural and forced convection from flat plates. For natural convection, the convection heat transfer coefficient, h_c, was:

$$h_c = B\left[\frac{\Delta T}{L}\right]^{\frac{1}{4}} \qquad (12)$$

where:

B = Constant depending on the plate orientation and plate temperature relative to the air.

L = Width of surface, cm.

ΔT = Difference in air and plate temperatures, ^{o}C.

For forced convection where a wind was involved, the convection coefficient was:

$$h_c = B\left[\frac{V}{L}\right]^{\frac{1}{2}} \qquad (13)$$

where:

$B = 5.73\ (10)^{-3}$

V = Air velocity, cm/sec.

L = Downwind plate dimension, cm.

Because real leaves are not perfectly flat, experimental observations seldom support Equation 13. A more satisfactory expression was given by Raschke (45) for leaves and was:

$$h_c = B \frac{V^{0.5}}{L^{0.3}}$$

where:

B = Some constant.

and the other terms are as previously defined.

Parkhurst et al. (43) presented average heat transfer coefficients over a flat plate by the use of dimensionless ratios of Nusselt, Grashof, and Reynolds Numbers.

The Nusselt Number, Nu, is a ratio of heat transferred through a moving boundary layer to the rate at which heat is transferred through a fixed boundary layer of the same thickness and is given by:

$$Nu = \frac{h_c L}{K} \qquad (14)$$

where:

L = The significant downwind length dimension, cm.

and the other terms are as previously defined.

The Grashof Number, Gr, is a ratio of the buoyancy forces to the viscous forces and is given by:

$$Gr = \frac{g\ L^3\ \rho_a^2\ B\ \Delta T}{M^2} \qquad (15)$$

where:

B = Temperature coefficient of the volume expansion of air, $1/^{o}C$.

g = Gravitational acceleration, cm/sec^2.

M = Viscosity, g/cm-sec.

and the other terms are as previously defined.

The Reynolds Number, Re, is a ratio of the inertia to viscous forces and is given by:

$$Re = \frac{\rho_a VL}{M} \qquad (16)$$

where:

V = Wind velocity, cm/sec.

and the other terms are as previously defined.

Parkhurst et al. (45) determined for ten real leaves significant dimension ratios, L_R, defined to be:

$$L_R = \frac{L}{L_{max}} \qquad (17)$$

where:

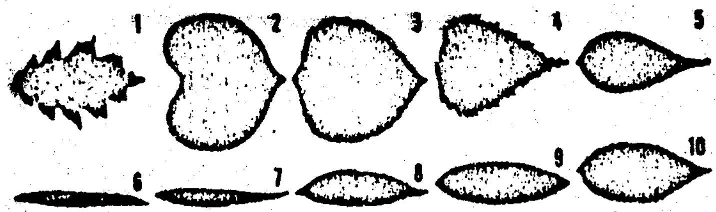
L = Significant dimension in the flow direction, cm.

L_{max} = Maximum leaf dimension in the flow direction, cm.

To obtain the significant dimension, L, to be used in the dimensionless correlation equation, L_R is read from Figure 7 and is multiplied by L_{max} as follows:

$$L = L_R \; L_{max} \qquad (18)$$

Parkhurst et al. then determined the average forced convection coefficient for single broad leaves of plants under windy conditions pre-



LEAF	1	2	3	4	5	6	7	8	9	10
X FORC.	.378	.594	.505	.407	.448	.681	.501	.508	.647	.471
X FREE	.465	.695	.610	.495	.526	.715	.577	.581	.697	.572
X TURB.	.480	.711	.628	.511	.541	.721	.591	.595	.705	.589
L FORC.	•	.811	.649	.487	.555	•	•	.612	.718	.636
L FREE	•	.828	.672	.529	.576	•	•	.643	.737	.657
L TURB.	•	.831	.677	.537	.580	•	•	.648	.740	.661

Significant dimension ratios for 10 real leaves; X indicates flow perpendicular to stem; L indicates flow parallel to stem; forc. indicates forced convection in laminar flow; free indicates free convection in laminar flow; and turb. indicates forced convection in turbulent flow

Figure 7. Significant Dimension Ratios for Real Leaves (43)

vailing in nature with an accuracy of ± 35 percent from the relation:

$$Nu = 0.6 \; Re^{\frac{1}{2}} \tag{19}$$

where Nu and Re are defined earlier, and the significant length dimension in the downwind direction is determined from Figure 7 and Equation 18 for a Reynolds Number larger than 1800. In a quiescent atmosphere, the average free convection heat transfer coefficient can be determined with an accuracy of ± 25 percent from the relation:

$$Nu = 0.37 \; Gr^{\frac{1}{4}} \; \alpha(\Theta) \tag{20}$$

where again the significant dimension, L, in the Nusselt and Grashof Numbers is determined from Figure 7 and Equation 18. The correction factor, $\alpha(\Theta)$, depends on the orientation of the leaf from the horizontal position and is determined from Figure 8.

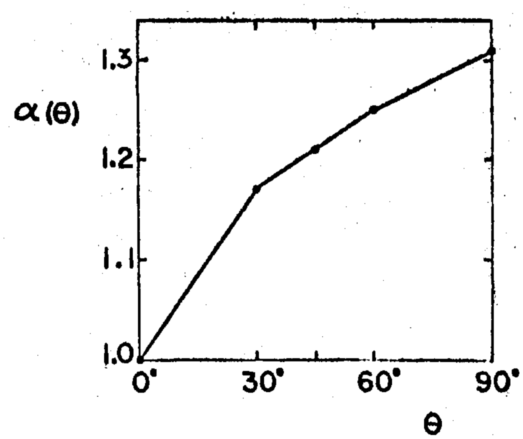


Figure 8. Experimental Alpha Factors (43)

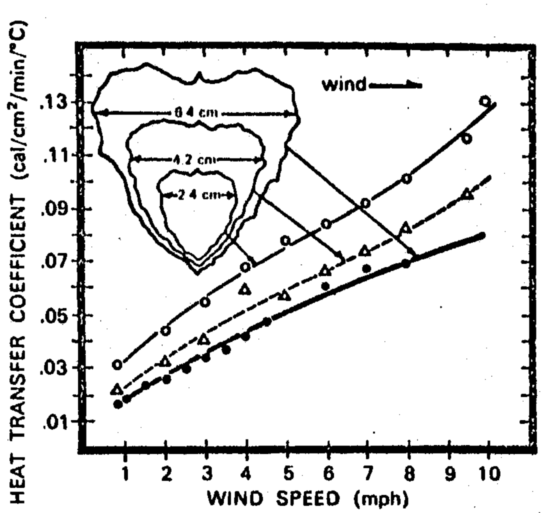


Figure 9. Heat Transfer Coefficients from Leaves of Different Sizes (48)

Salisbury and Ross (48) illustrated the results of another investigator for the heat transfer coefficient as a function of wind velocity and leaf length parallel to wind direction. Their results are shown in Figure 9 and illustrate that the smaller length dimension results in maximum heat transfer per unit area.

A comparison of Parkhurst's et al. (45) Equation 19, Gates' (15) Equation 13, and the graph presented by Salisbury and Ross (48), Figure 9, of the heat transfer coefficient is illustrated in Figure 10.

Other investigators, Linacre (36) and Pearman (44), reviewed methods to determine the heat transfer coefficient of a leaf.

Sensible heat gain is easily solved from Equation 6 if a value for the heat transfer coefficient can be determined.

Latent Heat

Latent heat transfer is indicated by transpiration, which for plant leaves involves water vapor loss from within the natural leaf surface to the leaf surface and then to the bulk air. The energy or driving force is the concentration gradient along this pathway.

The diffusion of material from one region to another, reviewed by Jacobs (27), was recognized by Fick in 1885 and is known as Fick's Law, stated mathematically for one dimension as:

$$dE = -D \frac{\partial c}{\partial x} d\theta \qquad (21)$$

where:

dE = Amount of material diffusing per unit area, g/cm^2.

D = Diffusion coefficient, cm^2/sec.

$d\theta$ = Time, min.

$\frac{\partial c}{\partial x}$ = Concentration gradient, g/cm^4.

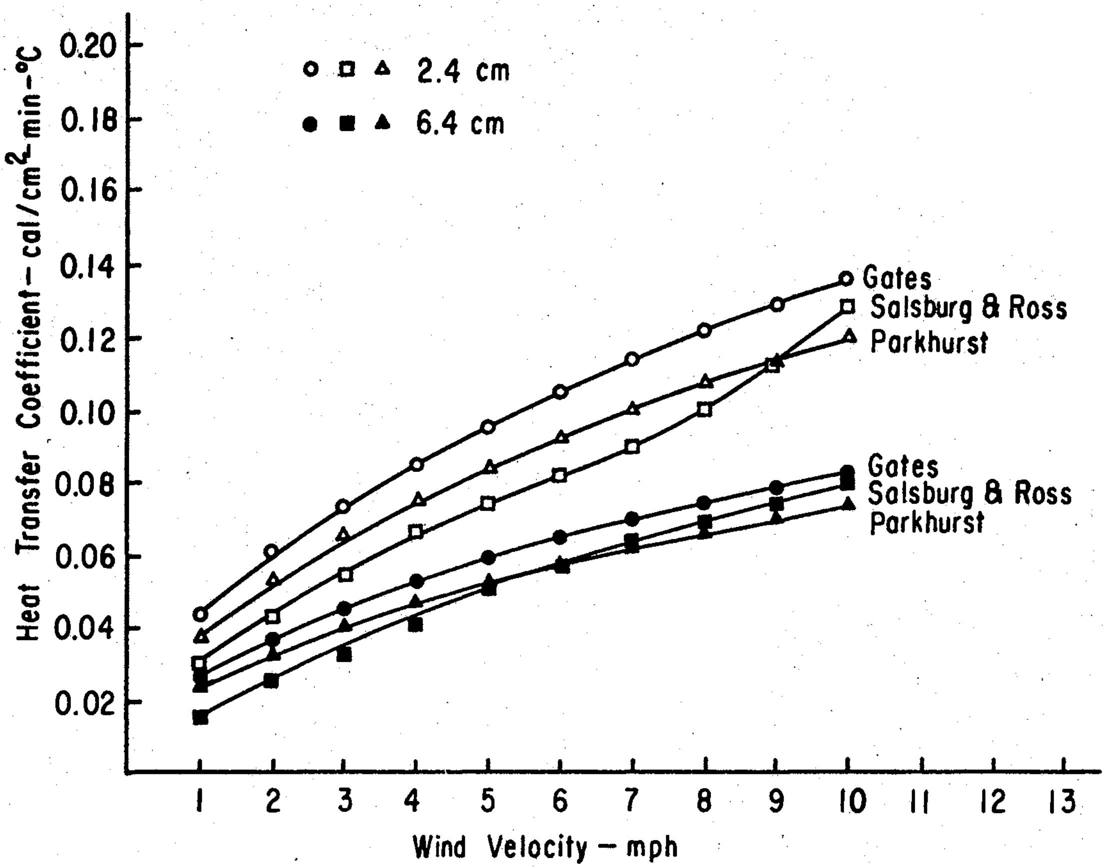


Figure 10. Comparison of Heat Transfer Coefficients from Three Investigators

Assuming appropriate boundary conditions, Equation 21 becomes:

$$E = D\,\frac{(c_1 - c_2)}{L} = \frac{c_1 - c_2}{L/D} \qquad (22)$$

where:

c = Concentration at 1 and 2, g/cm^3.

The ratio L/D is defined as a resistance term, r, in sec/cm, mathematically written as:

$$r = L/D \qquad (23)$$

Slatyer (49) and Kramer (31) wrote the equation for diffusion of water vapor from a free surface to be:

$$E = \frac{C_w - C_a}{r_a} \qquad (24)$$

where:

E = Evaporation, g/cm^2-sec.

C_w = Water vapor concentration at the water surface, g/cm^3.

C_a = Water vapor concentration in the bulk air, g/cm^3.

r_a = Surface boundary layer resistance to diffusing water vapor molecules, sec/cm.

Transpiration differs from evaporation, as there is an additional resistance term due to internal leaf resistance. Equation 24 becomes for a leaf:

$$E = \frac{C_l - C_a}{r_l + r_a} = \frac{0.622\rho_a}{P} \frac{(e_l - e_a)}{(r_l + r_a)} \qquad (25)$$

where:

C_l = Water vapor concentration of the evaporating surfaces within the leaf, g/cm^3.

r_l = Diffusion resistance within the leaf, sec/cm.

e_l = Water vapor pressure of the leaf, mm Hg.

e_a = Water vapor pressure of the air, mm Hg.

ρ_a = Density of air, g/cm^3.

P = Atmospheric pressure, mm Hg.

The factor $0.622 \rho_a / P$ is a conversion factor from concentration, C, to vapor pressure, e.

The driving force is the difference in water vapor pressure or concentration between the leaf and bulk air. The difference depends on two variables which are the water vapor pressure of the bulk air and the water vapor pressure at the evaporating surface of the leaf. The vapor pressure at the evaporating surface is assumed to be the saturation vapor pressure at the leaf surface temperature (14, 24, 30, 36).

The quantity of water vapor loss is dependent upon the resistance to mass transfer of the leaf, r_l, and air, r_a. Kramer (31) illustrated the various pathways of resistance to diffusion of water vapor from a leaf in Figure 11. There are two principal sites of evaporation from a leaf, the mesophyll cells and intercellular spaces, and the outer surfaces of the epidermal cells. The outer surfaces of the epidermal cells can present considerable resistance to diffusion because of the wax-like covering over the epidermal cells. Most evaporation is through the stomatal, but when the stomatal cells are closed, the only pathway is through the cuticle.

The magnitude of the external resistance term, r_a, depends on the downwind leaf length and the wind velocity. Typical values for the external resistance for a cotton leaf 10 cm wide are illustrated in Figure 12. For a cotton leaf, the external resistance can range from three sec/cm to 0.3 sec/cm for velocities from 0.1 m/sec to 10 m/sec, respectively.

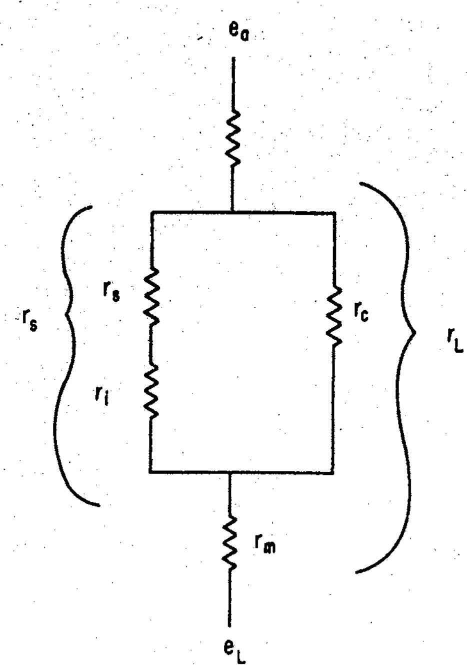


Figure 11. Resistance Paths to Diffusion of Water Vapor from a Leaf (31)

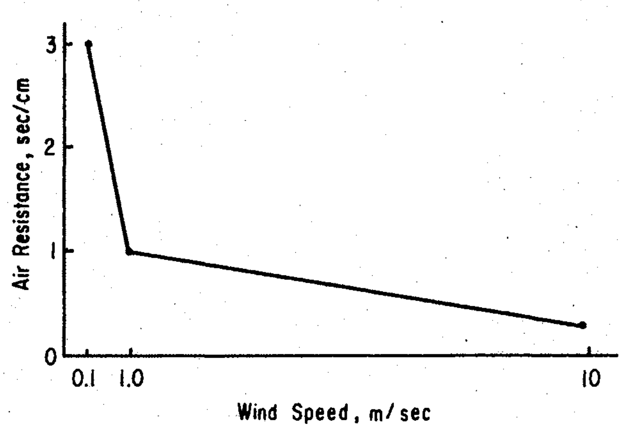


Figure 12. Variation of Air Resistance with Wind Speed (49)

Drake (11) reported a relationship for the boundary layer resistance, r_a, as a function of wind speed for a leaf model of 6.4 cm in width as:

$$r_a = 7.5\ V^{-0.58} \tag{26}$$

where:

V = Wind speed below 200 cm/sec.

When V is greater than 200 cm/sec, the relationship is:

$$r_a = 23\ V^{-0.82} \tag{27}$$

Gates (15) reported that laboratory determinations of the external resistance term, r_a, resulted in the following expression:

$$r_a = K_z \frac{D^{0.35}\ W^{0.20}}{V^{0.55}} \tag{28}$$

where:

V = Wind speed, cm/sec.

D = Dimension of the leaf in direction of the wind, cm.

W = Dimension of the leaf transverse to the wind, cm.

K_z = 0.035 for $W \gg D$ or $W = D > 5$ cm.

K_z = 0.026 for $W \ll D$ or $W = D \leq 5$ cm.

Impens et al. (25) gave the mean external resistance per unit area for Zea Mays as:

$$r_a = \frac{c_p}{2\ (Pr^{0.333} 0.066\ Re^{0.5} \frac{k}{L})} \tag{29}$$

or he summarized Equation 29 as:

$$r_a = 0.06\ V^{-0.5}$$

where:

Pr = Prandtl Number.

and the other terms are as previously defined.

Estimates of cuticular resistance, r_c, range from 10 sec/cm for shade plants to 100 sec/cm for xerophytes. For cotton, Kramer (31) reported a value determined by Slatyer to be 64.4 sec/cm, and Kozlowski (30) reported a value of 60 sec/cm for cotton. The stomatal resistance term, r_s, is dependent upon the aperture of the stomatal. For wide open stomata, Kramer (31) reported values of r_s for cotton to be 2.0 sec/cm, and Kozlowski (30) reported a value of 1.8 sec/cm. Stomatal resistance is also very dependent on light intensity. As light intensity increases, stomatal resistance, r_s, decreases as illustrated in Figure 13 for a bean. Stomatal aperture on the control

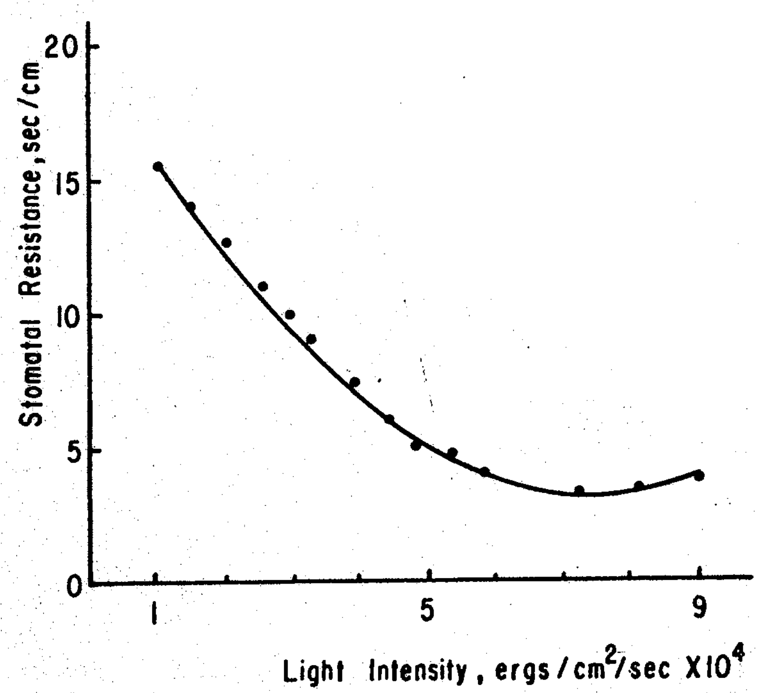


Figure 13. Effect of Light Intensity on Stomatal Opening of a Bean (31)

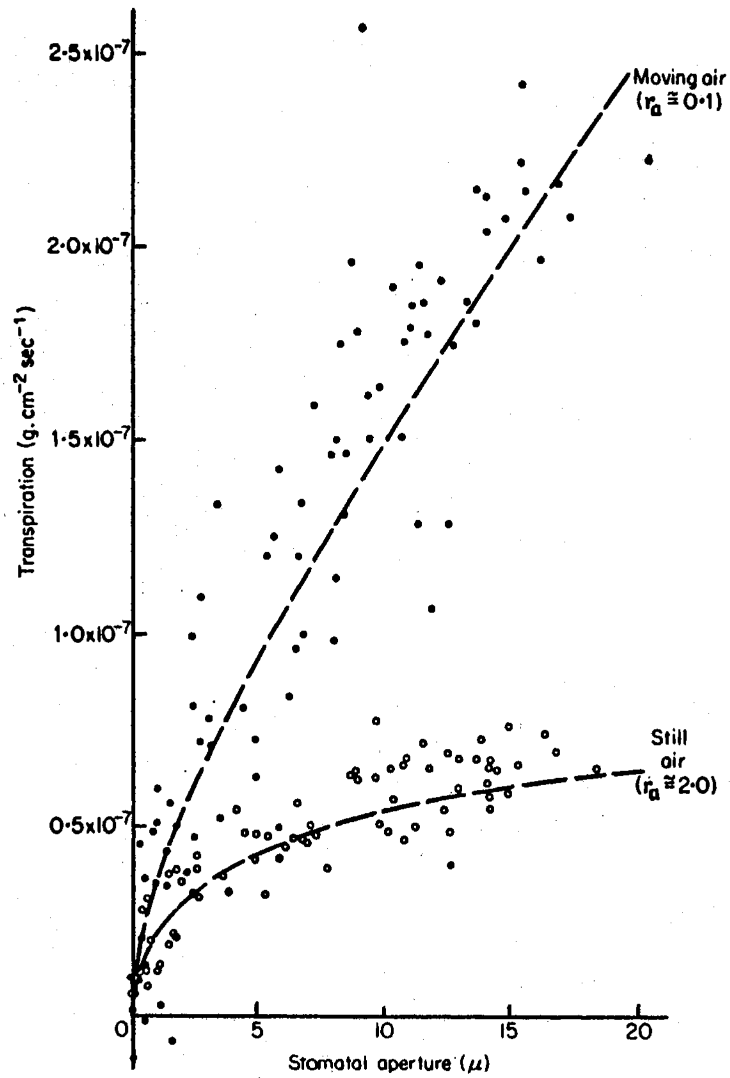


Figure 14. Influence of Stomatal Aperature on Transpiration of Zebrine Leaves Under Moving and Still Air (49)

of transpiration is illustrated in Figure 14. For still air and open stomata, $r_s \ll r_a$. Therefore, there is little stomatal control. For moving air, $r_s \gg r_a$, and control of transpiration is effected through the range of stomatal aperture.

Resistance of intercellular spaces, r_i, and mesophyll cells, r_m, are difficult to determine, and there are conflicting views. Weatherspoon, cited in (31), reported a negligible amount of mesophyll resistance in mesophytic types of leaves.

Drake et al. (11) determined leaf resistance, r_l, from Xanthium Strumarium L. leaves. In dry air, a linear relationship obtained by regression was:

$$r_l = 7.95 - 0.18\ T_l \tag{30}$$

and for moist air a second order polynomial is presented as:

$$r_l = 0.292 + 0.1397\ T_l - 0.00342\ T_l^{\,2} \tag{31}$$

where:

T_l = Leaf temperature, °C.

r_l = Leaf resistance, sec/cm.

His results indicated that leaf resistance was dependent on leaf temperature, and he stated that as leaf temperature and moisture content of the air increased, leaf resistance decreased.

<u>Overall</u>

The relative magnitudes of the three modes of heat transfer from a plant leaf are illustrated in Figure 15. Equation 2 can be written as:

$$R_n = H + I\ E \tag{32}$$

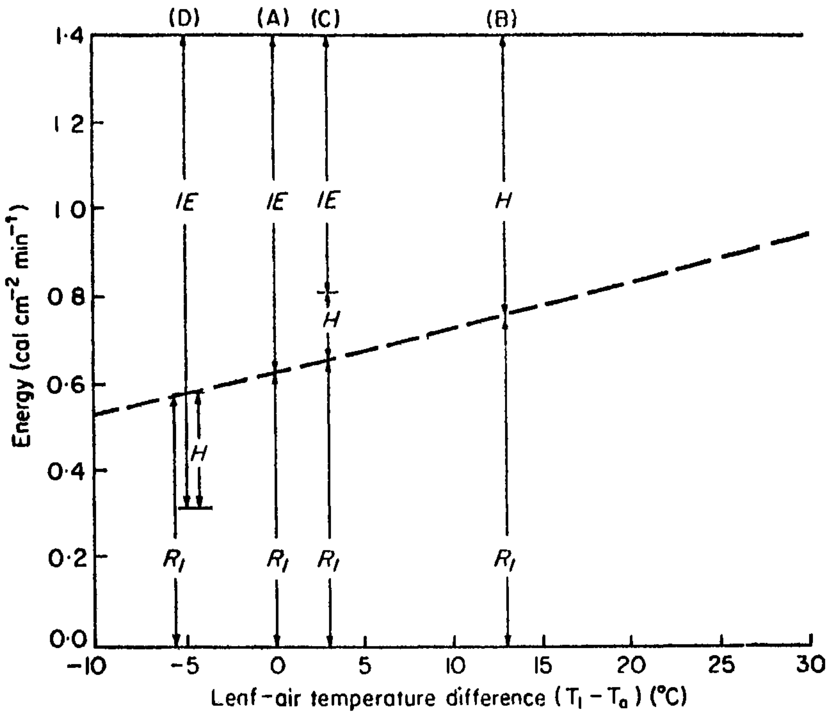


Figure 15. Estimated Energy Exchange by Transpiration IE, Radiation R, and Sensible Heat Transfer H, for a Leaf 10 cm wide at 25 °C with Wind Velocity of 200 cm/sec. (49)

where R_n is defined in Equation 5. It is assumed in Figure 15 that 1.4 cal/cm^2-min is the total energy absorbed. The figure illustrates four cases as follows: A) where leaf and air temperatures are equal, all energy will be reradiated or dissipated by transpiration; B) when transpiration is zero, leaf temperature increases, and heat is dissipated by sensible heat loss, H, and reradiation, R_1; C) all three modes of heat transfer are used in the energy budget of the leaf; and D) the air is warmer than the leaf, and a flow of sensible heat, H, to the leaf occurs. This increases the transpiration loss to dissipate the heat.

As illustrated in Figure 15, reradiation is the most important energy dissipator. Slatyer (49) reported that often more heat was dissipated from individual leaves by sensible heat transfer, but that transpiration was the more important mechanism for crops.

Idso and Baker (25) reported that high relative humidities and/or cool temperatures curtailed transpiration. Conditions of high air temperature and low relative humidity were favorable to transpiration. Convection, or sensible heat transfer, was dependent mostly on wind velocity and differences between air and leaf temperatures.

Equation 32 can be rewritten, steady state being assumed, by substituting Equations 11 and 25 for H and LE as follows:

$$R_h = h_c\, A\, (T_l - T_a) + \frac{L\, A\, (C_l - C_a)}{r_l + r_a} \qquad (33)$$

Equation 33 can be considered a simple steady state mathematical expression of an energy balance of a leaf.

CHAPTER III

DEVELOPMENT OF EXPERIMENTAL TECHNIQUE

The heat absorbed by a leaf results in a change of the internal energy of the leaf and evaporating water. In the transient state of heat conduction, the heat entering and leaving a leaf is not constant with time. The difference in energy flow increases the internal energy of the leaf. This energy change can be written as:

$$dH = c_p \, m \, \frac{\partial t}{\partial \theta} \, d\theta \qquad (34)$$

where:

dH = Internal energy, cal.

c_p = Specific heat, cal/g-^{o}C.

m = Mass, grams.

t = Temperature, ^{o}C.

θ = Time, min.

The latent heat can be determined by multiplying Equation 21 by the enthalpy of evaporation, L, to give:

$$LdE = DL \, \frac{\partial c}{\partial x} \, d\theta \qquad (35)$$

where:

LdE = Latent heat, cal/cm^2.

and the other terms are as previously defined. Ignoring radiation, the total energy input to the leaf surface is the summation of Equations 34 and 35 or:

$$dQ = c_p m \frac{\partial t}{\partial \theta} d\theta + DLA \frac{\partial c}{\partial x} d\theta \qquad (36)$$

where:

Q = Energy input, calories.

The heating of the leaf took place in a turbulent medium at an elevated temperature. Treating the leaf as a black body, simple calculations indicated that the heat inputs to the leaf by thermal radiation would account for a maximum of 10 to 15 percent of the total heat absorbed by the leaf. However, in most instances the heat input by thermal radiation would be considerably less than 10 percent. The heat input by thermal radiation was, therefore, ignored in this investigation. The bulk of the energy exchange was by convection and mass transfer.

Sensible and latent heat were determined by measuring the change in leaf temperature and the moisture loss of the leaf during treatment.

Sensible Heat

The maximum change in internal energy or sensible heat gain of a leaf was determined by use of Equation 34, which rewritten in incremental form is:

$$\Delta H = c_p m \frac{\Delta t}{\Delta \theta} \Delta \theta$$

or:

$$H = c_p m \, (T_f - T_i) \qquad (37)$$

where:

H = Energy, calories.

T_f = Maximum leaf temperatures, ^{o}C.

T_i = Initial leaf temperature, ^{o}C.

and the other terms are as previously defined. The value for specific heat, c_p, of leaf material was 0.87 cal/g-^{o}C as reported by Linacre (37). Linacre did not report the moisture content of the leaf material. It is recognized that the value for specific heat will vary with moisture content and age of the leaf.

Measurement of leaf temperatures has been reported by many investigators. Ansari and Loomis (2) and Mellor et al. (41) measured leaf temperatures by inserting thermocouples in the leaves. Gates (13) used a radiometer to determine the surface temperature of a leaf. The radiometer responds to energy emitted from a surface according to Equation 4. Mellor et al. (41) compared the method of using a radiometer to that of using a 30-gauge copper-constantan thermocouple threaded in a leaf as described by Curtis (6) to measure the surface temperature of a leaf. The difference in leaf temperature between the two methods was within $\pm$ 1.0^{o}C.

Edling et al. (12) reported inserting 40-gauge copper-constantan thermocouples into the veins of cucumber leaves to record leaf temperatures in situ. Drake (11) measured leaf temperatures by pressing the soldered junction of a thermocouple onto the leaf surface and securing the sensor by an extension of the constantan which was passed through the leaf and bent in a hook-like fashion.

In this investigation, 36-gauge copper-constantan thermocouples were inserted into a primary or secondary vein of a cotton leaf. The thermocouple was inserted from the bottom side of the leaf under the vein in such a way that the thermocouple junction was under the epidermal layer on the top side of the leaf. The temperature change of the leaf during treatment was then easily recorded. The sensible heat gain of the leaf was calculated using Equation 37.

Latent Heat

The moisture loss during treatment could not be recorded continually as was temperature. The method used to determine moisture loss was described by Salisbury and Ross (48) as the cut shoot method for determining transpiration. Immediately before treatment a leaf was detached from the plant, weighed, and reattached. Immediately after treatment, the leaf was weighed again. The difference in weight was the moisture loss of the leaf during treatment. The leaf area was then determined by planimeter, and the moisture loss per unit area of the leaf was calculated. After a series of treatments, a mathematical expression for the moisture loss per unit area was determined by a regression equation. The assumption was made that for a given treatment, the moisture loss per unit area of all leaves in that particular treatment was the same. The moisture loss of the instrumented leaves had to be estimated because they could not be detached and weighed, as their response was not observed until seven days after treatment. This afforded a technique to estimate latent heat loss from the instrumented leaves.

Criteria of Evaluation of Treatments

The evaluation of treatments was accomplished by observing the overall condition of the plant and leaves seven days after treatment.

For the instrumented leaves and plant, four responses were possible for any leaf and plant from any applied treatment. They were:

1) no response; 2) leaf desiccation; 3) leaf defoliation; and 4) plant desiccation.

The category of no response included leaves that were still viable and which exhibited little or no evidence of heat injury.

The category of leaf desiccation included leaves that exhibited excessive chlorosis or were completely dried, but the plant being viable with possible evidence of new growth.

The category of leaf defoliation included leaves that dropped from the plant with the plant being viable.

The category of plant desiccation included those plants that were killed by the treatment.

Area, Mass, and Volume

In order to define sensible and latent heat transfer for the instrumented leaves, area and mass of the leaves were fundamental. Because of the method of evaluating leaf response, a nondestructive method was required.

Investigators (3, 20, 28, 50) have determined the areas of cotton leaves by nondestructive methods. These methods consisted of formulating regression equations regressing area on leaf length and width.

Grimes and Carter (20) formulated an expression for the area of a cotton leaf of the variety Acala SJ-1 as a function of length of the main vein. Their expression was of the form:

$$Y = C_1 X^{C_2} \tag{38}$$

where:

Y = Leaf area.

C_1, C_2 = Constant.

X = Leaf length of the central main vein.

Ashley et al. (3) formulated equations for five cotton varieties; Stoneville 7, Rex, Auburn 56, Deltapine 15, and Acola 4-42, using as a mathematical model:

$$Y = W\ L\ C_3 \tag{39}$$

where:

Y = Leaf area.

W = Leaf width.

L = Leaf length.

C_3= Constant.

with leaf length and width measured as indicated in Figure 16. Their results indicated that for best results of area estimation, a different mathematical expression should be formulated.

For this investigation, leaf length and width were measured according to Figure 16. Expressions for leaf area, mass, and volume were obtained by regressing area, width, and volume on leaf length and width.

Simulation of Temperature Response

Mellor et al. (41) reported that the heating and cooling curves of leaves in their investigation suggested a behavior of Newtonian heating and cooling. Newtonian heating and cooling assumes no temperature gradients within the object at any instant of time and no mass transfer. The heat transfer process is controlled only by surface resistance, as the object is assumed to be of high thermal conductivity.

The rate of heat transfer is given by Equation 34 and Equation 6 or:

$$q = c_p \, m \frac{dt}{d\Theta} = h_c A \, (t_x - t) \tag{40}$$

where:

q = Heat gain, cal/min.

t_x = Ambient fluid temperature, ^{o}C.

t = Temperature at instant Θ, ^{o}C.

and the other variables are as earlier defined. To determine $t\ (\Theta)$, a general solution to the differential equation:

$$\frac{dt}{d\Theta} = \frac{h_c A}{c_p m} (t_x - t) \tag{41}$$

is required. With an initial condition of $t = t_i$ at $\Theta = 0$, a solution to Equation 41 is:

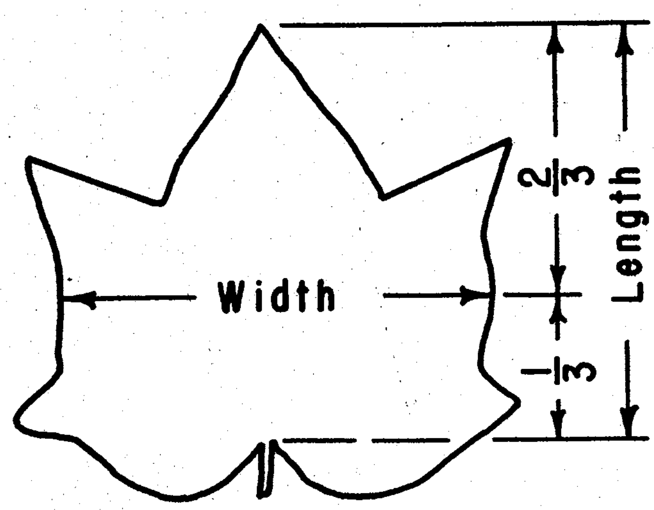


Figure 16. Diagram of Locations of Leaf Length and Width Measurements

$$\frac{t-t_x}{t_i-t_x} = \exp\left[\frac{(h_c A)\,\theta}{c_p m}\right] \qquad (42)$$

Equation 42 can be solved at any instant, θ, for the heat transfer coefficient, h_c, if the temperature, t, is known.

The availability of the IBM Continuous Systems Modeling Program (CSMP) offered a computer tool to solve Equation 41. The use of CSMP allowed the computer to select an h_c such that the simulation of the temperature-time response matched the actual temperature-time response. The specific heat, c_p, area, A, and mass, m, of a leaf were constants which were known or could be calculated.

The heat transfer coefficient, h_c, determined in this manner accounted only for the sensible heat transfer of the leaf. A viable plant leaf violated the assumption of no mass transfer and no internal temperature gradient. However, the simulated temperature response curves of leaves were important if they could be used to estimate leaf response.

CHAPTER IV

EXPERIMENTAL APPARATUS AND PROCEDURES

The method used to apply the treatments was patterned after that used by Kent and Porterfield (29). The treatments consisted of exposing cotton plants to various combinations of air temperatures and exposure times. The method used by Kent and Porterfield consisted of using a 4-bar linkage to manually raise a cotton plant into a hover, in which heated air was circulating. The plant was held in the hover for the required exposure time. Treatments were also applied to mature field plants using a field defoliator unit.

Description of Treatments

Laboratory Treatments

The treatments used in the laboratory were comprised of four separate series of treatments: 1) single exposure; 2) double or two exposures separated by a delay; 3) a combination of single and double exposures; and 4) treatments with several different air velocities.

The single exposure treatments were designated Series A for identification. Series A consisted of a factorial design of seven air temperatures from 200 (93) to 500°F (260°C) in fifty degree increments, five exposure times from one to five seconds with one-second increments and two air velocities of approximately 865 (4.4) and 965 ft/min (5.0 m/sec). The experiment was replicated twice requiring a total of 140 separate treatments.

The series of treatments with two exposure times separated by a delay were designated as Series B. Series B consisted of a factorial design of four air temperatures from 250 (121) to 400°F (204°C) in fifty-degree increments, three exposure times of three to five seconds with one second-increments, and two delay times of 2.5 and 4.0 seconds. The experiment was replicated twice, requiring a total of 48 separate treatments. The exposure times given were total time. Therefore, each single exposure was one half of the given time.

The combination of single and double exposure treatments were designated Series C for identification. Series C consisted of four air temperatures from 250 (121) to 400°F (204°C) with fifty-degree increments, and three exposure times of two to four seconds with one-second increments. The treatments were each run for a single and double exposure. The experiment was replicated twice, requiring a total of 48 separate treatments. The delay time between exposures for the double exposure treatments was two seconds, and each separate exposure was 1.0, 1.5, or 2.0 seconds, giving a total exposure of 2.0, 3.0, or 4.0 seconds, respectively. The total exposure times for the single and double exposure factors were therefore the same within each respective treatment.

The series of treatments with different air velocities were designated as Series D for identification. Series D consisted of two air temperatures of 300 (149) and 400°F (204°C), two exposure times of two and five seconds, two air velocities of approximately 1140 (5.8) and 855 ft/min (4.3 m/sec). This required a total of eight separate treatments. Four additional treatments were run at an air temperature of 350°F (177°C) and 3.5 seconds for air velocities of approximately 855 (4.3), 865 (4.4), 970 (5.1), and 1140 ft/min (5.8 m/sec). Series D was not replicated.

Field Treatments

The treatments applied in the field were designated as the Field Series. The Field Series consisted of three air temperatures of 300 (149), 400 (204), and 500°F (260°C), and three forward speeds of two, three, and four MPH. The experiment was replicated twice, giving a total of eighteen treatments. A series of treatments at 600°F (315°C) were originally planned but then eliminated after one treatment, as the air temperature was excessive for the thermocouple wire insulation.

Plants

The cotton plants used in the laboratory study were of the variety Stoneville 213 and were grown in a greenhouse. Quart-size milk cartons were used as containers and three to four plants were grown per container. The soil used was a clay-sand mixture, with sand being the predominate soil type. The plants were watered with a Hoagland (9) nutrient solution to maintain a proper nutrient balance. They were subjected to a heat treatment when approximately fourteen to eighteen inches in height.

The plants used in the field treatments were of the variety Lankart 3840 and were grown at the Oklahoma Cotton Research Station, Chickasha. The plants were exposed to a heat treatment when the bolls were approximately 50 percent open and ready for defoliation prior to harvest.

Equipment

The equipment required for this investigation was determined by the type of treatments. A method was needed to expose a cotton plant to a heat stress for a controlled time period while recording leaf temperature. Exposure time, air temperature, and air velocity were to be easily controlled and changed as necessary.

Laboratory

The laboratory equipment used for this study consisted of a variable speed fan, heating chamber, treatment chamber, and a duct to control the air flow from the fan, through the heating chamber, to the treatment chamber, and back to the fan inlet.

The heated air was recycled because the burners were not capable of producing the required air temperature in one cycle. Recycling also minimized increasing the ambient temperature in the laboratory.

The fan was a centrifugal fan with backward curved blades on a 10-25/32 inches diameter wheel. The fan was belt driven and power was supplied by a one-half horsepower motor with a variable-pitch sheave on the motor for fan speed control.

The heating chamber was constructed from asbestos board and was two feet long with a duct area of one square foot. Three Gotcher flame weeder LP gas burners, used to heat the air, were installed in the bottom of the chamber. A spark plug was inserted into the top of each burner, and a 12-volt ignition system was used to ignite the burners and insure their continued burning during operation. A plate with a six-inch orfice was installed inside the heating chamber just below the burners. Without the orfice plate in the heating chamber, the flame was blown out through the burners. The fan, heating chamber, two of the three burners, and the burner ignition system are shown in Figure 17.

The duct system consisted of twelve-inch diameter pipe, except for the vertical duct where the treatment chamber was located. The vertical duct was fabricated from 24-gauge sheet metal and was one foot square.

The pipe in the duct system was wrapped with 3-inch thick fiber glass insulation to protect the duct from excessive heat loss.

The treatment chamber, 24 inches high, twelve inches wide, and 24 inches long, was fabricated from 24-gauge sheet metal. The chamber was open-ended and enclosed the plant on four sides. A horizontal slot, extending the length of the chamber on one side, was necessary to allow a station for the plant and thermocouple wires. The actual treatment area was one foot in length and one foot wide.

The plant station included a bracket and platform assembly to hold the plant container. A microswitch was mounted to the bottom of the platform assembly and was wired to an event marker on a recorder to give a record of plant exposure time. The treatment chamber and plant station are shown in Figure 18.

The entire system was mounted on two tracks. Locomotion was provided to the system by a variable-speed drive unit, Figure 19, through a moving chain assembly. For a single plant exposure, the system was pulled along the tracks by the engagement of a pawl,

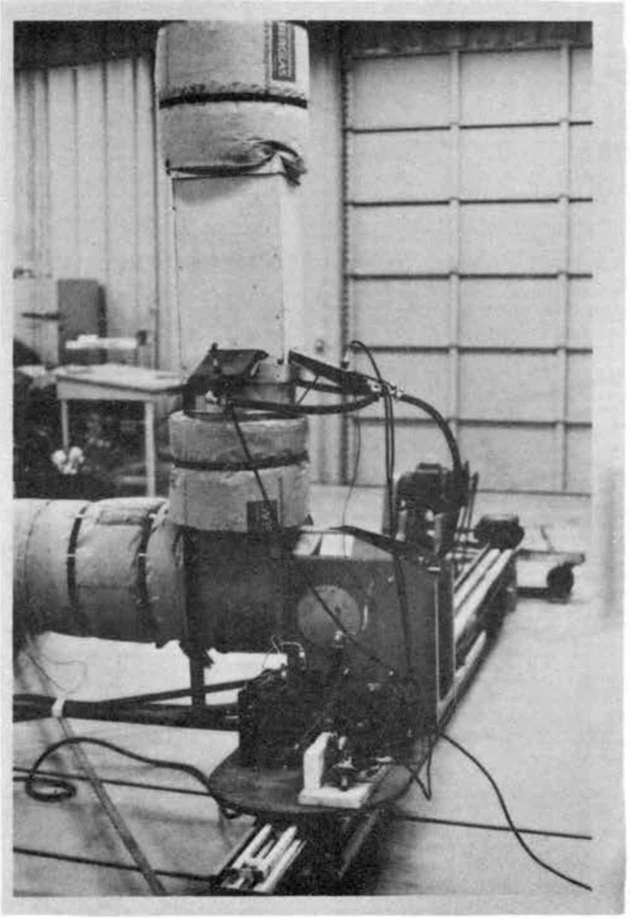


Figure 17. Fan, Heating Chamber, Burners, and Burner Ignition System

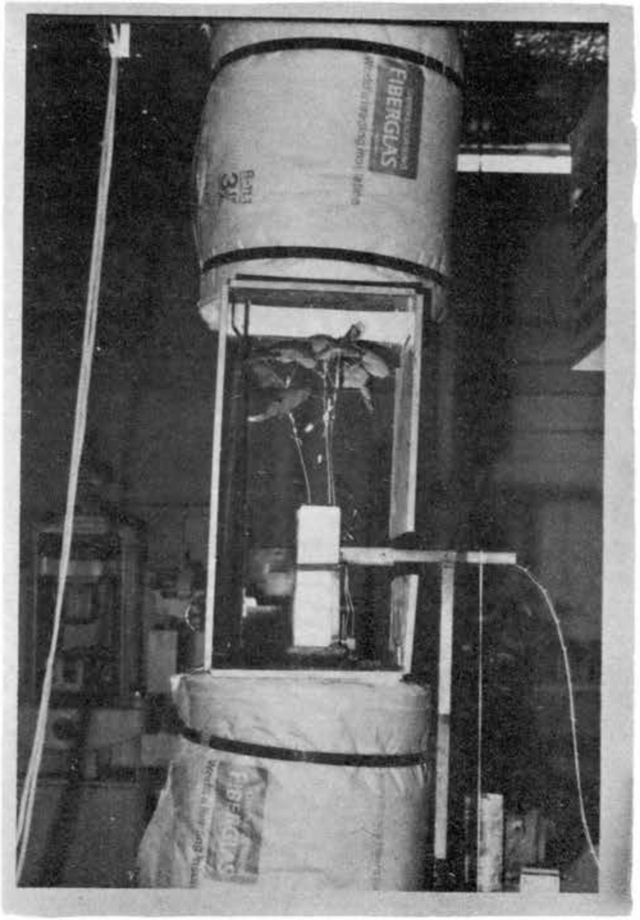


Figure 18. Treatment Chamber and Plant Station

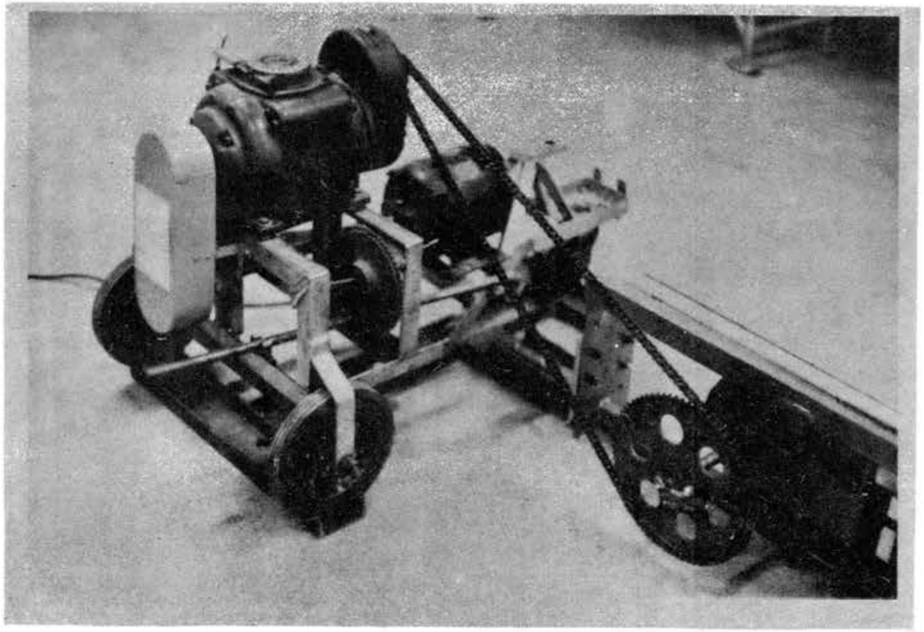


Figure 19. The Variable Speed Drive Unit and Linkage to the Track System

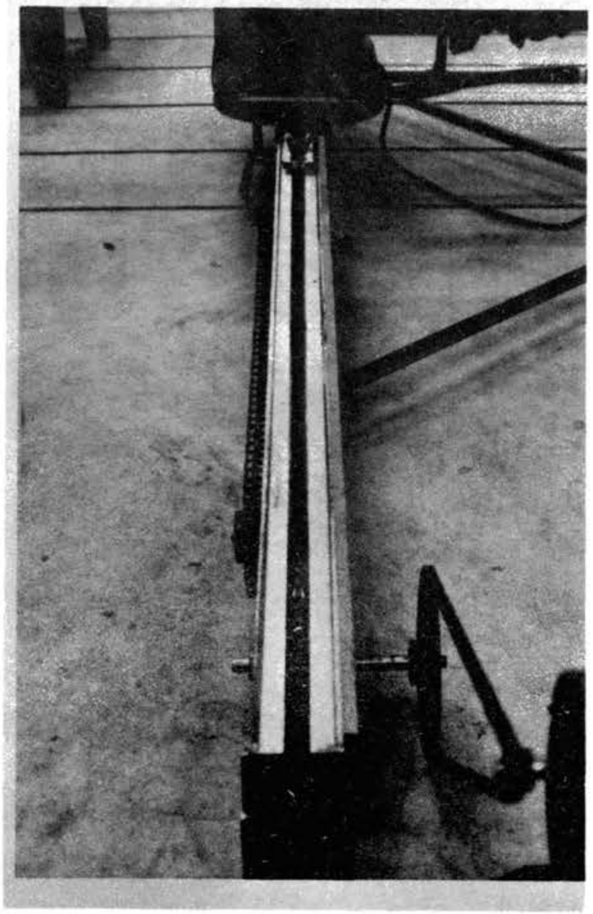


Figure 20. Track System Under the Blower Including the Chains Used for Locomotion of the System

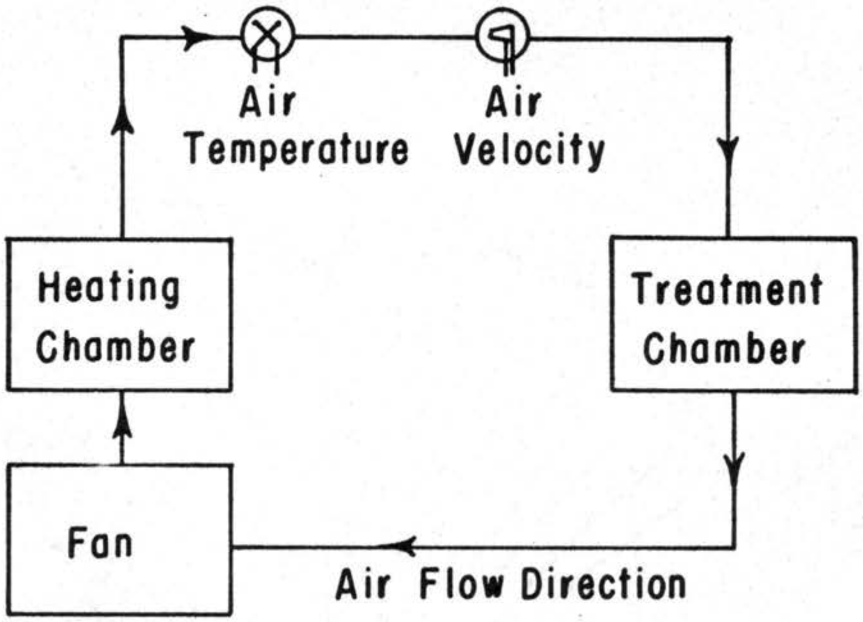
mounted on the fan base, onto a link in the chain assembly. The pawl was automatically disengaged by a throwout plate at the end of the track. The length of exposure was controlled by the speed of the chain assembly. For a double exposure treatment, the system was connected to a secondary chain drive by a pitman arm. The delay time was controlled by the length of the pitman arm.

The track system under the fan base is illustrated in Figure 20. The chain in the center of the track is used for locomotion for the single exposure treatments. The secondary chain on the left side of the track is used for locomotion for the double exposure treatments. The pitman arm is seen attached to the secondary chain system.

The laboratory system is illustrated in Figure 21 where the relative positions of the fan, heating chamber, treatment chamber, and duct system are seen. The air flow is clockwise, as viewed in Figure 21.

A shielded 16-gauge iron-constantan thermocouple was installed in the top horizontal duct, and the air temperature was monitored by a Leeds and Northrup Speedomax H recorder. The air temperature was controlled with a pressure regulator on the outlet of an LP gas tank.

The air velocity was measured with a pitot-static tube, installed in the top horizontal duct. The pitot-static tube was connected to a micro-manometer and the air velocity was determined as a function of inches of water.



Equipment Schematic

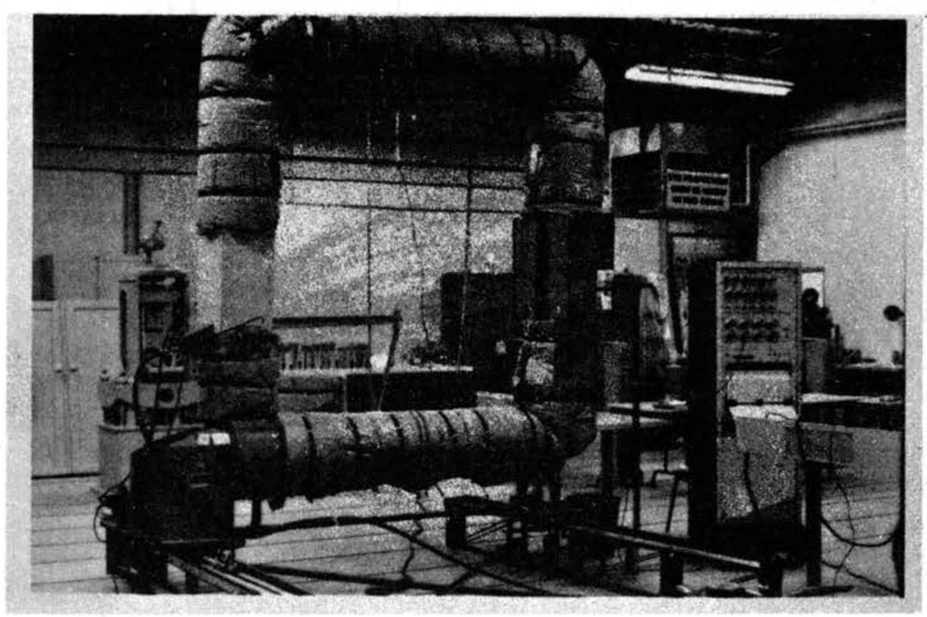


Figure 21. The Laboratory Equipment

Field

The field unit consisted primarily of a self-propelled hover where ground speed and air temperature were easily controlled. A schematic diagram of the field defoliator is illustrated in Figure 22. The width of the unit was 60 inches to allow the treatment of two rows of cotton simultaneously. A front view of the defoliator is illustrated in Figure 23. The entrance and exit to the defoliator were covered by spring-loaded doors. The doors guarded against excessive heat losses during the turn-around period but were easily opened by the plants.

Data Recording

Leaf temperatures for both the laboratory and field treatments were recorded with a Beckman eight-channel recorder. Six channels were used to record leaf temperatures, and one channel was used as an event marker for the microswitch on the plant station. The paper speed on the recorder was timed and operated at 0.1 or 0.2 cm/sec for all treatments.

The thermocouples used were 36-gauge copper-constantan. The thermocouple beads had an average mass of 0.0004 grams and an average diameter of 0.0441 cm. The output of the thermocouples was recorded as millivolts referenced to 0.0°C with an ice bath. During the analysis of data, millivolts were transformed to degrees Celsius by a regression equation formulated from an appropriate millivolt-temperature table. The regression equation was:

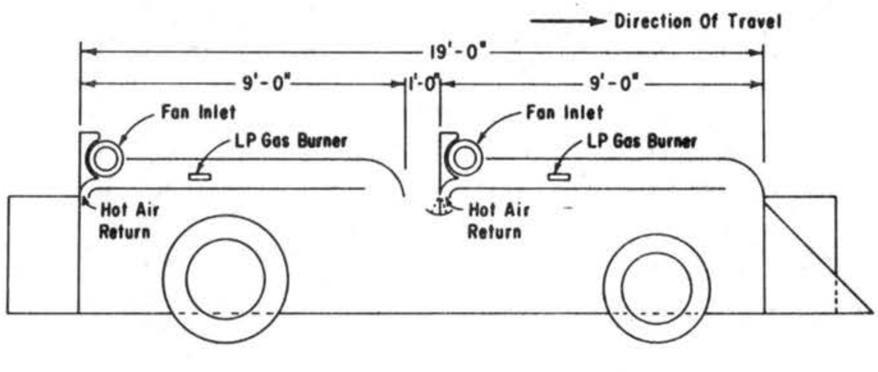


Figure 22. A Schematic of the Field Defoliator

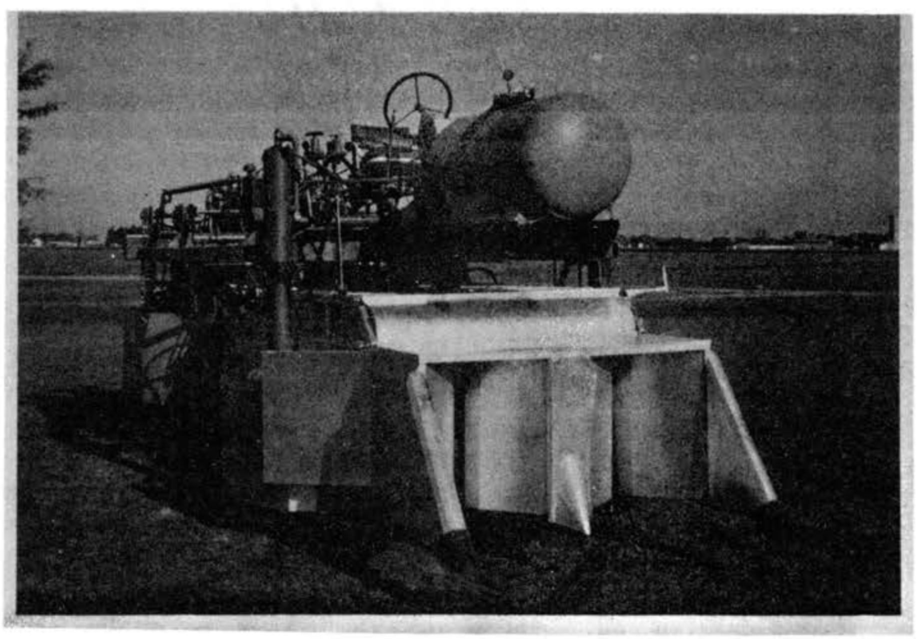


Figure 23. Field Defoliator as Seen from the Front

$$^{o}C = 1.493 + 24.443\ MV - 0.336\ MV^2 \quad (43)$$

$$R^2 = 0.999$$

where:

^{o}C = Temperature, ^{o}C

MV = Millivolts above an ice-bath reference.

A 110-volt AC generator powered by a gas engine was used to power the recorder during the field treatments.

The thermocouples used in the laboratory were approximately 10 feet in length. However, the field treatments required temperature measurements to a distance of 70 feet on either side of the recorder. Therefore, a 12-pair copper-constantan thermocouple extension cable 70 feet in length was used. Each thermocouple in the cable terminated with a two-conductor mini-jack, mounted in a small chassis box. The chassis box was positioned at the base of the plant, while the leaf temperatures were being monitored. The thermocouples were connected by two-conductor mini-plugs to the chassis box.

The cable was placed inside a one and a fourth-inch galvanized pipe for the last six feet leading to the chassis box. The pipe was laid flat on the ground and provided protection for the cable, as the field defoliator unit ran over the pipe during a treatment.

The event marker used in the field to determine exposure time was operated manually.

A tracing of a single and double exposure laboratory treatment is illustrated in Figures 24 and 25, respectively. The exposure times are indicated by the event marker responses. However, no significance can be placed on the position of the event marker response relative to the leaf temperature response. The microswitch

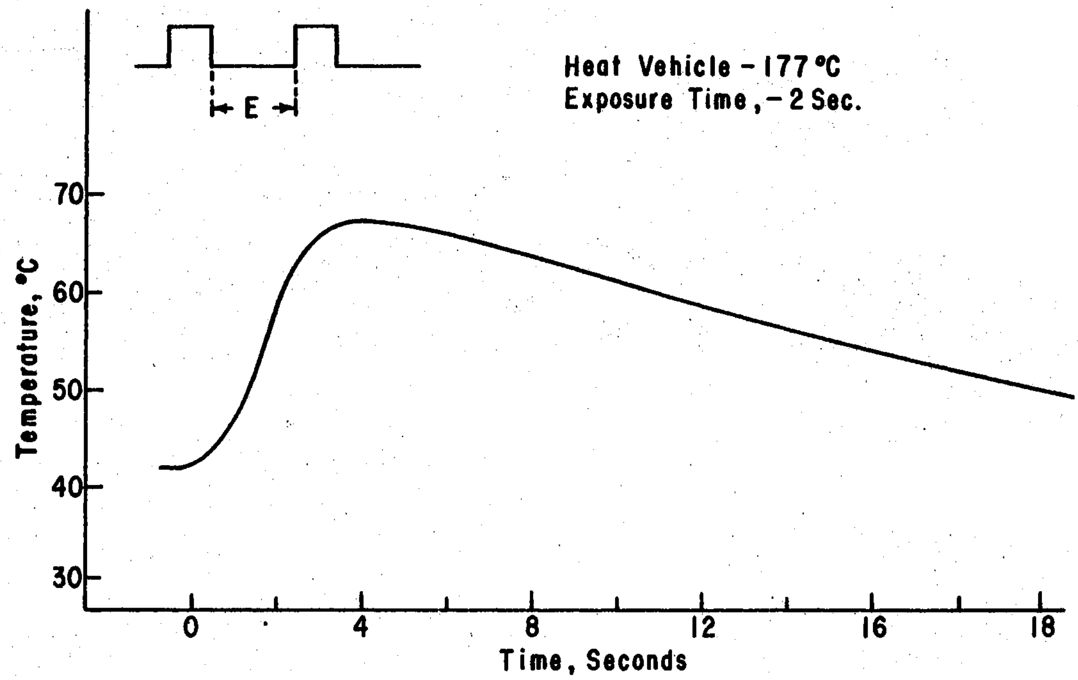


Figure 24. Temperature Response of a Leaf Subjected to a Single Exposure

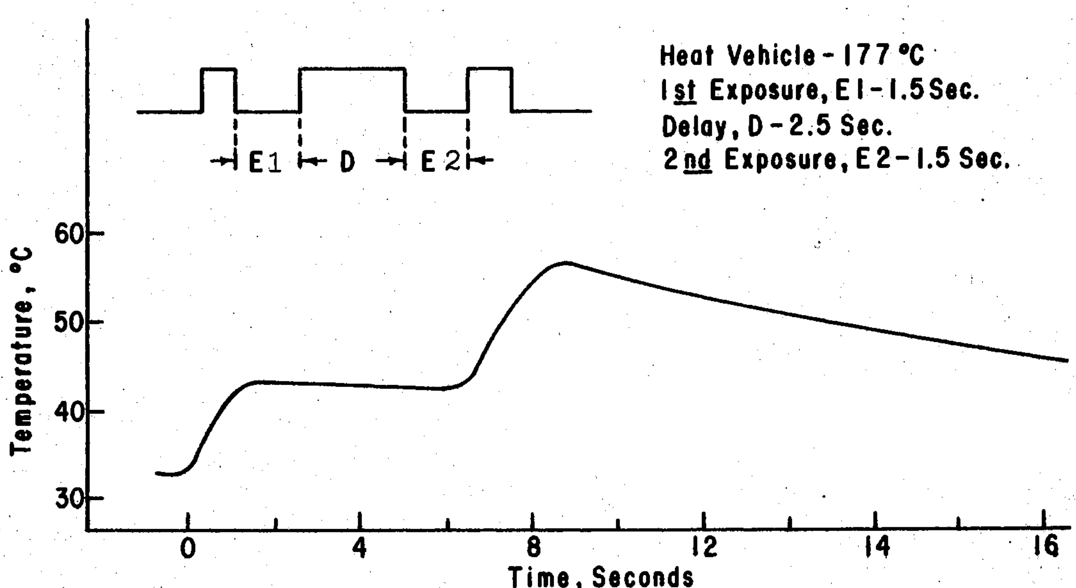


Figure 25. Temperature Response of a Leaf Subjected to a Double Exposure

for the event marker was positioned under the center of the plant container. Therefore, the leaves on the plant could lead or lag the microswitch through the treatment chamber. The event marker was significant for the time of exposure only.

Procedures for Measuring Leaf Area, Mass, and Volume

Leaf area and mass measurements were obtained during the completion of Series A and B, and leaf volume measurements were obtained from Series B only. Leaf area for the Field Series treatments was obtained a year prior to the treatments. The cotton variety was the same both years.

Plants were selected at random intervals during the treatment applications. All leaves on the plant that were measured were of similar size to the leaves instrumented.

Leaf length and width were measured to the nearest 1/64th of an inch according to Figure 16. The leaf was planimetered to determine leaf area. The mass of the leaf was determined with a Mettler balance. The volume of the leaf was determined by submerging the leaf in a graduated cylinder and observing the water displaced by the leaf. The volume was recorded to the nearest 0.10 cubic centimeter. Mathematical expressions for leaf area, mass, and volume were obtained as described earlier, by a regression analysis.

General Procedure for a Treatment

The containers of the plants grown in the greenhouse for the laboratory experiments were assigned a number. The containers of plants treated on any given day were then selected by a random number process.

All treatments in each series were also assigned a number. The sequence of treatments was selected by a random number process.

The plants in each container were thinned until the two best remained. Of these two, one was selected for instrumentation. Three or four leaves were then tagged to be instrumented. A hypodermic needle was used to make a guide hole in a primary or secondary leaf vein. A secondary vein was chosen on the larger leaves to minimize the effect of leaf mass. The thermocouple was then inserted and laid along the leaf surface and taped in place, as shown in Figure 26. After all thermocouples were in place, the fan was turned on and the burners ignited. After the air was heated to the required temperature, one or two leaves from the second plant were abscissed, weighed, and then reattached in their original position. The recorder was then activated to record the initial leaf temperatures, and the system was brought past the plant for the required exposure time. The abscissed leaves were then immediately reweighed and the leaves planimetered for area. The moisture loss per unit area was then obtained.

The instrumented leaves were marked and their length and width measured, as indicated in Figure 16. The number of leaves on each of the two plants were counted and recorded.

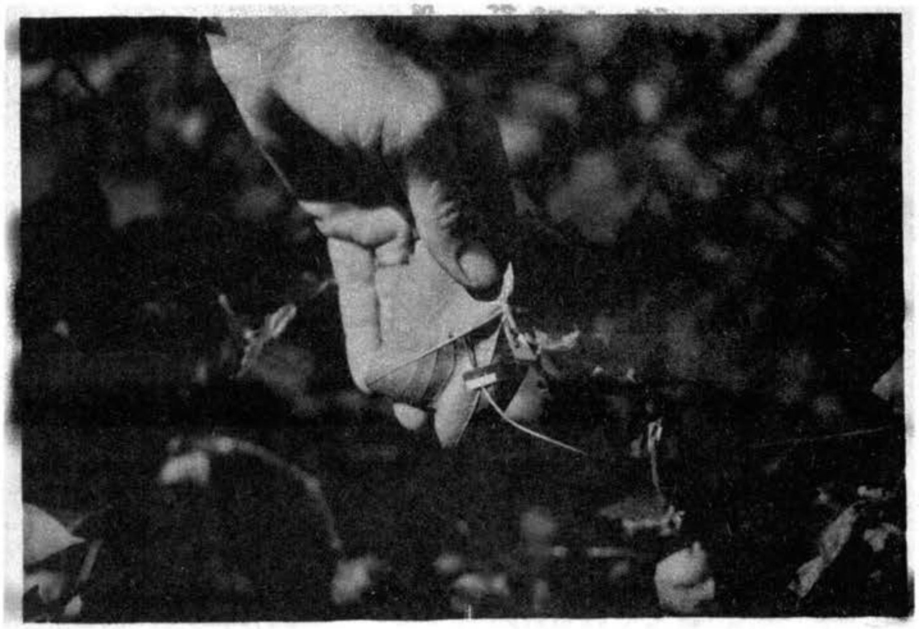


Figure 26. A Leaf with a Thermocouple in Place

The plants used in the field treatments were preselected and the leaves counted. The leaves to be instrumented were tagged and the length and width measurements recorded. No data was collected regarding moisture loss during the field treatments. Also, treatments were randomized relative to sequence.

Evaluation of Responses

The plant responses were evaluated seven days after treatment. The recordings made after the lapsed time were: 1) number of leaves on each plant; 2) number of dead leaves on each plant; 3) general condition of any live leaves; 4) whether the plant was dead or alive;

and 5) general condition of the petioles. The instrumented leaves and the plant were then classified according to one of four responses described earlier.

Method of Regression

The regression analysis used was a step-wise regression program. The program selected the independent variable according to its contribution to percent reduction in the sums of squares of variation about the mean. The order of entrance into the regression by the independent variables indicated their order of significance to the overall reduction in sums of squares.

CHAPTER V

RESULTS AND DISCUSSION

The laboratory plants were approximately four months old when treated and their leaves were, therefore, smaller than those from mature field plants. A comparison was made of the leaf areas between mature field plants and those plants used in the laboratory. Leaves from 25 mature field plants were planimetered to determine leaf area. The leaves were then categorized into increments of area of 20 square cm in a distribution histogram as illustrated in Figure 27. The distribution of all leaves instrumented in the laboratory study was categorized into 10 square cm increments as illustrated in Figure 28. The area distribution of leaves instrumented in Series A, B, C, D, and the Field Series are illustrated in Figures 29, 30, 31, 32, and 33, respectively.

All leaf areas were total leaf areas which were, therefore, the sum of the area of both sides of the leaf.

Regression equations formulated for the area, volume, and mass of the cotton leafs are shown in Table I. The regression equations for Series A were formulated from 341 observations, for Series B from 75 observations, and for the Field Series from 1373 observations. The equations used to determine leaf area and mass for Series C were those equations formulated for Series B. The equation for leaf mass of Series A was used to estimate leaf mass of the Field Series.

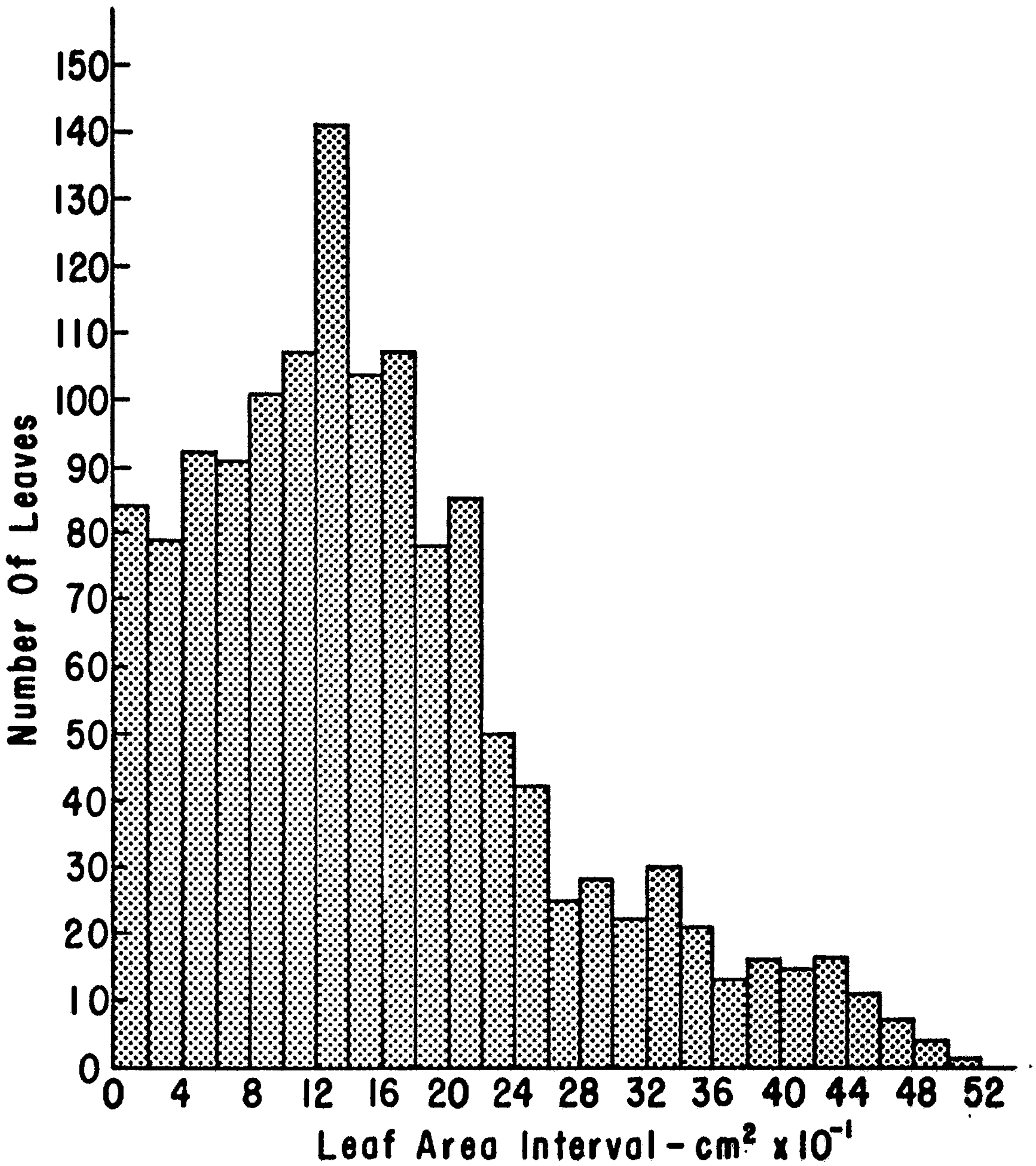


Figure 27. Area Distribution of Twenty-Five Field Plants

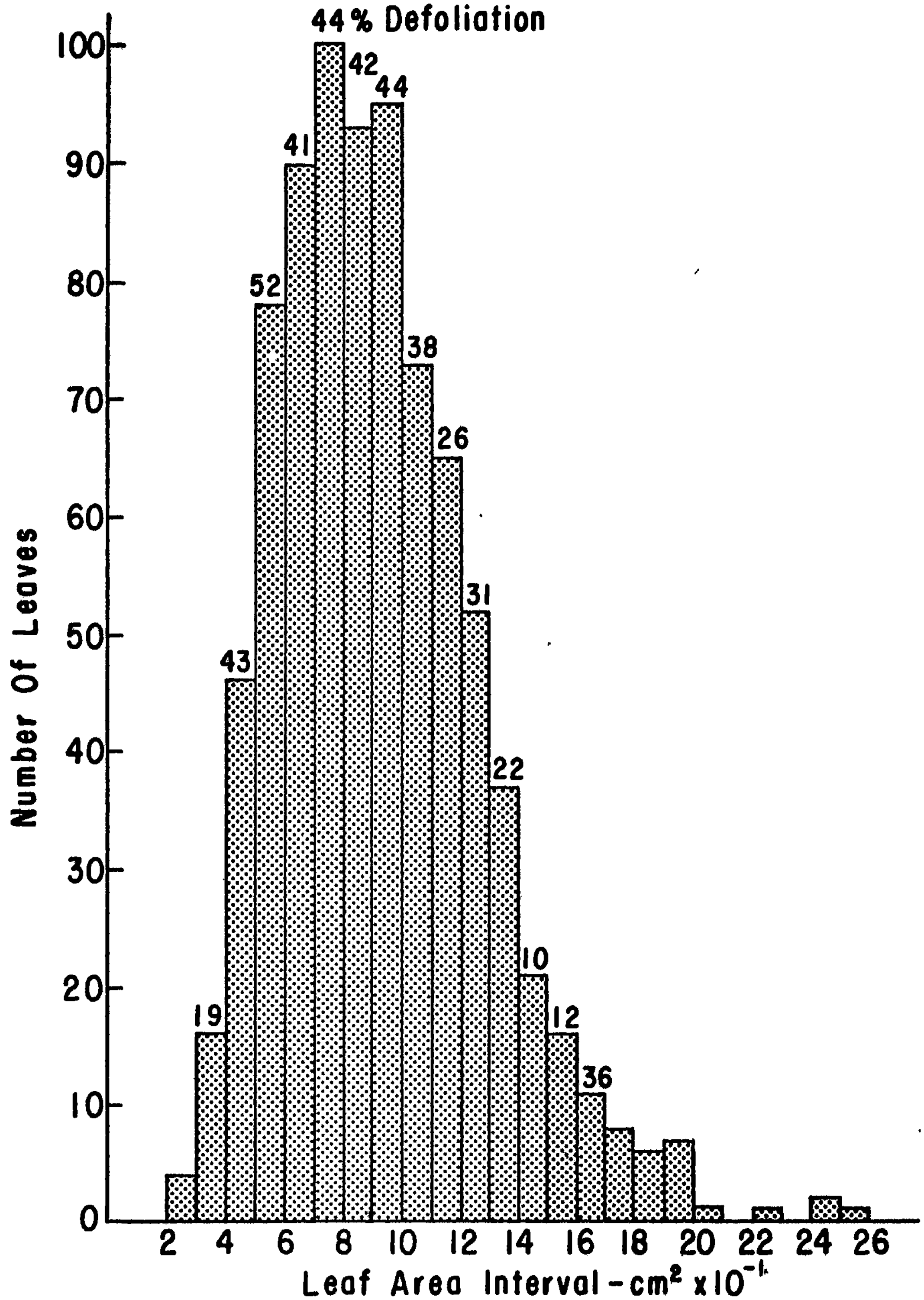


Figure 28. Area Distribution of All Leaves Instrumented in the Laboratory Study

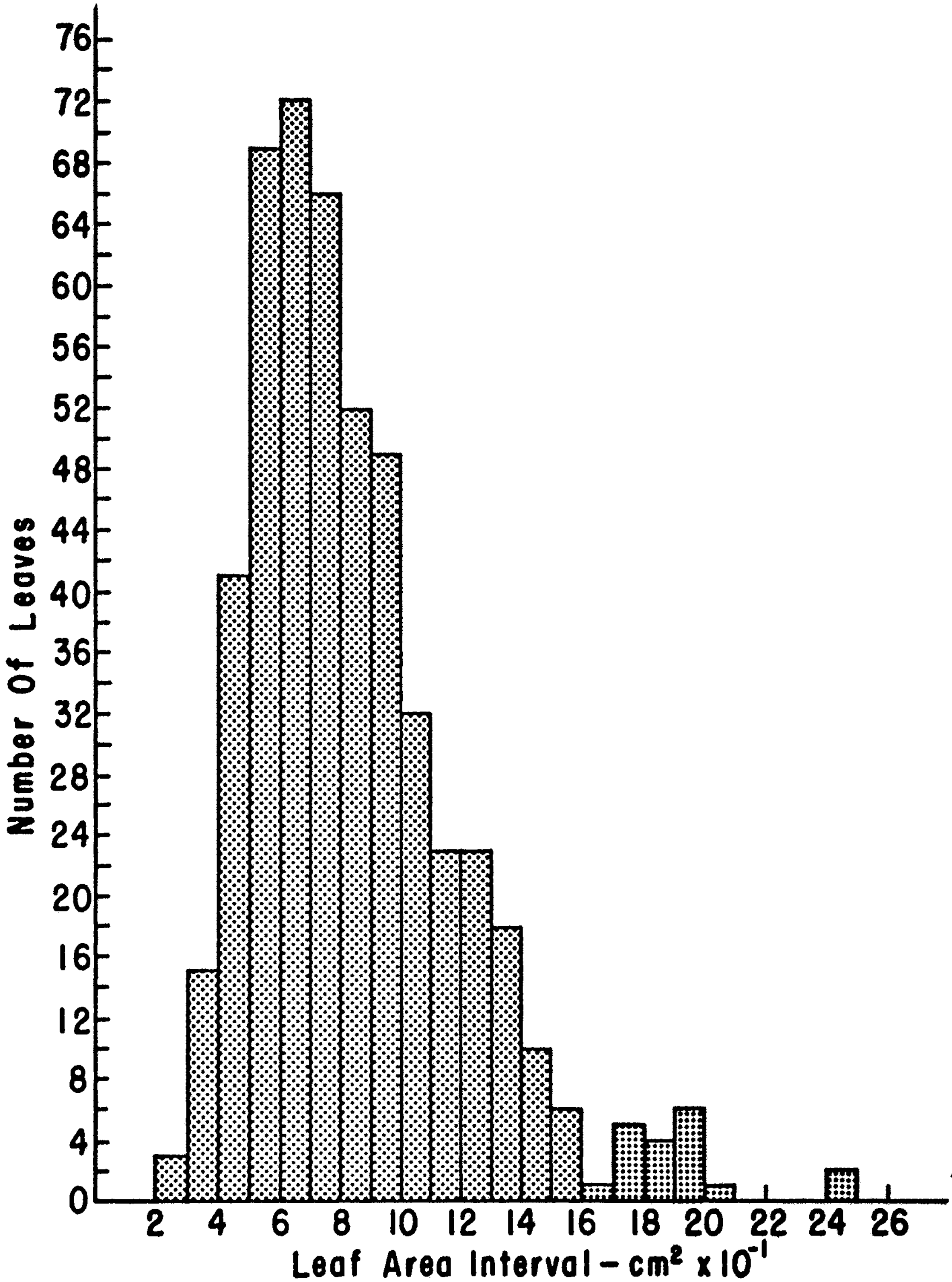


Figure 29. Area Distribution of Instrumented Leaves in Series A

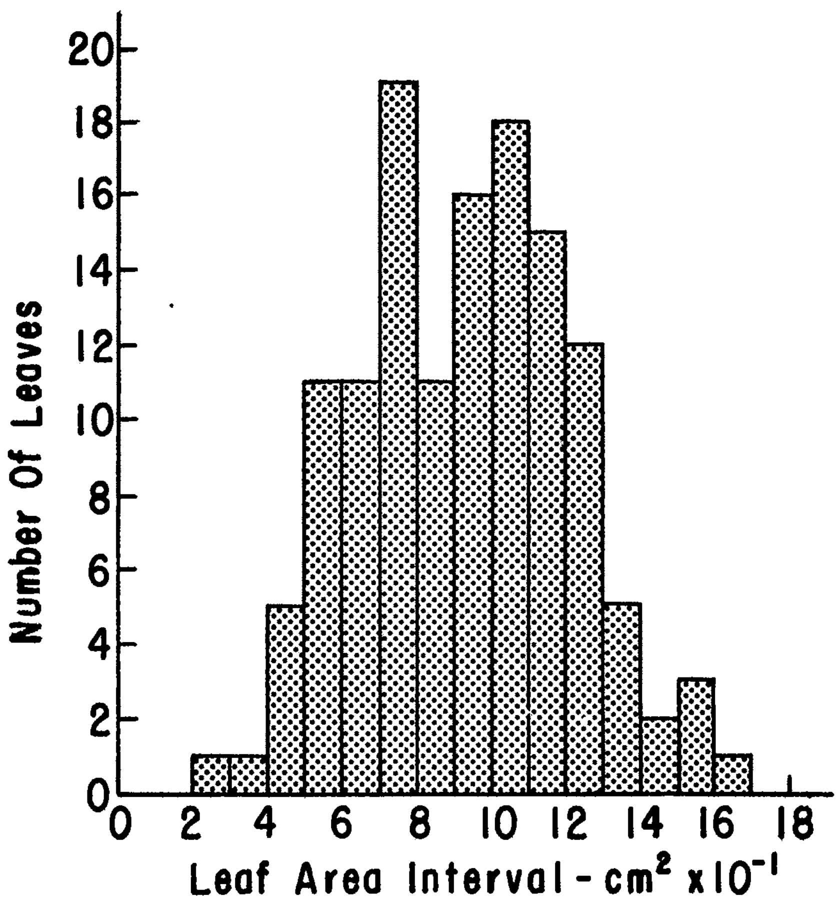


Figure 30. Area Distribution of Instrumented Leaves in Series B

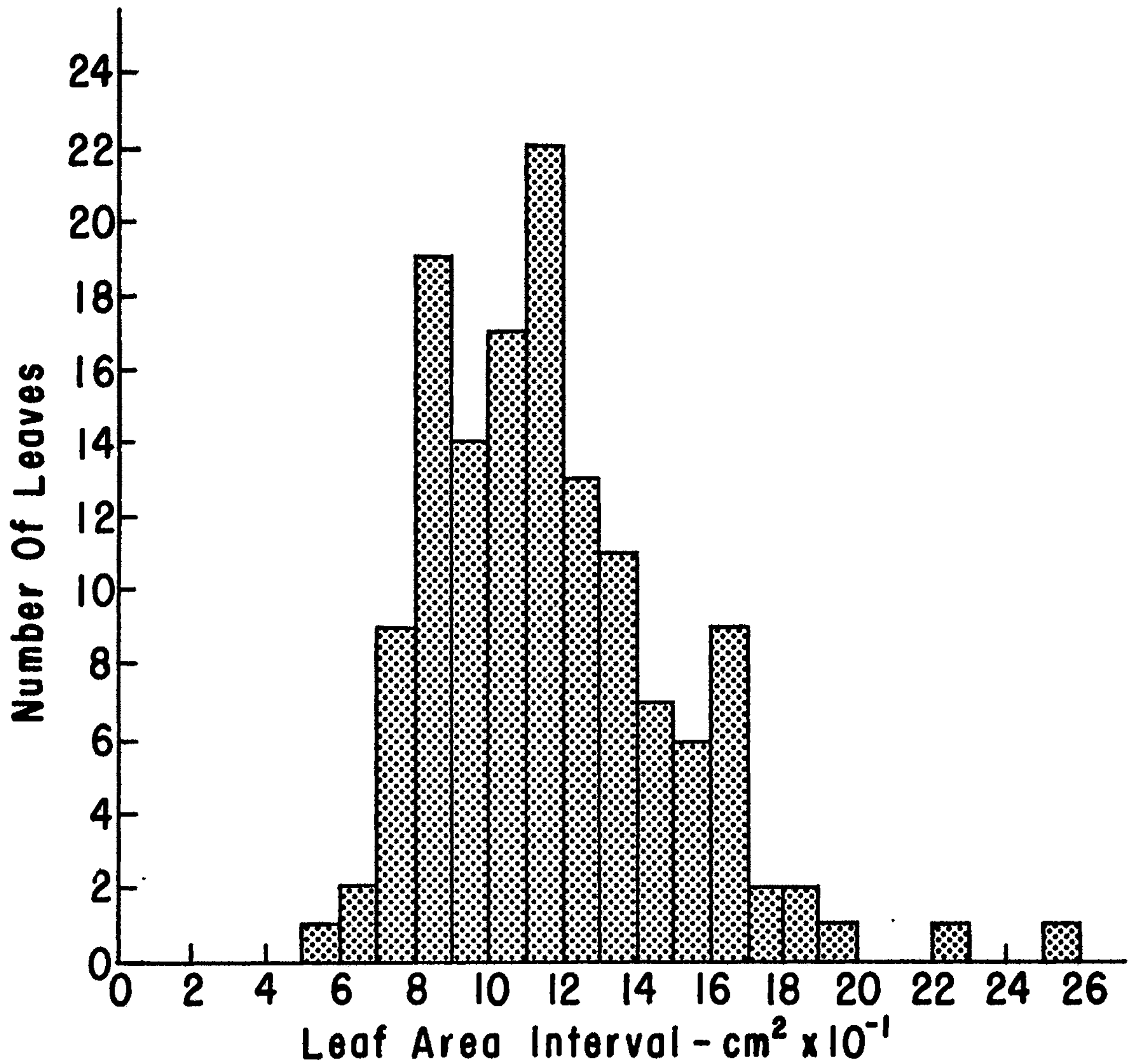


Figure 31. Area Distribution of Instrumented Leaves in Series C

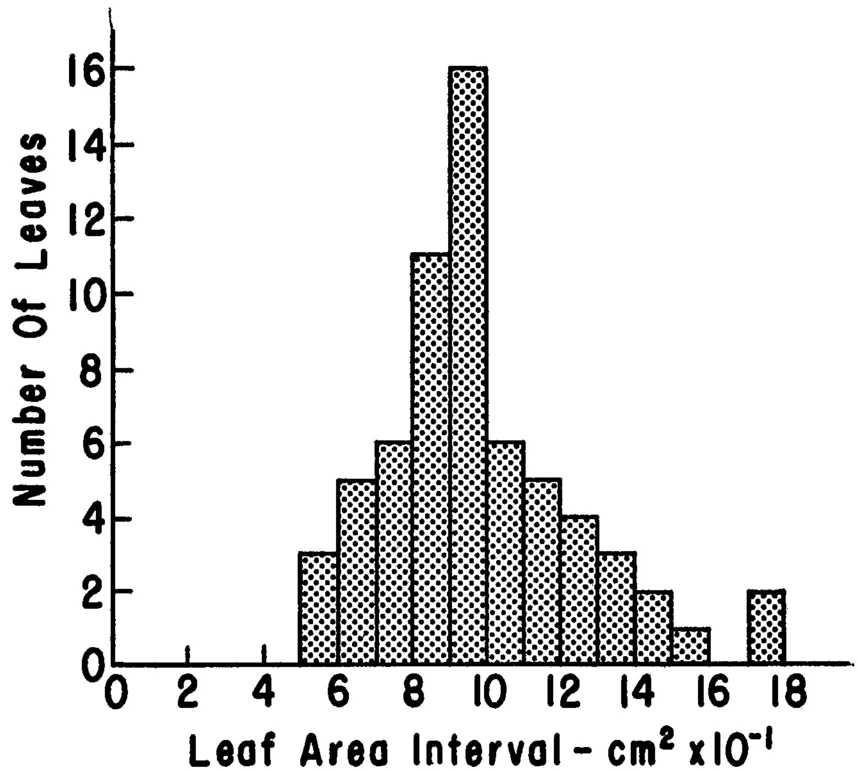


Figure 32. Area Distribution of Instrumented Leaves in Series D

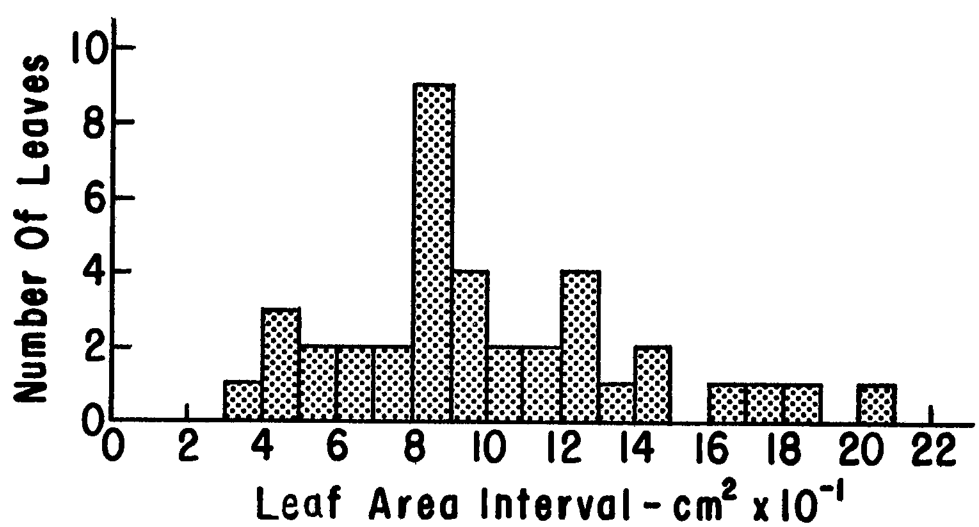


Figure 33. Area Distribution of Instrumented Leaves in the Field Series

TABLE I

REGRESSION EQUATIONS FOR AREA, MASS, AND VOLUME OF LEAVES

Series	Regression Equation*	Units of Dependent Variable	Correlation Coefficient	Standard Error of the Estimate
A	$Area = 2.29 + 0.82\ L\ W + 0.56\ W^2$	$cm.^2$	0.97	6.57 $cm.^2$
	$Mass = 207.37 + 74.00\ W + 3.55\ W\ L + 1.50\ W^2$	grams x 1000	0.90	0.08 grams
B	$Area = 0.80 - 1.81\ L\ W + 1.67\ W^2 + 1.54\ L^2$	$cm.^2$	0.99	3.96 $cm.^2$
	$Mass = 17.04 + 16.54\ W^2 + 13.65\ L^2 - 19.05\ L\ W$	grams x 1000	0.98	0.05 grams
	$Volume = 0.43 + 0.01\ L\ W + 0.11\ W$	$cm.^3$	0.96	0.09 $cm.^3$
Field	$Area = 6.33 - 3.02\ L\ W + 5.36\ W^2 + 8.92\ L^2 - 17.53\ L + 9.84\ W$	$cm.^2$	0.99	16.57 $cm.^2$

*Length (L) and width (W) of leaf are in centimeters

The analysis of variance (AOV) tables for Series A, B, and C are included in Tables II, III, and IV, respectively. The criterion of evaluation for all AOV analysis was percent defoliation.

The mathematical formulas presented for sensible heat transfer were expressed as sensible heat gain divided by specific heat. To determine the sensible heat transfer, the expressions were multiplied by the specific heat of the leaf material and the total leaf area. The regression equations for sensible heat gain per specific heat per unit area of Series A, B, C, D, and the Field Series are included in Table V. In addition the multiple correlation coefficient and the standard error of the estimate are included.

The equations were formulated by multiplying the difference between initial and maximum leaf temperature by the leaf mass and dividing by the total area. The proposed statistical model to represent sensible heat gain was:

$$\frac{(T_m - T_i)\ m}{A} = f\ (\text{air temperature, exposure time}) \qquad (44)$$

where:

T_m, T_i = Maximum and initial leaf temperature, respectively, $^{\circ}C$.

m = Leaf mass, grams.

A = Leaf area, cm^2.

The moisture loss per unit area of a leaf was determined as described earlier. The moisture loss per unit area was then regressed on exposure time and air temperature. Depending on the series, except for the Field Series, moisture loss was calculated for one or two leaves per treatment. In some cases the abscissed leaves used for moisture measurement were lost during treatment due to the air

TABLE II

ANALYSIS OF VARIANCE FOR SERIES A

Source of Variation	df	SS	Mean Square	F
Replication	1	414.2893	414.29	0.54
E-Exposure time	4	10565.690	2641.42	3.44*
T-Temperature	6	23460.730	3910.12	5.09**
F-Fan speed	1	3815.96	3815.96	4.97*
ET	24	38550.144	1606.25	2.09*
EF	4	3653.83	913.46	1.19
TF	6	2684.63	447.44	0.58
ETF	24	18481.74	770.07	1.00
Error	70	53800.091	768.57	
Total	139	155427.10		

*0.05 level of significance

**0.01 level of significance

TABLE III

ANALYSIS OF VARIANCE FOR SERIES B

Source of Variation	df	SS	Mean Square	F
Replication	1	223.77	223.77	0.26
T-Temperature	3	2389.03	796.34	0.94
E-Exposure Time	2	3259.89	1629.94	1.92
D-Delay	1	67.14	67.14	0.08
TE	6	3756.99	626.16	0.74
TD	3	237.65	79.21	0.09
ED	2	888.89	444.44	0.52
TED	6	5897.42	982.90	1.16
Error	23	19562.78	850.55	
Total	47	36283.56		

TABLE IV

ANALYSIS OF VARIANCE FOR SERIES C

Source of Variation	df	SS	MS	F
Replication	1	158.691	158.691	0.56
T-Temperature	3	11244.910	3748.304	13.35**
E-Exposure time	2	9529.156	4764.578	16.97**
SD-Single or Double	1	101.130	101.130	0.36
TE	6	1056.370	176.062	0.63
TSD	3	205.259	68.420	0.24
ESD	2	690.805	345.402	1.23
TESD	6	5853.726	975.621	3.48*
Error	23	6456.843	280.732	
Total	47	35296.890		

*0.05 level of significance

**0.01 level of significance

TABLE V

REGRESSION EQUATIONS OF SENSIBLE HEAT TRANSFER

Series[1]	Regression Equation*	Multiple Correlation Coefficient	Standard Error of the Est.**
A	$\overline{SH} = -0.083 + 8.16E{-}04\ T\ \overline{ET} - 4.66E{-}05\ T\ \overline{ET}^2 - 1.20E{-}06\ T^2\ \overline{ET} + 6.21E{-}04\ T$	0.83	0.07
B	$\overline{SH} = 2.60 - 3.08E{-}05\ T^2\ \overline{ET} + 1.09E{-}02\ T\ \overline{ET} + 1.14E{-}04\ T^2 - 1.49E{-}04\ T\ \overline{ET}^2 - 3.64E{-}02\ T - 0.70\ \overline{ET}$	0.83	0.05
C	$\overline{SH} = -1.39 - 3.93E{-}03\ T\ \overline{ET} - 8.36E{-}05\ T\ \overline{ET}^2 + 1.26E{-}05\ T^2\ \overline{ET} - 4.31E{-}05\ T^2 + 0.44\ \overline{ET} + 1.55E{-}02T$	0.72	0.07
D	$\overline{SH} = 0.01 - 1.96E{-}06\ T^2\ \overline{ET} + 9.27E{-}06\ T^2 + 9.22E{-}05\ T\ \overline{ET}^2$	0.78	0.07
Field	$\overline{SH} = -0.18 - 2.22E{-}07\ T^2\ \overline{ET} + 1.52E{-}03\ T + 0.03\ \overline{ET}$	0.65	0.08

* $\overline{SH}$ = sensible heat/specific heat, $^{\circ}$C-grams/cm^2
T = air temperature, $^{\circ}$C
$\overline{ET}$ = exposure time, sec

** Units of standard error of the estimate, $^{\circ}$C-grams/cm^2

1 Ranges of the independent variables; temperature and time

Series A: $93 \leq T \leq 260^{\circ}C$; $1.0 \leq \overline{ET} \leq 5.0$ sec
Series B: $121 \leq T \leq 204^{\circ}C$; $3.0 \leq \overline{ET} \leq 5.0$ sec
Series C: $121 \leq T \leq 204^{\circ}C$; $2.0 \leq \overline{ET} \leq 4.0$ sec
Series D: $149 \leq T \leq 204^{\circ}C$; $2.0 \leq \overline{ET} \leq 5.0$ sec
Field: $149 \leq T \leq 260^{\circ}C$; $3.7 \leq \overline{ET} \leq 7.6$ sec

Exponential format is used, e.g.; E-04 = 10^{-4}

circulation over the plants. The regression equations for moisture loss per unit area are included in Table VI.

The latent heat transfer of a leaf was calculated by multiplying the moisture loss of a leaf by the enthalpy of evaporation. The expression used for the enthalpy of evaporation was formulated by regressing enthalpy on temperature, the observations being taken from the steam tables. The temperature used to calculate the enthalpy of evaporation was the average of the maximum and initial leaf temperature. The regression equation for the evaporation enthalpy was:

$$L = 592.76 - 0.43\ T_a - 0.0011\ T_a^2 \qquad (45)$$

$R^2 = 0.99$

$S = 0.51$ cal/g.

where:

L = Enthalpy of evaporation, cal/g.

T_a = Average leaf temperature, ^oC.

R^2 = Coefficient of determination

S = Standard error of the estimate

The regression equations for latent heat were formulated by regressing latent heat on exposure time and air temperature and are included in Table VII.

Total heat gain of a leaf is calculated as sensible plus latent heat. Sensible heat gain was calculated for each instrumented leaf directly by the use of Equation 37. Depending on the series the appropriate equations for mass were used. The latent heat was determined by calculating the moisture loss from the appropriate equation in Table VI and multiplying by the enthalpy of evaporation, determined from Equation 45. The sum of latent and sensible heat was regressed

TABLE VI

REGRESSION EQUATIONS OF MOISTURE LOSS

Series*[1]	Regression Equation*	Multiple Correlation Coefficient	Standard Error of the Estimate
A	$ML = 0.5E\text{-}05 + 0.68E\text{-}08\ T^2\ \overline{ET}$	0.91	0.000
B	$ML = -5.85E\text{-}05 + 4.93E\text{-}01\ T^2\ \overline{ET}$	0.80	1.61E-04
C	$ML = -3.15E\text{-}05 + 6.30E\text{-}01\ T^2\ \overline{ET}$	0.75	2.07E-04
D	$ML = -1.65E\text{-}04 + 1.18\ T^2\ \overline{ET} - 8.09E\text{-}05\ \overline{ET}$	0.91	2.68E-04

*ML = Moisture Loss, $grams/cm^2$
T = Air temperature, ^oC
$\overline{ET}$ = Exposure time, sec

**Units of standard error of the estimate, $grams/cm.^2$

[1]See Table V for the limits of the independent variables

TABLE VII

REGRESSION EQUATIONS OF LATENT HEAT TRANSFER

Series[1]	Regression Equation*	Multiple Correlation Coefficient	Standard Error of the Estimate**
A	$\overline{LH} = 0.38E{-}05\ T^2\ \overline{ET} + 0.05E{-}03\ T + 0.001\ \overline{ET}$	0.99	0.002
B	$\overline{LH} = -\ 0.03 + 2.79E{-}06\ T^2\ \overline{ET}$	0.99	0.001
C	$\overline{LH} = -\ 0.01 + 3.55E{-}06\ T^2\ \overline{ET}$	0.99	0.001
D	$\overline{LH} = 0.09 + 6.60E{-}06\ T^2\ \overline{ET} - 0.05\ \overline{ET}$	0.99	0.003

* $\overline{LH}$ = latent heat, cal/cm^2
T = air temperature, ^oC
$\overline{ET}$ = exposure time, sec

**Units of standard error of the estimate, cal/cm^2

[1] See Table V for the limits on the independent variables

on exposure time and air temperature. The regression equations for total heat gain are included in Table VIII. Response surfaces for the equations in Table VIII are illustrated in Figures 34, 35, 36, and 37. The regimes of responses of the instrumented leaves are included on the response surfaces.

The response surface of sensible heat gain for the Field Series is illustrated in Figure 38. Sensible heat gain was determined by multiplying the Field Series regression equation in Table V by the specific heat. Total heat transfer was not calculated because moisture loss during the field treatments was not measured.

A graph of sensible versus latent heat for Series A was plotted in Figure 39. The values of sensible and latent heat were determined from their respective regression equations in Tables V and VII. The parameter in Figure 39 is air temperature. This graph illustrates the relative contribution of sensible and latent heat transfer to the total heat transfer of a leaf.

Regression equations for percent defoliation and percent desiccation are included in Table IX. For a given treatment, the sensible and latent heat were calculated from the equations of Tables V and VII, respectively. Equations were formulated by regressing percent defoliation and percent desiccation on sensible and latent heat transfer. The response surfaces of the equations in Table IX are illustrated in Figures 40, 41, 42, and 43. However, the independent variables in the figures are air temperature and exposure time, not sensible and latent heat transfer. This allowed for easier interpretation of the response surfaces.

TABLE VIII

REGRESSION EQUATIONS OF TOTAL HEAT TRANSFER

Series[1]	Regression Equation[*]	Multiple Correlation Coefficient	Standard Error of the Estimate[**]
A	$\overline{THG} = -\ 0.07 + 2.68E{-}06\ T^2\ \overline{ET} + 7.34E{-}04\ T\ \overline{ET} + 5.68E{-}04\ T - 4.23E{-}05\ T\ \overline{ET}^2$	0.98	0.06
B	$\overline{THG} = -\ 10.10 - 2.98E{-}08\ T^2\ \overline{ET} + 7.10E{-}04\ T\ \overline{ET} + 7.23E{-}06\ T^2$	0.97	0.04
C	$\overline{THG} = -\ 0.12 - 5.01E{-}07\ T^2\ \overline{ET} + 1.04E{-}03\ T\ \overline{ET} + 5.96E{-}06\ T^2$	0.95	0.06
D	$\overline{THG} = -\ 0.14 + 6.45E{-}06\ T^2\ \overline{ET} + 6.06E{-}06\ T^2$	0.98	0.06

[*] $\overline{THG}$ = total heat gain, cal/cm^2
T = air temperature, ^oC
$\overline{ET}$ = exposure time, sec

[**] Units of standard error of the estimate, cal/cm^2

[1] See Table V for the limits of the independent variables

Equation for response surface in Table VIII

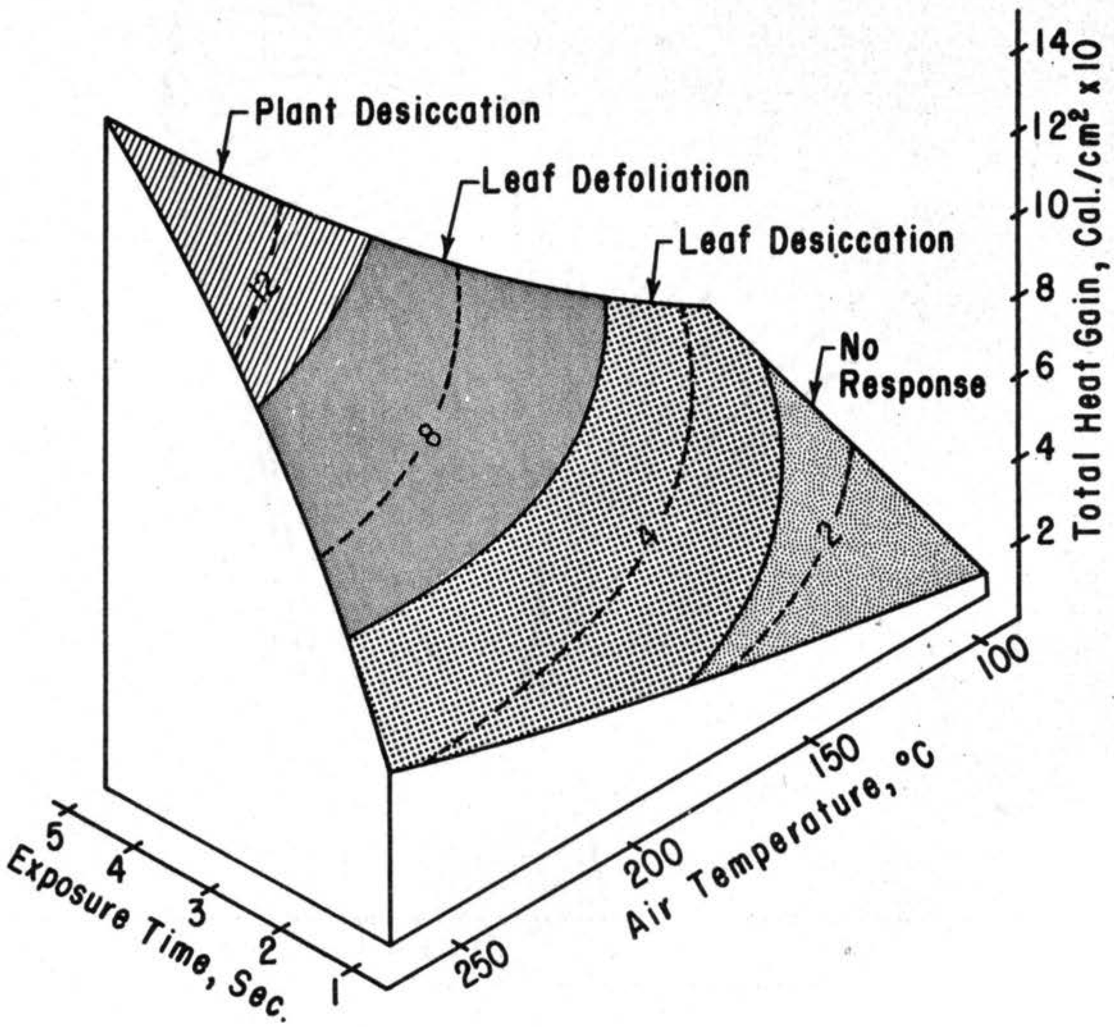


Figure 34. Total Heat Transfer Response Surface for Series A

Equations for response surfaces in Table VIII

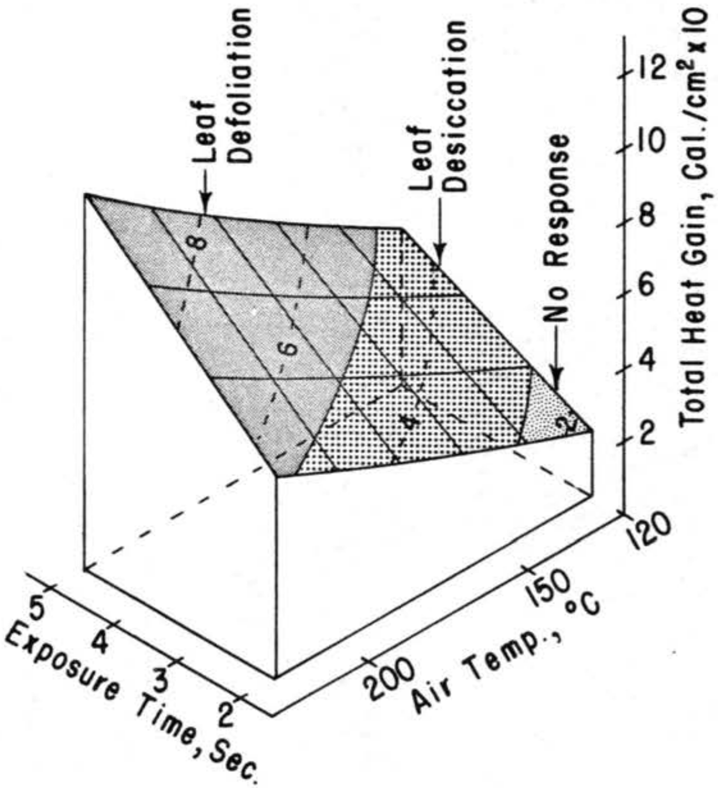


Figure 35. Total Heat Transfer Response Surface for Series B

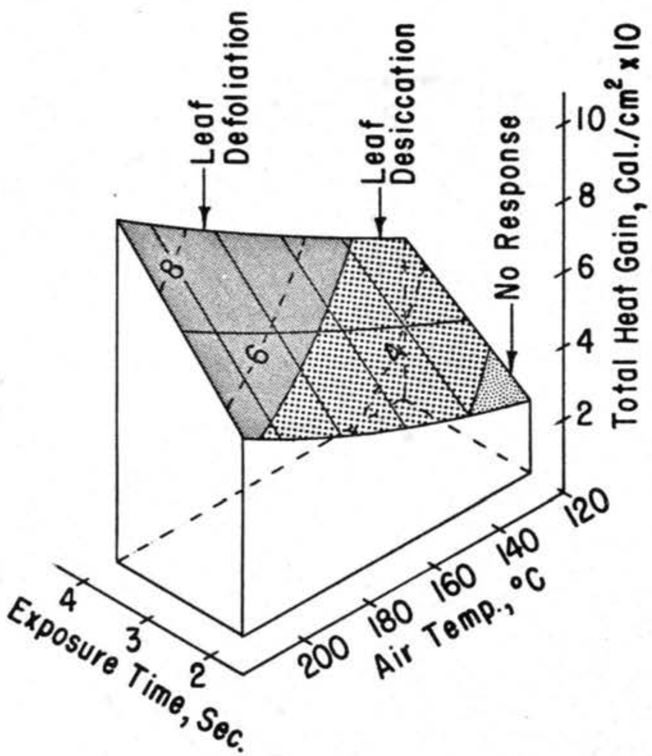


Figure 36. Total Heat Transfer Response Surface for Series C

Equation for response surface in Table VIII

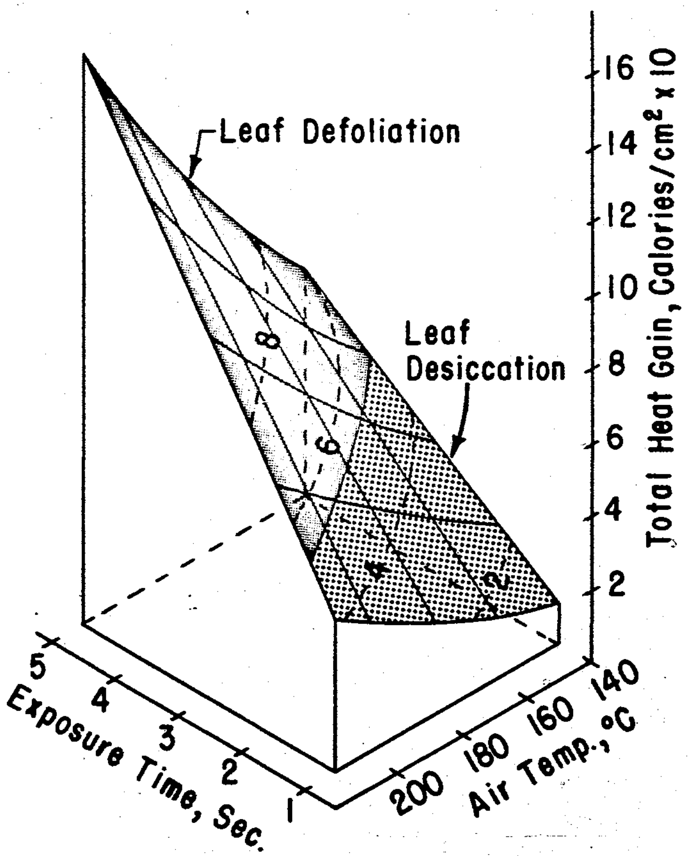


Figure 37. Total Heat Transfer Response Surface for Series D

Equation for response surface in Table V

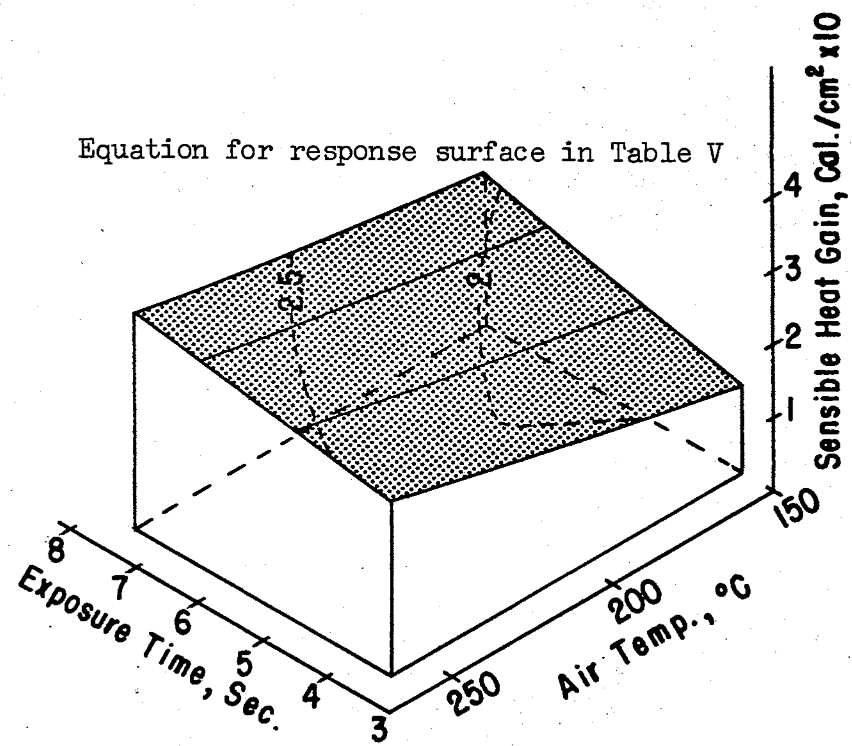


Figure 38. Sensible Heat Transfer Response Surface for the Field Series

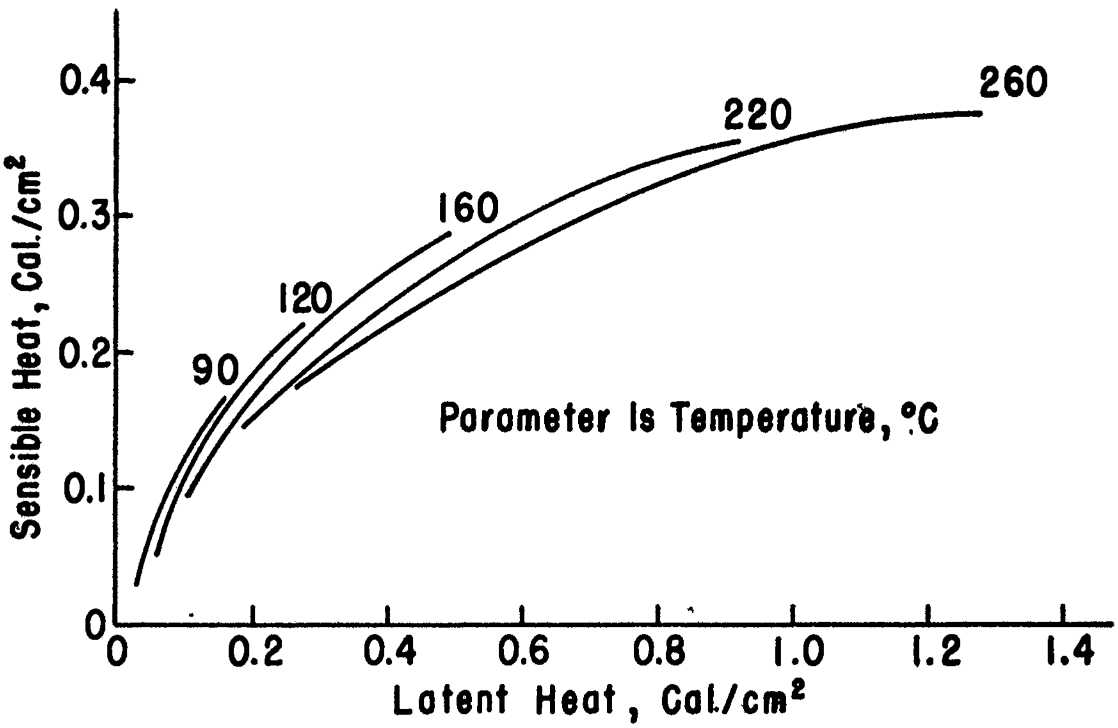


Figure 39. Sensible versus Latent Heat Transfer for Series A

TABLE IX

REGRESSION EQUATIONS OF PERCENT DEFOLIATION AND DESICCATION FOR DESIGNATED SERIES

Series	Regression Equation*	Multiple Correlation Coefficient	Standard Error of the Est.**
A	$DEF = -45.96 - 17284.04\,\overline{SH} + 16436.12\,\overline{SH}^2 - 9464.90\,\overline{LH} - 28082.24\,\overline{LH}\,\overline{SH} + 1368.51\,\overline{SH}\,\overline{LH}^2 + 31859.15\,\overline{LH}\,\overline{SH}^2 + 14059.13\,(\overline{LH} + \overline{SH})$	0.58	27.09
	$DES = -61.66 + 1242.99\,\overline{SH} - 2752.30\,\overline{SH}^2 + 65.03\,\overline{LH}$	0.84	20.44
B	$DEF = 16.21 + 517.55\,\overline{LH} - 1164.25\,\overline{SH}\,\overline{LH}$	0.28	27.24
	$DES = 8.69 + 641.71\,\overline{SH} - 1097.00\,\overline{SH}^2$	0.51	7.28
C	$DEF = -13.23 + 94.99\,(\overline{SH} + \overline{LH})$	0.70	18.42
	$DES = -95.03 + 1673.45\,\overline{SH} - 3773.64\,\overline{SH}^2 + 467.23\,\overline{SH}\,\overline{LH}^2$	0.86	11.65
D	$DEF = 352.15 - 4210.73\,\overline{SH} + 6655.59\,\overline{SH}^2 + 674.30\,(\overline{SH} + \overline{LH}) - 561.95\,\overline{LH}^2$	0.92	12.21
	$DES = 21.41 + 466.59\,\overline{SH} - 675.67\,\overline{SH}^2$	0.71	8.48

* DEF = percent defoliation
DES = percent desiccation
$\overline{SH}$ = sensible heat, cal/cm^2
$\overline{LH}$ = latent heat, cal/cm^2

** Standard error of the estimate units are percent

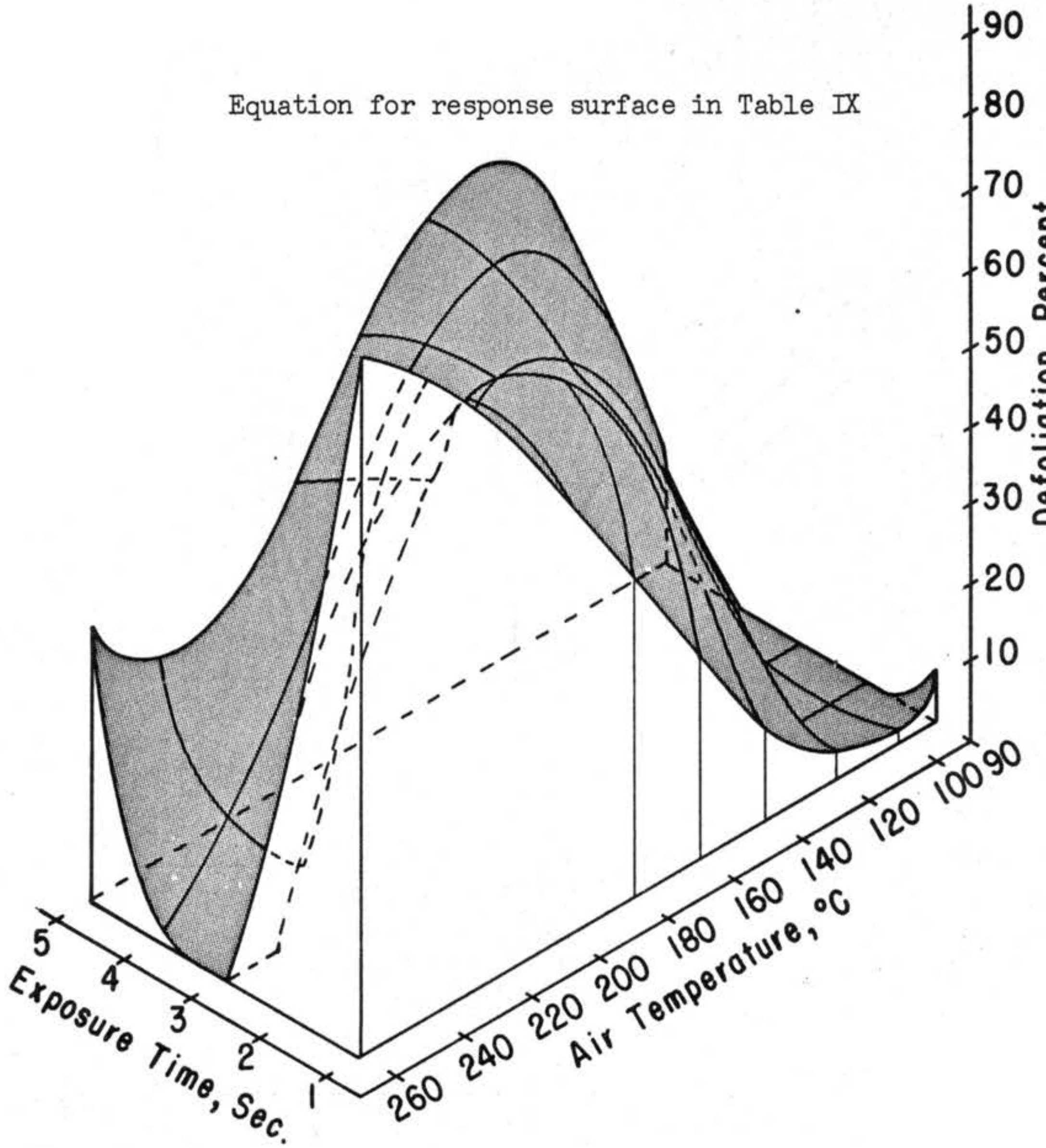


Figure 40. Defoliation Response Surface for Series A

Equation for response surface in Table IX

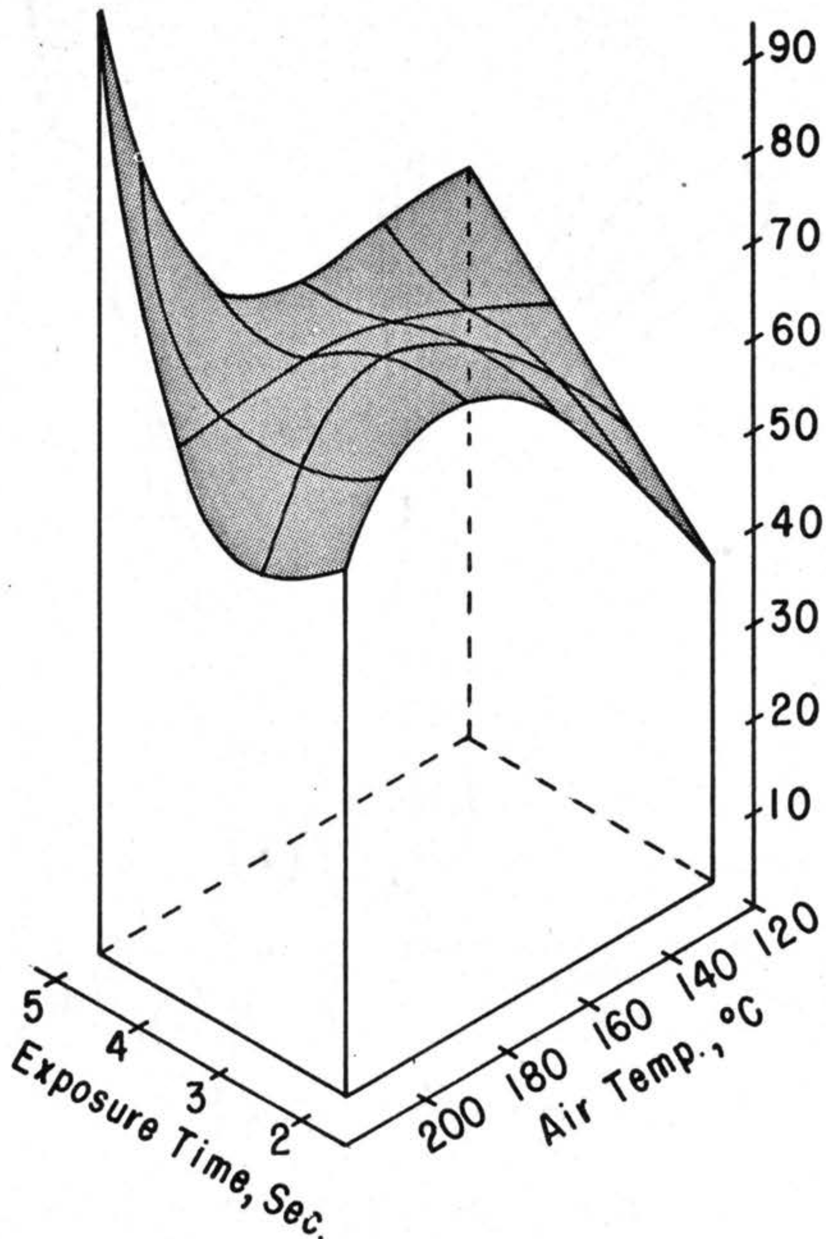


Figure 41. Defoliation Response Surface for Series B

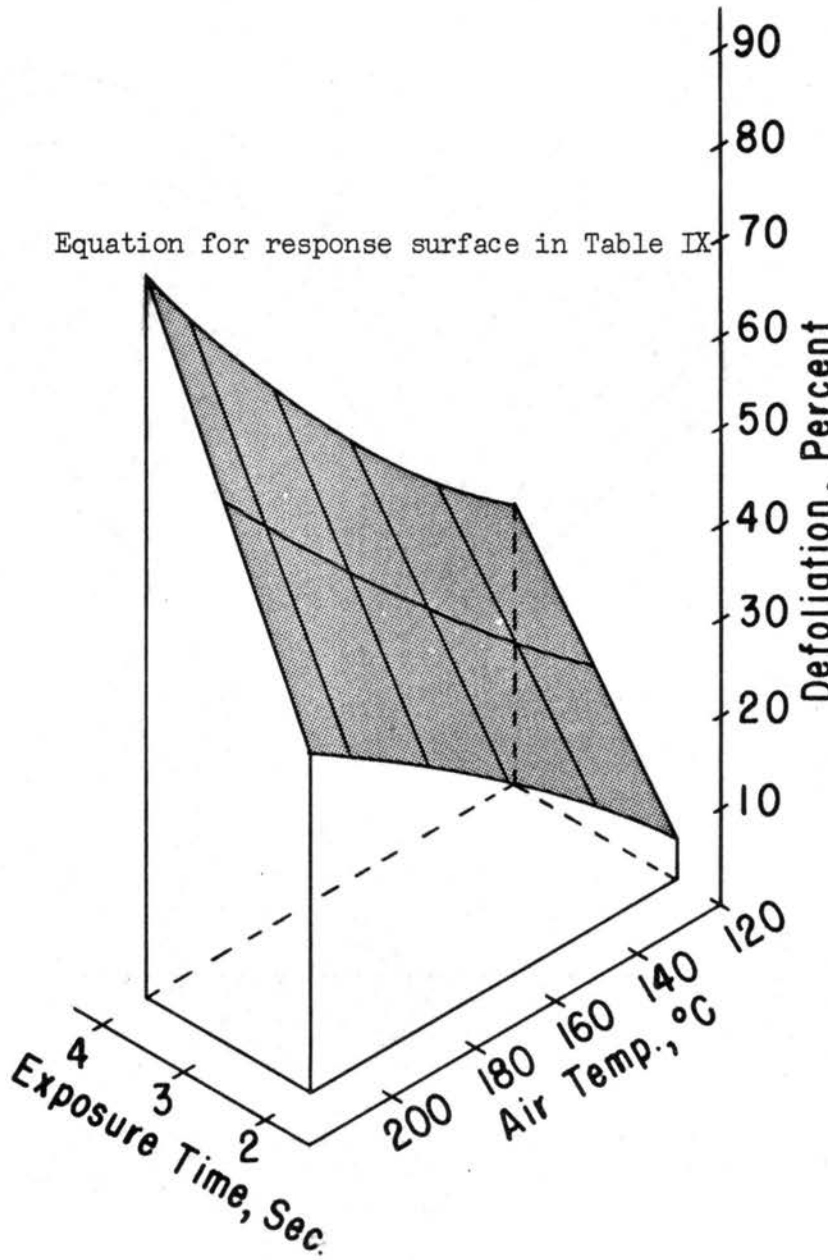


Figure 42. Defoliation Response Surface for Series C

Equation for response surface in Table IX

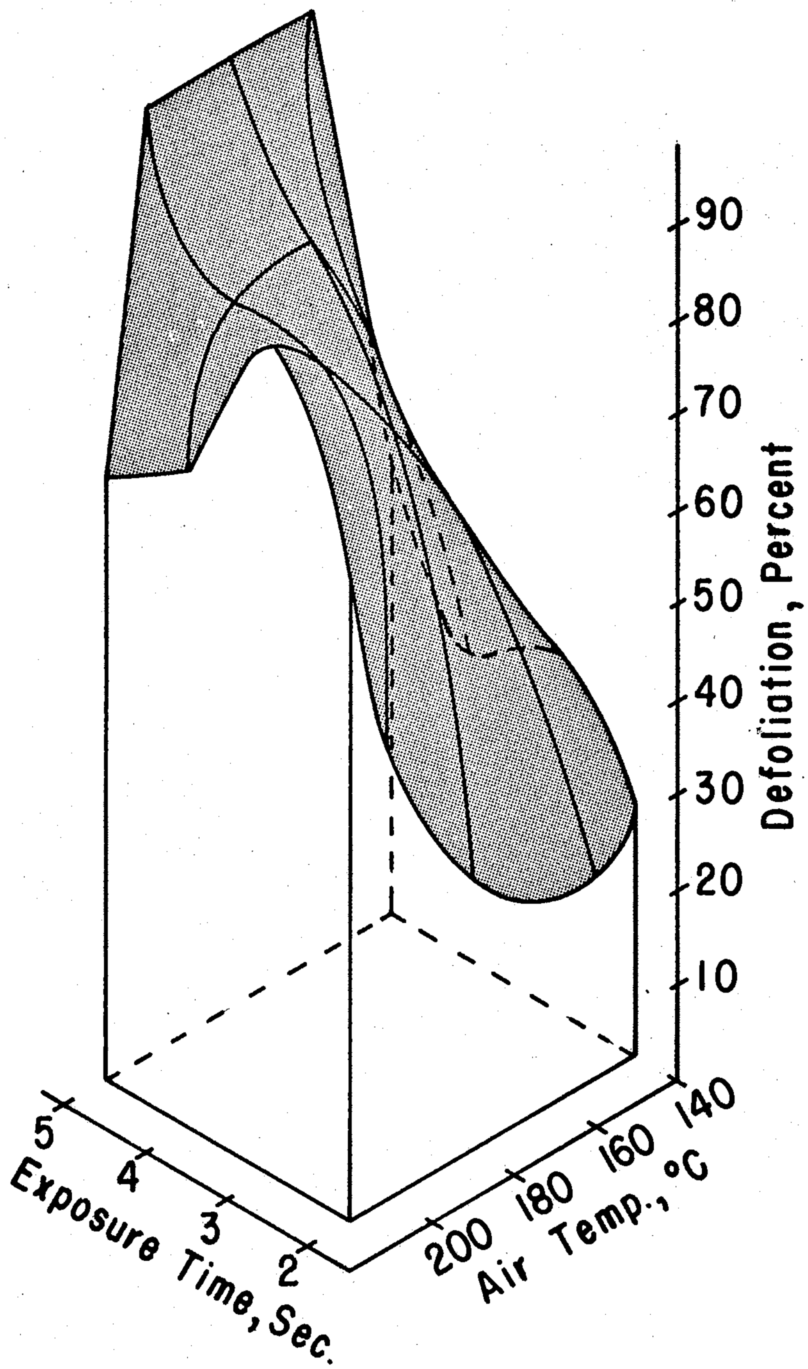


Figure 43. Defoliation Response Surface for Series D

The leaf and plant responses of Series A for an air velocity of 865 ft/min (4.4 m/sec) were categorized according to air temperature and exposure time. The division of the responses into regimes is illustrated in Figure 44.

The results of Series A were used to plot air temperature versus total leaf area with leaf response as the parameter. Figures 45, 46, 47, 48, and 49 were plotted with one, two, three, four, and five-second exposure times, respectively. The regimes for the responses are included on the figures.

Ignoring series and treatment effects, the percent defoliation occurring in each area interval for all instrumented leaves is included in Figure 28. For areas for which there are less than 10 observations, defoliation is not included.

Model leaf temperature responses could be simulated with Newtonian theory, Equation 40, by selecting a correct value for the heat transfer coefficient, h_c. To solve Equation 41 using the CSMP language, the time interval for integration must be specified. To accomplish this, a time rise to maximum temperature was estimated by a regression equation by regressing time to maximum temperature on air temperature, exposure time, and leaf length and width. The regression model proposed was:

$$TMAX = f(\overline{ET}, T, L, W)$$

where:

TMAX = Time to maximum temperature, sec

$\overline{ET}$ = Exposure, time, sec

T = Air temperature, $^{\circ}C$

L = Leaf length, cm

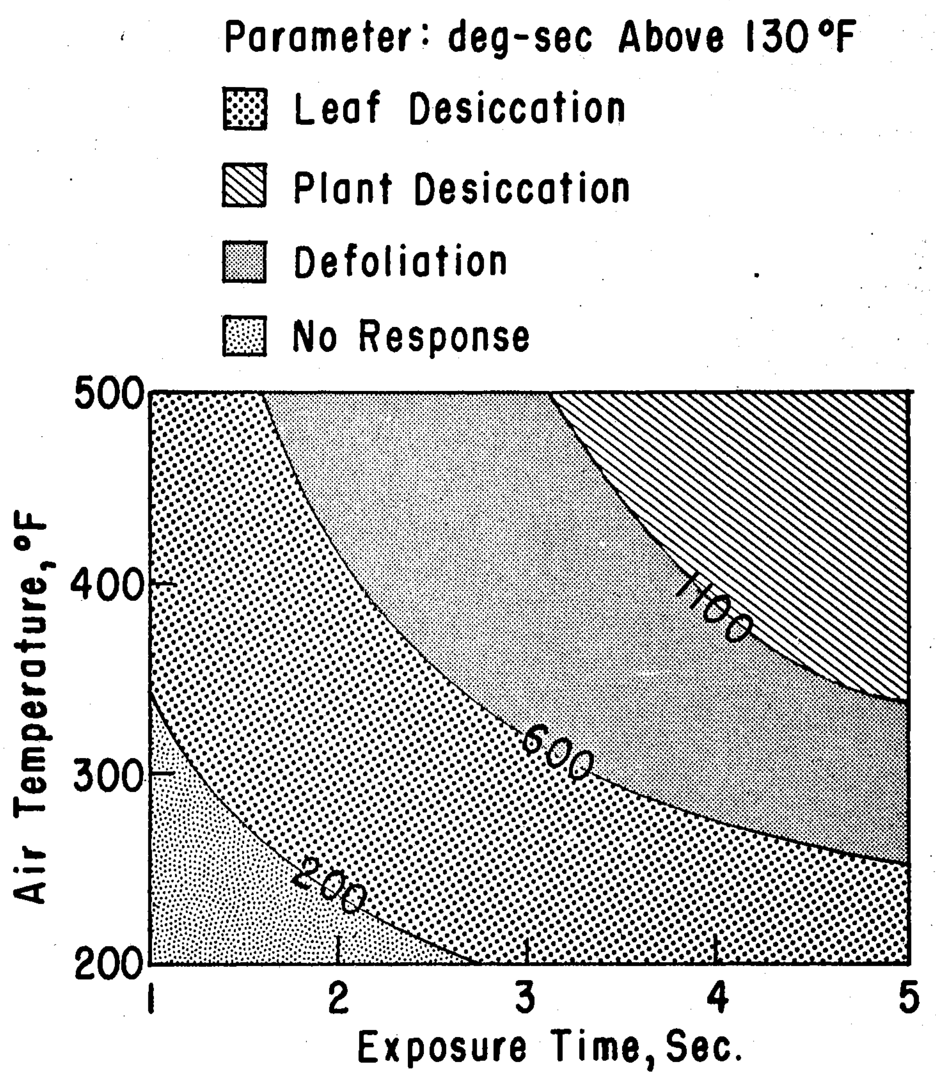


Figure 44. Effects of Temperature vs. Time of Exposure on Cotton Plants

See Figure 44 for legend

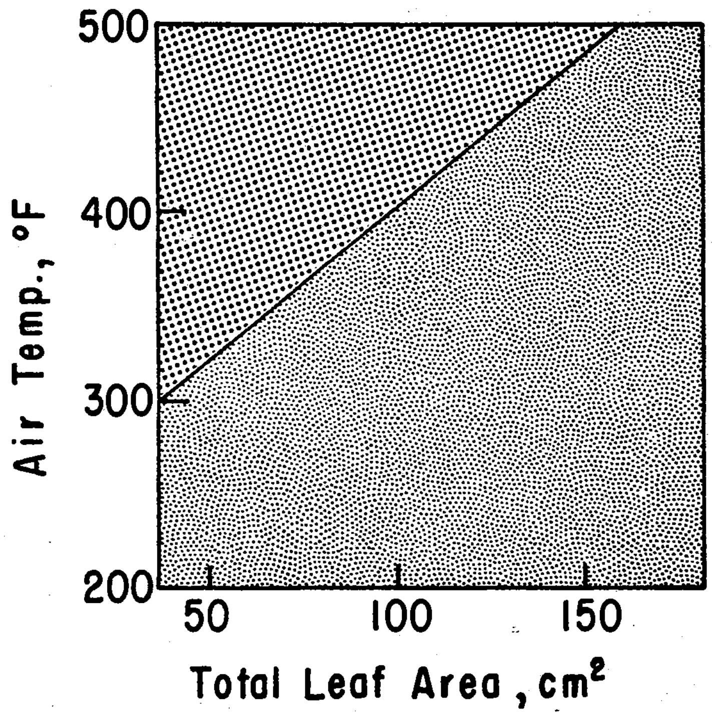


Figure 45. Leaf Responses of Series A as a Function of Total Leaf Area and Air Temperature for a One-Second Exposure

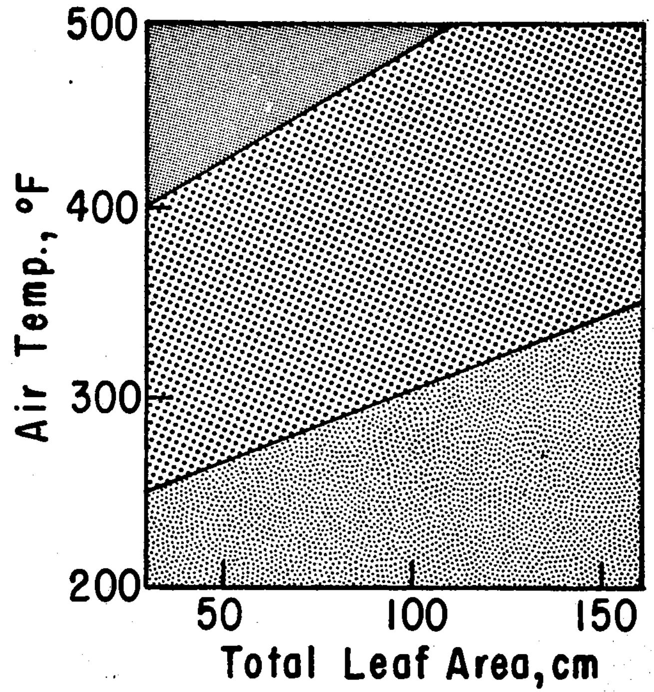


Figure 46. Leaf Responses of Series A as a Function of Total Leaf Area and Air Temperature for a Two-Second Exposure

See Figure 44 for legend

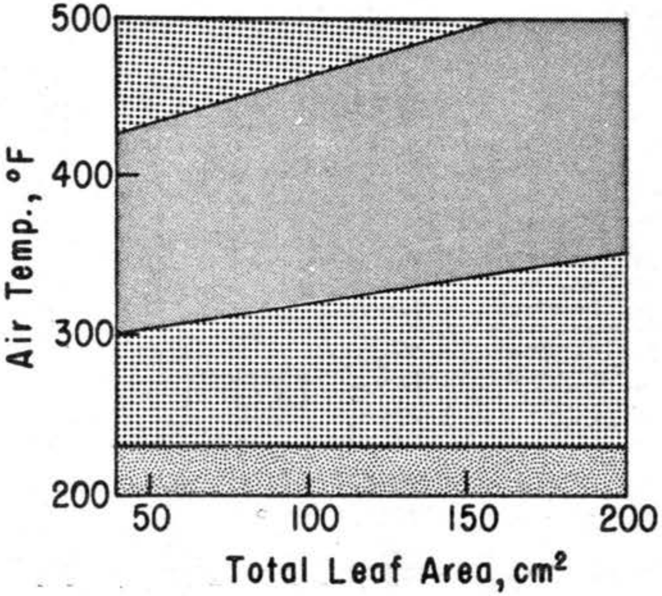


Figure 47. Leaf Responses of Series A as a Function of Total Leaf Area and Air Temperature for a Three-Second Exposure

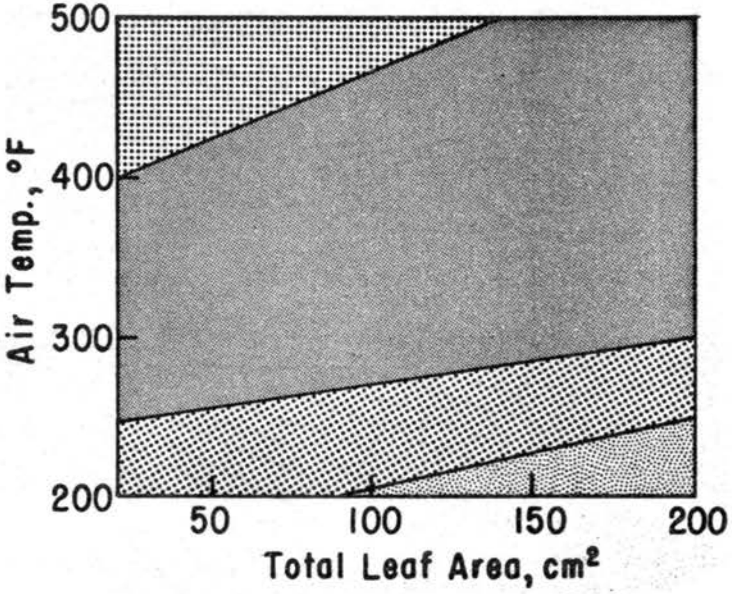


Figure 48. Leaf Responses of Series A as a Function of Total Leaf Area and Air Temperature for a Four-Second Exposure

See Figure 44 for legend

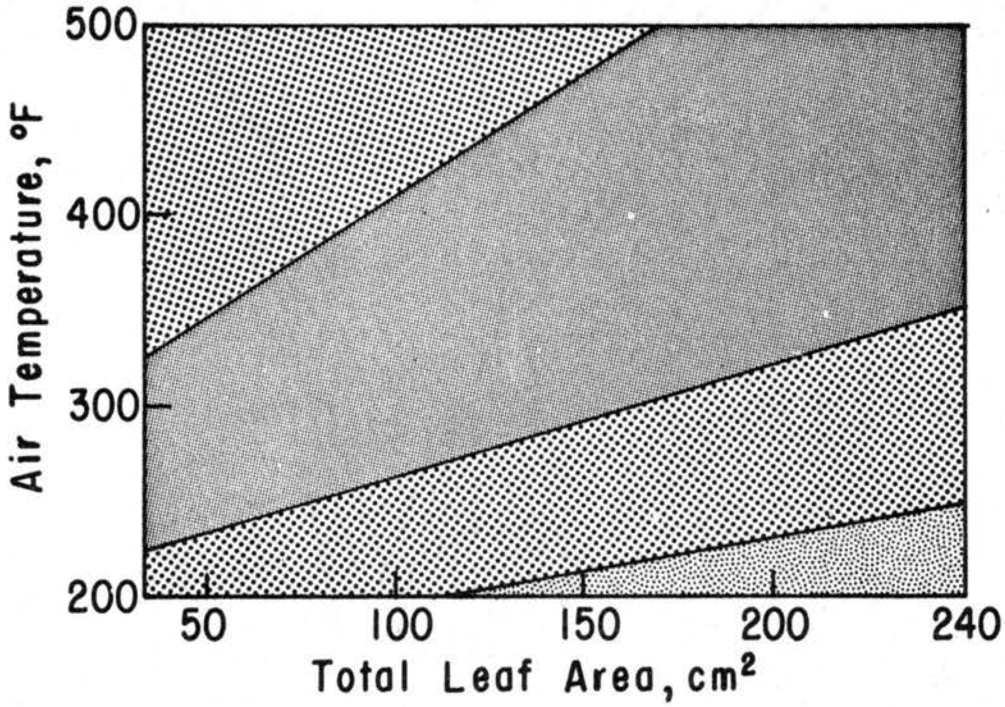


Figure 49. Leaf Responses of Series A as a Function of Total Leaf Area and Air Temperature for a Five-Second Exposure

The regression equation formulated was:

$$\overline{TMAX} = -0.94 + 1.27\ \overline{ET} - 0.09\ L + 1.81\ T - 4.02E\text{-}05\ T^2 - 1.86E\text{-}04\ T\ \overline{ET}^2$$

$R = 0.89$

$S = 0.83$ sec

where the other variables are as previously defined.

The simulated temperature responses of two leaves are illustrated in Figures 50 and 51 and can be compared with the actual temperature responses.

Heat transfer coefficients during the heating of the leaf were determined for 35 leaves from the Series A treatments. Selections were made to give heat transfer coefficients for various exposure times and air temperatures. A regression equation was formulated by regressing the selected heat transfer coefficients on leaf length, exposure time, and air temperature. The equation formulated was:

$$h_c = 0.05 - 0.00006\ T - 0.0013E\text{-}03\ L\ \overline{ET}\ T \qquad (47)$$

$R = 0.73$

$S = 0.005\ \text{cal/cm}^2\text{-min-}^{\circ}\text{C}$

where:

h_c = Heat transfer coefficient, $\text{cal/cm}^2\text{-min-}^{\circ}\text{C}$

and the other variables are as previously defined.

A graph of the heat transfer coefficient versus air temperature with time and length as the parameters is shown in Figure 52.

Comparisons of the simulated, projected, and actual temperature responses are illustrated in Figure 53. The projected response is identified as that response derived using the heat transfer coefficient estimated from Equation 47. The simulated response, which approached

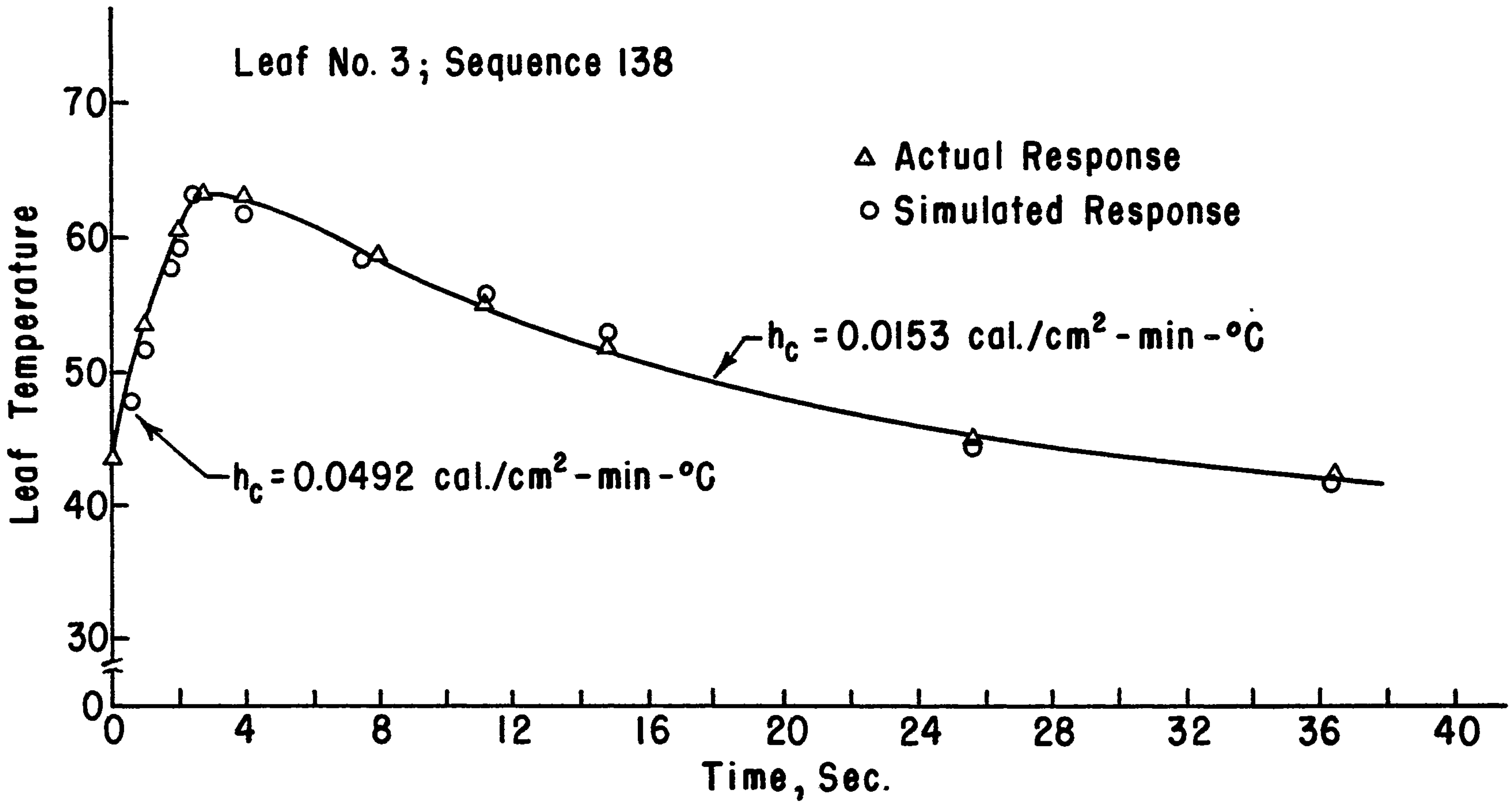


Figure 50. Simulated Compared to Actual Temperature Responses

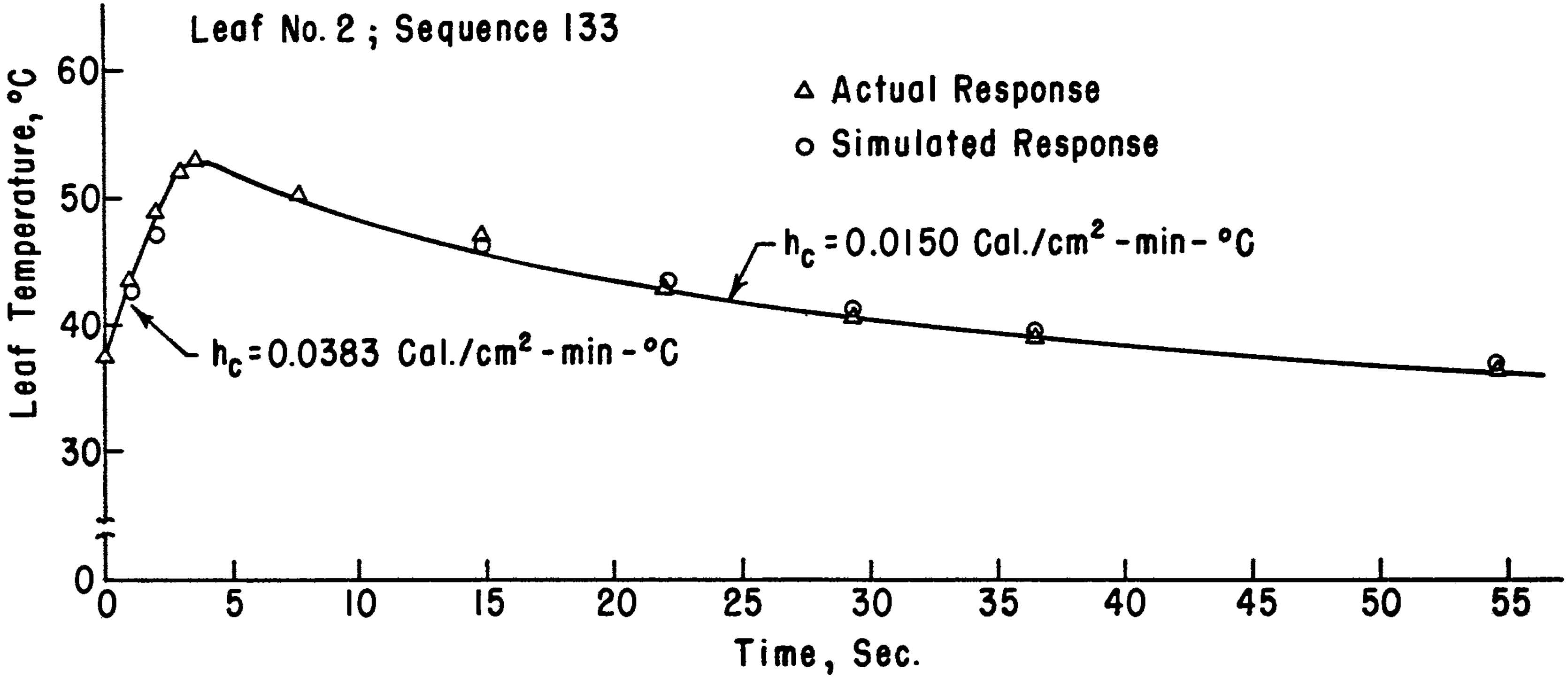


Figure 51. Simulated Compared to Actual Temperature Responses

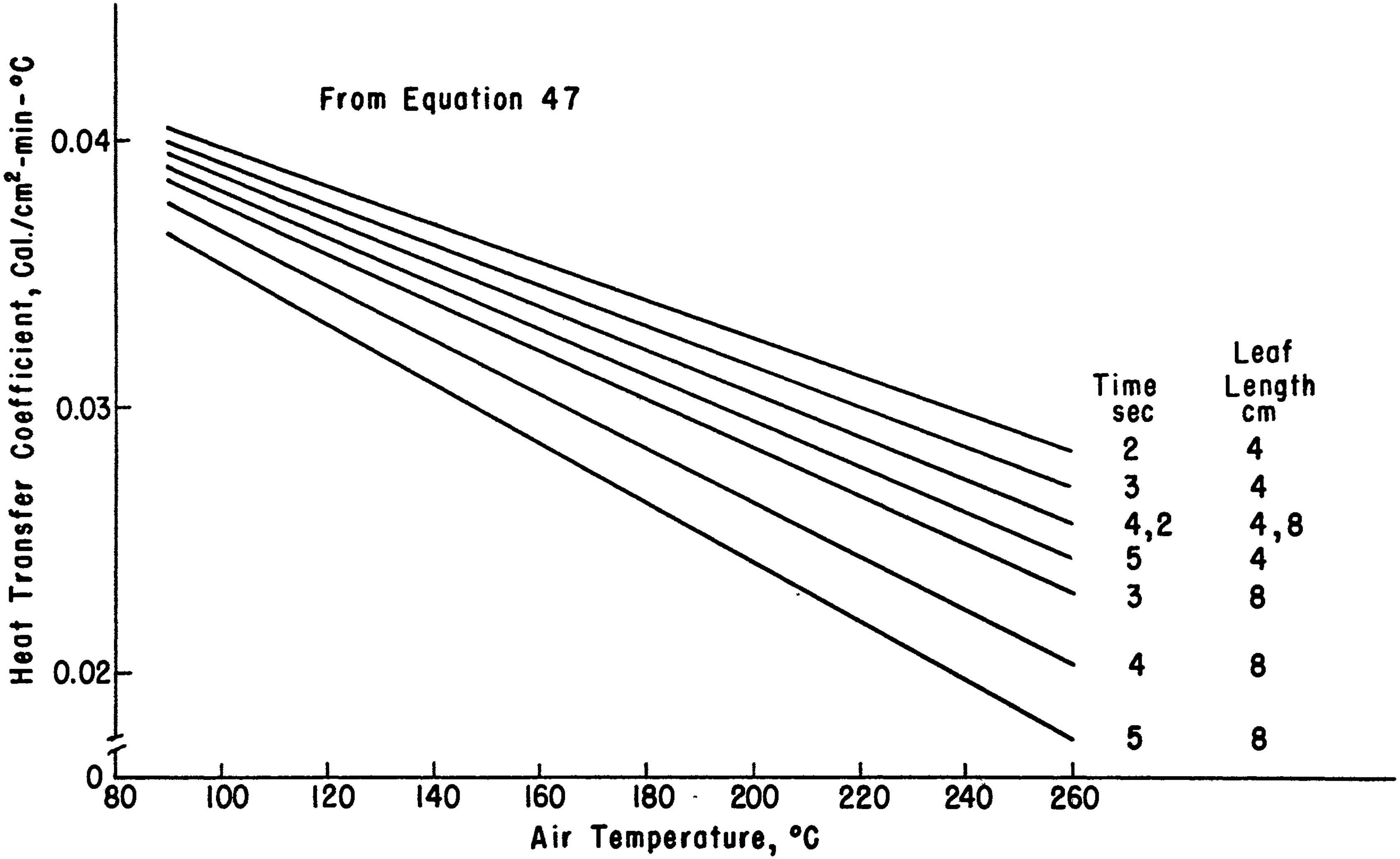


Figure 52. Heat Transfer Coefficient versus Air Temperature With Time and Leaf Length as Parameters

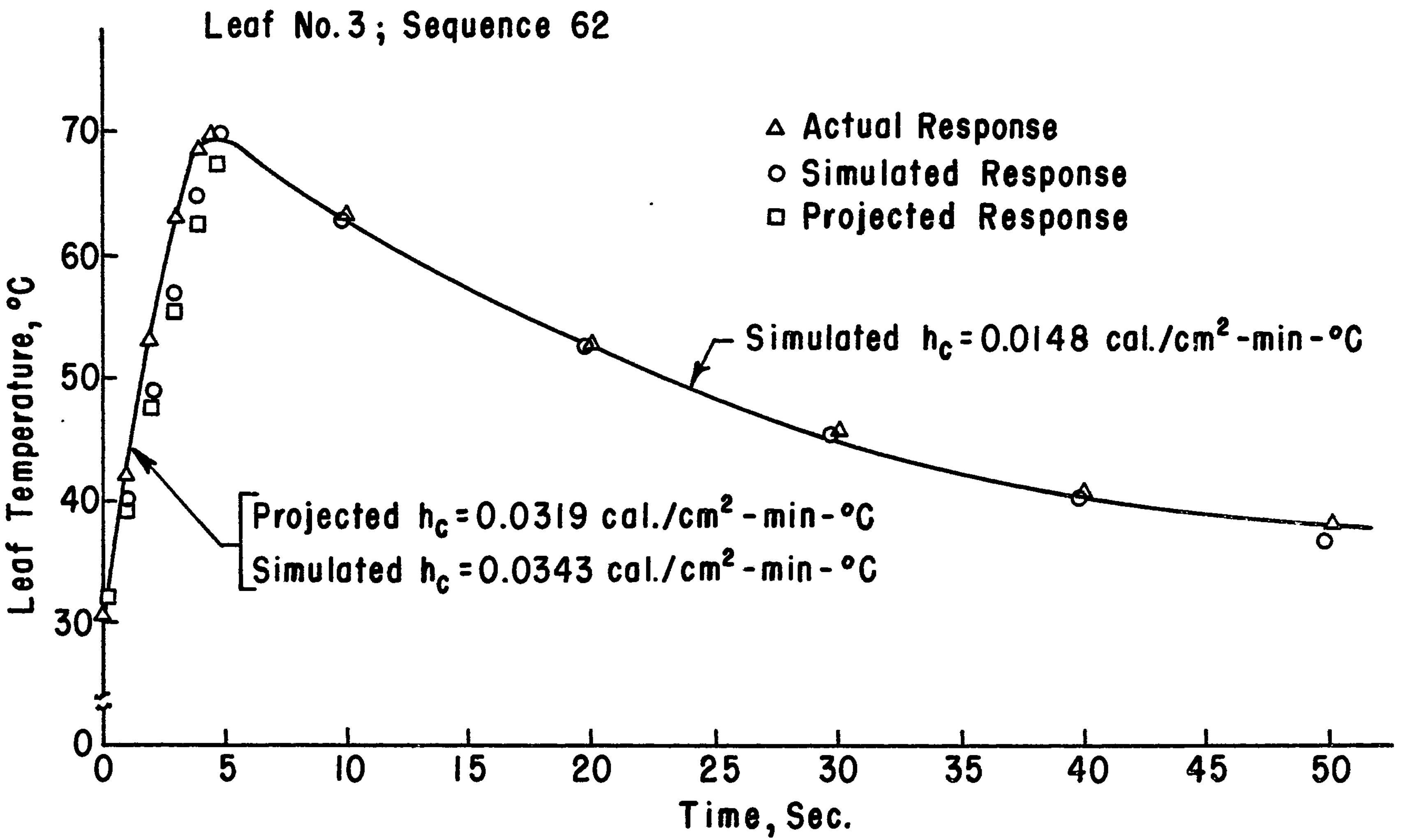


Figure 53. A Comparison of Actual, Simulated, and Projected Leaf Temperature Response

the actual response, required a heat transfer coefficient of 0.0343 compared to the estimated coefficient of 0.0319 cal/cm^2-min-^{o}C used in the projected response.

Summaries of the average leaf temperatures for Series A, B, C, and the Field Series are included in Tables X, XI, XII, and XIII, respectively. The average exposure times and the number of leaves investigated within each series are also included. The average increase of temperature above the initial temperature is also included. The values for the tables were obtained by dividing the leaves into their respective response categories within each series and averaging the temperatures and times indicated.

Discussion

Illustrations of treatment responses of the plants are included in Figures 54, 55, 56, 57, 58, and 59. A plant which experienced no response to a treatment is illustrated in Figure 54. Plants which indicated a slight chlorosis around the leaf edges were also included in this category, as illustrated in Figure 55. Leaves that experienced excessive chlorosis are shown in Figure 56. Discretion was necessary to categorize leaves, such as those in Figure 55 as to the degree of heat injury sustained. Leaves such as those illustrated in Figure 56 would be categorized as desiccated for identification of type of leaf response. A plant that defoliated is illustrated in Figure 57. Desiccated leaves are included in Figures 58 and 59. However, the plant in Figure 59 is also desiccated. This was easy to determine, as the petiole of desiccated plants lost their turgidity but were still solidly attached to the plant. Turgid petioles, such as those in

TABLE X

SUMMARY OF AVERAGE LEAF TEMPERATURES FOR NO RESPONSE

	Series A		Series B	Series C		Field Series
				Single Exposure	Double Exposure	
Air velocity, m/sec	4.4	5.0	4.4	5.1	5.1	
Air temperature, °C	129	109	121	128	121	176
Initial leaf temperature, °C	38	35	28	32	30	24
1st peak temperature, °C	50	48	36	52	41	40
2nd initial leaf temperature, °C	--	--	36	--	41	--
2nd peak temperature, °C	--	--	46	--	49	--
Temperature increase, °C	12	13	18	20	11	16
Exposure time, sec	1.63	2.18	4.27	2.14	2.00	3.65
Number of leaves	60	44	3	8	3	2

TABLE XI

SUMMARY OF AVERAGE LEAF TEMPERATURES FOR LEAF DESICCATION

	Series A		Series B	Series C		Field Series
Air velocity, m/sec				Single Exposure	Double Exposure	
	4.4	5.0	4.4	5.1	5.1	
Air temperature, °C	170	178	157	154	161	237
Initial leaf temperature, °C	36	37	28	32	29	24
1st peak temperature, °C	67	65	48	59	46	57
2nd initial leaf temperature, °C	—	—	48	—	46	—
2nd peak temperature, °C	—	—	64	—	61	—
Temperature increase, °C	31	28	36	27	32	33
Exposure time, sec	3.06	2.87	4.86	2.78	2.87	5.65
Number of leaves	77	71	62	44	37	5

TABLE XII

SUMMARY OF AVERAGE LEAF TEMPERATURES FOR DEFOLIATION

	Series A		Series B	Series C		Field Series
				Single Exposure	Double Exposure	
Air velocity, m/sec	4.4	5.0	4.4	5.1	5.1	
Air temperature, °C	171	191	166	175	181	206
Initial leaf temperature, °C	39	40	28	33	28	26
1st peak temperature, °C	74	74	52	74	48	60
2nd initial leaf temperature, °C	—	—	51	—	48	—
2nd peak temperature, °C	—	—	69	—	65	—
Temperature increase, °C	35	34	41	41	37	34
Exposure time, sec	3.33	3.11	5.31	3.64	3.16	5.35
Number of leaves	111	67	66	22	19	36

TABLE XIII

SUMMARY OF AVERAGE LEAF TEMPERATURES FOR PLANT DESICCATION

	Series A		Series B	Series C		Field Series
Air velocity, m/sec	4.4	5.0	4.4	Single Exposure 5.1	Double Exposure 5.1	
Air temperature, °C	220	221	—	204	—	—
Initial leaf temperature, °C	39	43	—	43	—	—
1st peak temperature, °C	97	86	—	81	—	—
2nd initial leaf temperature, °C	—	—	—	—	—	—
2nd peak temperature, °C	—	—	—	—	—	—
Temperature increase, °C	58	43	—	38	—	—
Exposure time, sec	4.5	4.2	—	2.5	—	—
Number of leaves	40	52	—	3	—	—

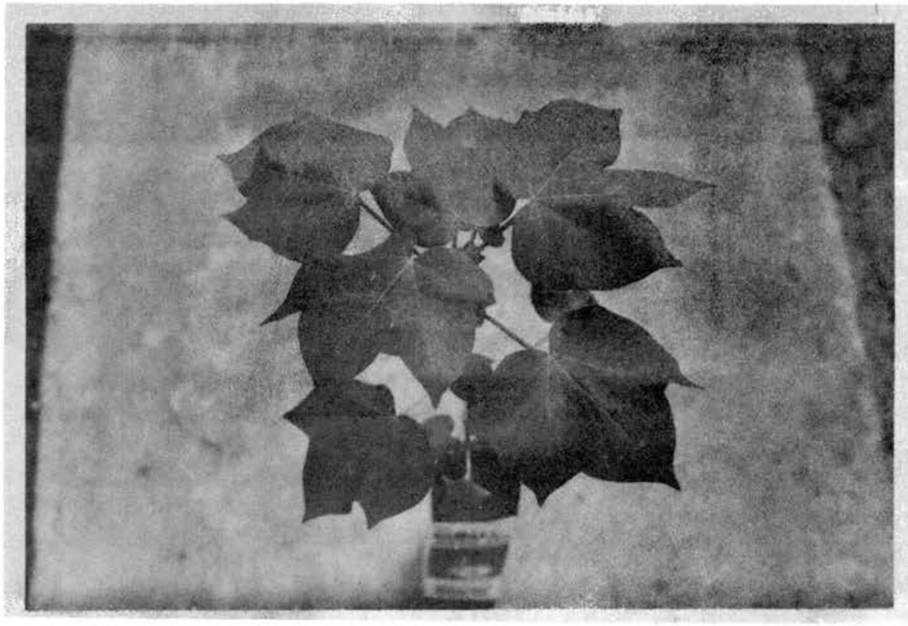


Figure 54. Plant Exhibiting No Thermal Injury

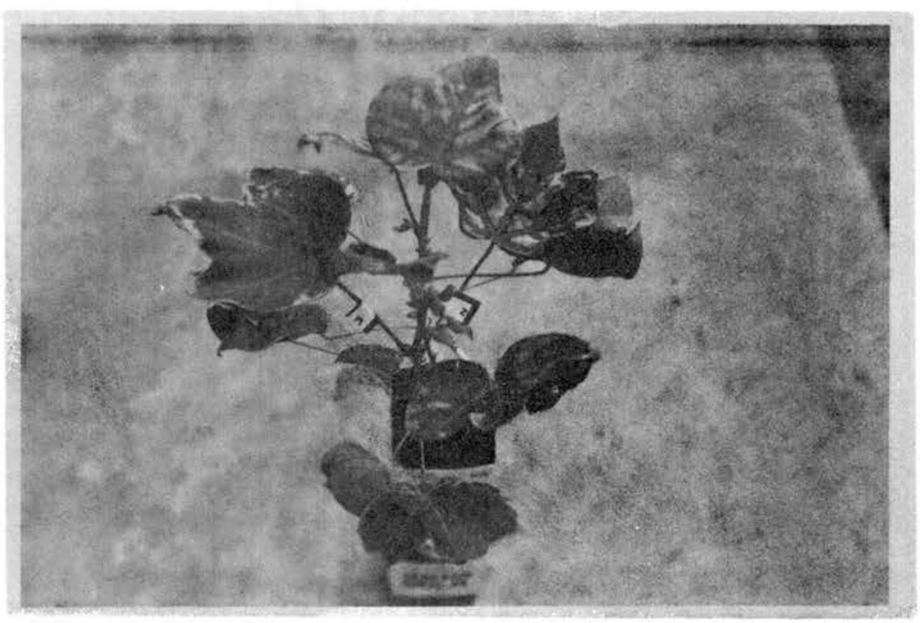


Figure 55. Plant Exhibiting Slight Chlorosis of the Leaves

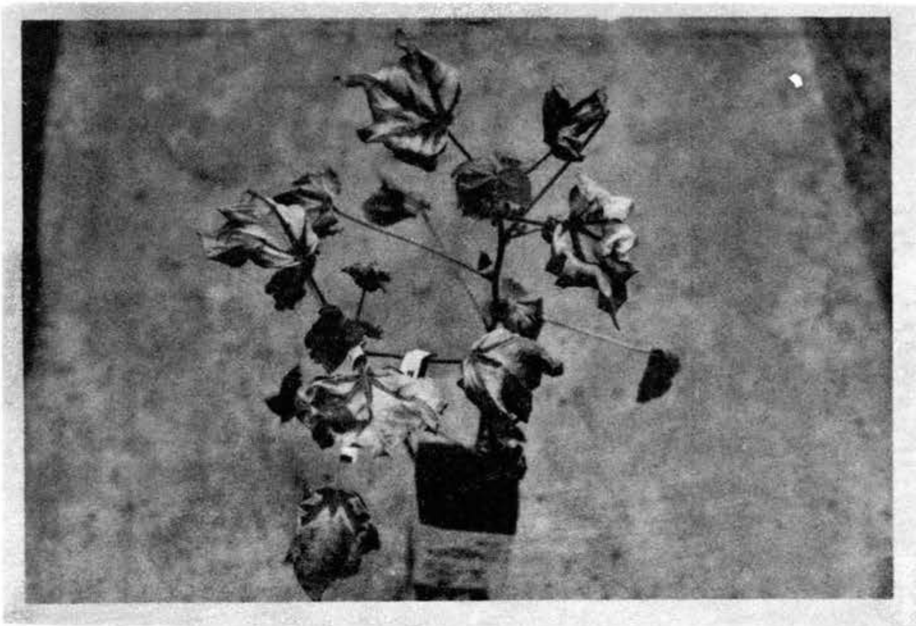


Figure 56. Plant Exhibiting Severe Chlorosis and Leaf Desiccation

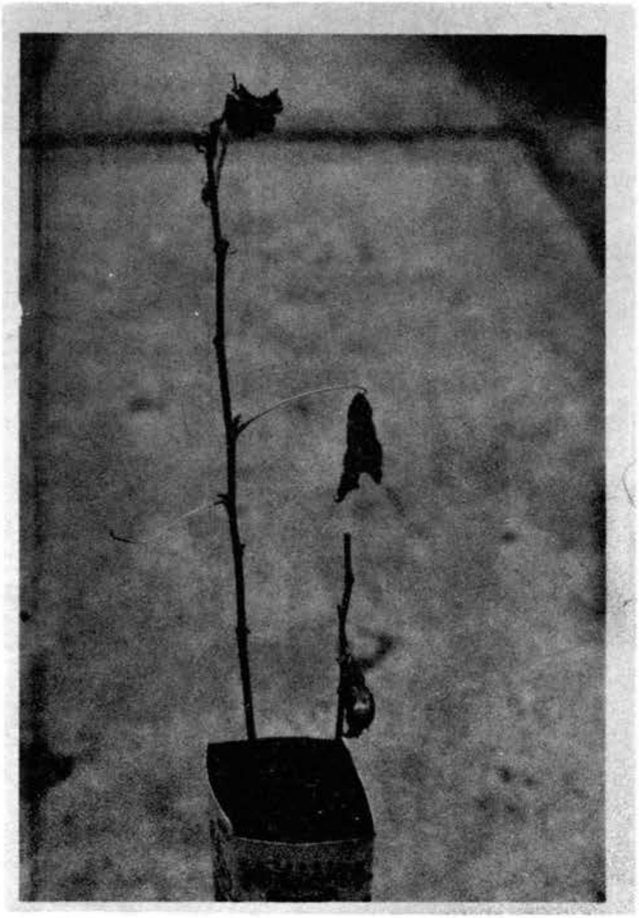


Figure 57. Defoliated Plant

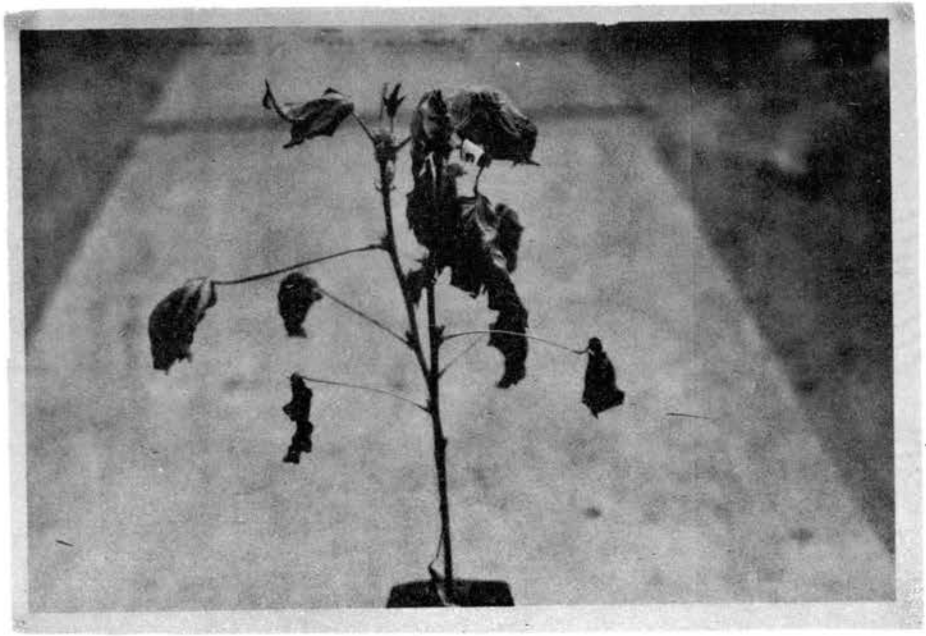


Figure 58. Plant Exhibiting Desiccated Leaves

Figure 59. Desiccated Plant

Figure 58, could be divided into two-color categories: green and blanched. The green petioles did not develop an abscission zone at their base. The blanched petioles did develop an abscission zone, and any agitation usually defoliated the leaves.

Comparing leaf areas of the laboratory plants to the leaf areas of mature field plants indicated that the laboratory plants had smaller leaves than the mature field plants. The two varieties of plants accounted for some of the difference, although a difference was clearly evident between the field series of leaves instrumented and the field plants. Figures 45, 46, 47, 48, and 49 indicate a tendency for larger leaves to be more resistant to heat injury than smaller leaves. This tendency is also indicated by the defoliation response of the leaves when categorized according to size, Figure 28.

The regression equations formulated for leaf area indicated the length by width interaction to be more important than any single factor or any other interaction. These expressions are similar to Equation 39 as proposed by Ashley et al. (3). As anticipated, leaf mass and volume were also adequately described by regression equations.

The AOV tables for Series A, B, and C, are included in Tables II, III, and IV, respectively. For the Series A treatments, temperature was significant at the 0.01 level of significance, whereas exposure time, air velocity, and the interaction of exposure time and temperature were significant at the 0.05 level of significance. The significant interaction can be interpreted as meaning that real differences in defoliation rate existed among the five exposure times for each air temperature at both air velocities. The importance of the interaction also suggested the use of the interaction term to describe response surfaces for heat gain of a leaf and for defoliation response of a plant.

The significant factor, fan speed/air velocity, presents evidence of differences in defoliation rate for various air velocities. The exposure time by air velocity and temperature by air velocity interactions were therefore examined, even though they were not significant.

An examination of the exposure time by air velocity interaction indicated that differences in defoliation rates at both air velocities were not significant for a four-second exposure. However, they were significant for two, three, and five-second exposure times in favor of the slower air velocity and also for the one-second exposure in favor of the faster air velocity.

An examination of the temperature by air velocity interaction indicated that differences in defoliation rate for two air velocities did not exist at 350°F (177°C), but significant differences in defoliation rates did exist at 200 (91), 250 (121), 300 (148), 400 (204), 450 (232) and 500°F (260°C) in favor of the slower air velicity.

The AOV for Series B, Table III, indicates no significance for any of the factors or their interactions. This reveals that the double-exposure treatments are not influenced by exposure time and temperature. It is possible that the delay period allowed a cooling of the leaf temperature to nullify temperature and exposure effects.

The AOV table for Series C, Table IV, indicates that temperature and exposure time are highly significant, and the three-factor interaction is significant. Since the three-factor interaction is significant and no two-factor interactions are significant, this is examined as an interaction of the interaction temperature by single-double with the factor, exposure time.

Examination of the temperature by single-double exposure interaction indicated no difference in defoliation rates for a single or double exposure over all exposure times for 250 (121) or 300°F (149°C) air temperatures. However, the difference in defoliation rate was significant in favor of double exposure at 350°F (177°C) and in favor of a single exposure at 400°F (204°C) air temperature.

The effects of a single or double exposure were then examined for an air temperature of 350 (177) and 400°F (204°C).

An examination of the exposure time by single-double exposure interaction for the 350°F (177°C) air temperature revealed that an exposure time of two seconds resulted in a significant difference in defoliation rate, whereas there was no difference in defoliation rate between the three or four-second exposure times. For a 400°F (204°C) air temperature, an exposure time of four seconds produced a significantly better defoliation rate than the two or three-second exposure times.

Regression equations of sensible heat transfer are included in Table V. The significance of the air temperature by time interaction is illustrated by the regression equations. The interaction term was selected first as contributing most to the variation in sums of squares in the step-wise regression model.

Regression equations of moisture loss and latent heat transfer are included in Tables VI and VII. The regression equations, as in sensible heat transfer, signify the importance of the temperature by exposure time interaction.

The high multiple correlation coefficients for the latent heat equations are a result of the method used to formulate these equations.

The equations were formulated from the product of the moisture loss equations of Table VI and the enthalpy of evaporation, Equation 45. The latent heat equations are, therefore, no better than the equations for moisture loss.

The response surfaces of the regression equations of Table VIII are shown in Figures 34, 35, 36, and 37 for Series A, B, C, and D, respectively. Constant total heat lines are included on the response surfaces. The regimes of response of the leaves for the different air temperatures and exposure times are indicated on the figures. There was no sharp dividing line between the four-response categories. Because of the nature of the material, overlapping responses certainly would be expected.

For Series A, Figure 34, the iso-heat line between the categories of no response and leaf desiccation lies approximately on the 0.3 cal/cm^2 line. The iso-heat line between leaf desiccation and defoliation and defoliation and plant desiccation occur at approximately 0.6 and 1.0 cal/cm^2, respectively.

For Series B, Figure 35, the four responses are more difficult to categorize according to total heat gain. The two responses of leaf desiccation and defoliation are separated by an iso-heat line of approximately 0.5 cal/cm^2. The response of plant desiccation did not occur because the necessary air temperature and exposure time were not attained.

For Series C, Figure 36, the categorization of leaf responses according to iso-heat lines is again difficult to determine. The iso-heat line of 0.2 cal/cm^2 passes through the leaves labeled as no response. The iso-heat line dividing leaf desiccation and defoliation is approximately 0.6 cal/cm^2. Again no plants were desiccated for the treatments applied.

For Series D, Figure 37, the leaf responses are similar to those of Series B and C. The iso-heat line between leaf desiccation and defoliation is approximately 0.6 cal/cm^2.

Ignoring the interaction of treatments, the four response categories lie approximately in the same iso-heat ranges for all four series of treatments. The heat gain for the total heat response surfaces are referenced from the leaves' initial temperature. The fact of similar heat ranges for similar responses for the laboratory series, therefore, indicates that initial leaf temperatures were not significant for the range of initial temperatures encountered.

For the Field Series, Figure 38, the sensible heat response indicates little difference in sensible heat gain for the different treatments. Defoliation response did occur at all treatments. The number of observations within each leaf response category were minimum. Dividing the responses by iso-heat lines would be very difficult.

A comparison of latent to sensible heat transfer is illustrated in Figure 39 with air temperature as the parameter. The large increases in latent heat for small increases in sensible heat at higher air temperatures reveals why the total heat gain response surfaces in Figures 34, 35, 36, and 37 increase so rapidly at the high temperatures and exposure times. The total heat response increases as the square of the temperature increases. This is due mainly to the latent heat approaching a sensible heat asymptote at high temperatures and long exposure times.

Regression equations of percent defoliation and desiccation are included in Table IX. The low multiple correlation coefficients and high standard error of the estimate indicate the difficulty in accounting for the variability of defoliation and desiccation. Defoliation and desiccation were calculated by using sensible and latent heat expressions, which are a function of exposure time and air temperature. Several mathematical models for describing defoliation and desiccation were examined. However, the best fit responses were with the factors, time and air temperature.

The response surfaces of defoliation response for the regression equations of Table IX are included in Figures 40, 41, 42, and 43.

The response surface of defoliation for Series A, Figure 40, illustrates well the significance of the air temperature and exposure time interaction as indicated by the AOV analysis of Table II. The maximum defoliation response ridge is from a two-second exposure at 260°C to a five-second exposure at 121°C. The defoliation response decreases at the small exposure times and temperatures due to no effect of the treatments and decreases at the high exposure times and temperatures due to plant desiccation.

An examination of simple effects indicated that an air velocity of 4.4 m/sec resulted in higher defoliation rates than an air velocity of 5.0 m/sec when defoliation rate was summed over all temperatures and exposure times. An air temperature of 350°F (177°C) yielded higher defoliation rates than the other temperatures when defoliation rate was summed over all exposure times and air velocities. An exposure time of two seconds yielded a higher defoliation rate than the other exposure times when defoliation rate was summed over all temperatures and air velocities.

The response surface of defoliation rate for Series B is illustrated in Figure 41 and illustrates the lack of significance in the AOV Table for Series B. Comparing the defoliation response surfaces of Series A to Series B illustrates the lack of a significant interaction term for Series B. The peak response at 200°C with a five-second exposure is misleading and is due only to the regression equation.

Examination of simple effects for Series B indicated a greater defoliation response at an air temperature of 300°F (148°C) than did the other air temperatures when defoliation rate was summed over all exposure times and both delay times. There was no difference in defoliation response between the delay periods when defoliation was summed over all temperatures and exposure times. Also, an exposure time of five seconds yielded a better defoliation rate than three or four seconds, when defoliation was summed over all temperatures and both delay periods.

The defoliation response surface of Series C, Figure 42, illustrates the lack of a significant two-factor interaction term, as indicated by the AOV of Table IV. The response surface indicates an increase in defoliation rate with temperature and time increases.

An examination of the simple effects reveals that a temperature of 350°F (177°C) resulted in a higher defoliation response than the other three temperatures when defoliation rate was summed over all exposure times and the two types of exposure. A total exposure time of four seconds indicated a higher defoliation response than either two or three-second exposures when defoliation rate was summed over all temperatures and the two types of exposure. In addition, the double-exposure method yielded higher defoliation rates than a single exposure, when defoliation rate was summed over all temperatures and exposure times.

A summary of the three series of treatments, A, B, and C reveals a similarity for simple effects, in that the highest defoliation rates for air temperatures were the same for Series A and C at 350°F (177°C) and at 300°F (148°C) for series B. However, for exposure times, maximum defoliation rates occurred at three, five, and four seconds for Series A, B, and C, respectively. The interactions of the other factors within each respective series would influence the responses to simple effects, e.g., a single exposure of three seconds, such as in Series A, might result in the same response as two exposures of 2.5 seconds separated by a short delay time for a total exposure time of five seconds, as in Series B, both treatments at the same air temperature.

The defoliation regression response surface of Series D is illustrated in Figure 43. Care must be exercised in its interpretation. The treatments for Series D were not replicated, and, therefore, no AOV analysis was performed. An examination of simple effects of the independent variables indicated that the defoliation rate for the five-second exposure was more than double the two-second exposure when defoliation rate was summed over both temperatures and air velocities. The 400°F (204°C) air temperature produced a slightly higher defoliation rate than the 300°F (148°C) air temperature, and the higher air velocity of 5.8 m/sec produced a higher defoliation rate than the slower air velocity of 4.3 m/sec.

Four treatments were also completed at 350°F (177°C) for air velocities of 4.3, 4.4, 5.1, and 5.8 m/sec with defoliation rates of 61.4, 75.0, 85.2, and 85.0 percent, respectively. Also, this was not replicated, but the defoliation responses indicated a relationship between defoliation rate and air velocity. The response of these treatments was also included in the response surface of Figure 43. The higher air temperatures and exposure times produced higher defoliation rates, but the defoliation response was not exactly as indicated by the response surface, even though the regression equation resulted in the lowest standard error of the estimate of all the defoliation regression equations.

Response surface and an AOV were not analyzed for the Field Series, as an 84-percent defoliation response resulted from the field treatments with a four-percent no response and a 12-percent leaf desiccation response of all leaves instrumented.

The regimes of iso-response for leaves and plants are illustrated in Figure 44. The division between no response and leaf desiccation is approximately 200 degree-seconds above 130°F. The boundaries for leaf defoliation are approximately 600 and 1100 degree-seconds above 130°F. An ideal defoliation temperature-time line is approximately 850 degree-seconds above 130°F. Comparing these results to those results in Figure 1, indicates that visible heat injury to cotton plants is in excess of the ideal 60 degree-second above 130°F line for cell tissue of corn stems. However, the iso-response lines for Figures 1 and 44 are of the same general shape.

Simulated and actual temperature response curves are included in Figures 50 and 51. The values of the heat transfer coefficient, h_c, resulting in the best fit simulations, are included. The temperature response for increasing leaf temperatures do not follow the actual temperature response. The actual leaf temperatures are always warmer than those estimated by Equation 41 for the temperature increase of the leaf. However, for the cooling curves of the leaves, the simulated and actual leaf temperature responses are very similar. For the simulation, the actual maximum leaf temperature was used as a control, so the simulated maximum leaf temperature would be identical to allow determination of an h_c to give the maximum leaf temperature in the required time. The time to maximum temperature was determined by equation 46.

The response curves plotted from the simulations to determine the heat transfer coefficient, h_c, are illustrated in Figure 52. The coefficient is defined as a function of air temperature, exposure time, and leaf length. The coefficient of determination indicates that only 54 percent of the variation is accounted for by the regression Equation 47 for the variability of h_c. Although the measurement of the heat transfer coefficient was not the primary objective of this research, the values obtained are the correct order of magnitude when comparing the values of h_c in Figure 52 to those in Figure 10. The values of the heat transfer coefficient during heating and cooling were different. The leaf was exposed to a turbulent medium during heating and was in an almost quiescent atmosphere during cooling. The higher values for the heat transfer coefficient were, therefore, expected during heating. Another significant point is that the heat transfer coefficient decreases as downwind leaf length increases, which is expected from theory. Again, it is important to note that the coefficient, h_c, determined accounts only for sensible heat transfer. The inclusion of latent heat transfer would cause the value of h_c to increase.

An examination of the differences between initial and maximum leaf temperatures in Tables X, XI, XII, and XIII indicates a possible pattern emerging that would support a statement to the effect that the higher the initial leaf temperature, the smaller the temperature increase of the leaf for a given treatment. This pattern indicates that as the temperature of the leaf increases, protective measures to guard against excessive temperature may have already occurred. The range of initial leaf temperatures was not of a great enough magnitude to warrant exploration of the possibility of initial leaf temperature interactions with other factors. Therefore, a positive statement can not be made. As in total heat transfer, the respective leaf responses for various temperature increases occurred in a narrow temperature range with some overlap.

Measurement Error

A planimeter was used to measure leaf area. Each planimeter unit was 0.25808 square centimeters. The largest percent error would occur at the smaller leaf areas. The smallest leaf measured was in the 20 cm^2 range. If the leaf area was measured within $\pm$ 2.0 planimeter units, the percent error for a leaf of 20.0 cm^2 area would be 2.5 percent. Using the planimeter to measure the area of the calibrated testing rule supplied with the planimeter indicated the area can be off as much as 6.5 percent depending on the planimeter geometry. The error in area measurement was less than 9.0 percent. However, an attempt was made during planimetering of a leaf to maintain planimeter geometry such that the error would be less than 5.0 percent.

The mass of a leaf was determined using a Mettler balance with an accuracy of ± 0.0001 grams. The lightest leaf weighed was approximately 0.2 grams. The error in mass determinations was less than 1.0 percent. The percent error of the balance is not known but is probably less than one-fourth percent.

The volume of a leaf was determined by water displacement of the leaf in a graduated cylinder. The cylinder was read to the nearest 0.10 cm^3. The smallest leaf measured was 0.3 cm^3 and the largest leaf was 1.6 cm^3. The approximate range of volume error was from 7 to 33 percent. This error was probably higher because a wetting agent was not used to reduce the occurrance of minute air bubbles on the leaf surface. This measurement was not used for any calculations so a more sophisticated method was not warranted.

The thermocouples used to measure leaf temperature were standard copper-constantan with limits of error of 1.5 percent from -60 to 90°C and 0.75 percent from 90 to 370°C.

The chart width for each channel of the recorder was 40 mm wide and the smallest chart division was 1.0 mm. Each 1.0 mm represented 0.10 mv of thermocouple output from the reference temperature. The chart was read to the nearest 0.05 mv. The minimum leaf temperature observed was 0.90 mv. Therefore, an error of 6.5 percent in temperature was possible from reading the chart. Instrument error was approximately ± 0.5 percent. Maximum temperature error was less than 9.0 percent.

The exposure time was observed from the chart and the accuracy of the chart speed was $\pm$ 1.0 percent. The chart divisions were observed to the nearest one-fourth percent. The possible error in exposure time was 1.25 percent.

Moisture loss was determined by use of the Mettler balance. The smallest observed moisture loss was 0.0005 grams of water. An error of 20 percent was possible in determining moisture loss.

Values for sensible heat gain of a leaf were determined by Equation 44. By summing the individual errors for each independent variable, an error in sensible heat per specific heat was approximately 19 percent.

It is pointed out that the use of regression equations to estimate dependent variable response also adds additional error. For example, a total heat gain of 0.2 cal/cm^2 with a standard error of the estimate of 0.06 cal/cm^2 indicates a possible error of 30 percent for estimation of a particular response.

The magnitudes of percent error are not necessarily excessive. No estimation can be made, but the variation between cotton plants or even between leaves of the same plant could conceivably be 50 percent or more.

CHAPTER VI

SUMMARY, CONCLUSIONS, AND SUGGESTIONS FOR FURTHER WORK

Summary

The research described in this thesis was directed primarily at determining the heat absorbed by a cotton leaf and correlating this heat to a particular leaf response. The four response categories were; 1) no response; 2) leaf desiccation; 3) leaf defoliation; and 4) plant desiccation. The desired response from the treatments was leaf defoliation. Defoliation was, therefore, used as the criterion of evaluation for the AOV tables and as the dependent variable for evaluation of treatment-factor interactions.

The objectives were accomplished using greenhouse-grown plants and mature field plants. The treatments were applied using laboratory equipment for the greenhouse plants and a field defoliator for the mature field plants.

The treatments consisted of exposing the plants to various combinations of elevated air temperatures and exposure times. Other factors included were air velocity and type of exposure, either a single exposure or two separate exposures with a delay period between exposures.

In collecting the data, the increase in temperature of a plant leaf was recorded, and the moisture loss of the leaf during a treatment was determined. The temperature response of a leaf was determined by recording the response of a 36-gauge copper-constantan thermocouple inserted in a leaf vein. The moisture loss of a leaf was determined by weighing a leaf both immediately before and after treatment. The moisture loss was then defined in terms of moisture loss per unit area as a function of air temperature and exposure time. Expressions for sensible and latent heat transfer of a leaf were formulated, and response surfaces for total heat transfer were represented in terms of air temperature and exposure time. Defoliation was described in terms of sensible and latent heat gain, and response surfaces of defoliation were presented in terms of air temperature and exposure time.

Necessary observations of total leaf area, mass, length, and width were made in order that regression equations regressing total leaf area and mass on leaf length and width could be formulated.

The temperature response of a cotton leaf was also simulated using Newtonian theory. From this simulation, an expression for the heat transfer coefficient for sensible heat transfer was formulated by a regression analysis.

Conclusions

The following conclusions are formed from the interpretation of the results.

1. Leaves with a larger area had a tendency to be more resistant to a heat treatment than were smaller leaves.
2. The significant air temperature by exposure time interaction from the AOV analysis of Series A was borne out

by the significance of these factors as independent variables in the regression equations for sensible and latent heat transfer.

3. An examination of simple effects resulted in the following:
   a) for Series A, an air temperature of 350°F (177°C), an air velocity of 4.4 m/sec, and an exposure time of two seconds yielded higher defoliation rates than did the other levels within each factor.
   b) for Series B, an air temperature of 300°F (148°C) and an exposure time of four seconds yielded higher defoliation rates than did the other levels within each factor. There was no difference between the two delay periods.
   c) for Series C, an air temperature of 350°F (177°C), an exposure time of four seconds, and a double exposure yielded higher defoliation rates than did the other levels within each factor.
4. An examination of two-factor interactions resulted in the following:
   a) for Series A, an air temperature of 400°F (204°C) with an air velocity of 4.4 m/sec and an air temperature of 350°F (177°C) with an exposure time of three seconds yielded higher defoliation rates than did the other levels within the two factor interactions.
   b) for Series B, an air temperature of 300°F (148°C) with a total exposure time of five seconds yielded higher

defoliation rates than did the other levels within the two interactions.

c) for Series C, an air temperature of 350°F (177°C) with an exposure time of four seconds and an air temperature of 350°F (177°C) with a double exposure yielded higher defoliation rates than did the other levels within the two-factor interactions.

5. In general but with overlapping boundaries:

a) heat inputs of less than 0.3 cal/cm^2 resulted in no leaf response.

b) heat inputs from 0.3 to 0.6 cal/cm^2 resulted in leaf desiccation.

c) heat inputs from 0.6 to 1.0 cal/cm^2 resulted in leaf defoliation.

d) heat inputs in excess of 1.0 cal/cm^2 resulted in plant desiccation. The rate of heat application was such that the heat input to the leaves occurred in a range of time periods from 1.0 to 5.0 seconds.

6. An ideal temperature-time exposure for a defoliation response was 850 degree-seconds above 130°F.

7. Sensible heat gain for field leaves was less than that for laboratory leaves for the same treatment. This indicated that a mature plant was more resistant to a heat treatment than a young plant, relative to plant desiccation.

8. Defoliation of leaves occurred at smaller values of sensible heat gain for the mature field leaves than for the laboratory leaves. This indicated that mature leaves are

more susceptible to defoliation than younger leaves. This is in part associated with natural senescence of the plant with age.

9. The higher the initial leaf temperature, the less the temperature increase for a given treatment. This was an observation with no statistical support.
10. Values of the heat transfer coefficient for sensible heat gain determined by simulation were of the correct order of magnitude when compared to values in the literature.
11. The significance of air velocity as an interaction with temperature and exposure time was not demonstrated.

Suggestions for Further Work

The recommendations for further study will, in most instances, require more sophisticated methods, equipment, and analysis.

1. The mass of a leaf changes with time during treatment, as moisture is lost to the environment. This variable was assummed constant in this study for sensible and latent heat determinations. Moisture loss, therefore, needs to be defined with the independent variable time included.
2. An investigation with initial leaf temperature as a factor is warranted. A hypothesis could be formulated from the fact that a plant at an initial temperature of 26^{o}C should be more able to withstand a 20 degree temperature increase than a plant with an initial temperature of 36^{o}C.
3. A factor included in this investigation, but with too narrow a range, was air velocity. With reference to Figure

12, a plot of boundary layer resistance versus air velocity, the air velocity range should be extended to include velocities in the less than 1.0 m/sec range as well as velocities in excess of 10 m/sec.

An observation of the reported literature on the effects of temperature on plants reveals that most investigations pertain to low or freezing temperatures. If heat is to become a strong competitive substitute for pest control, the effect of high temperatures for short exposure time, as opposed to drought conditions, on the plant must be investigated and defined.

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APPENDIX

ORIGINAL DATA FOR ALL TREATMENTS

Included in the Appendix are the data for all treatment series and the instrumented leaves. The symbols used on the heading in the tables are identified as follows.

Symbol	Identification	Units
AT	Heated air temperature	^{o}F
BAR	Barometer	in. Hg.
D	Delay time	sec
DB	Dry bulb temperature	^{o}F
D1	Leaf defoliated	
D2	Leaf desiccated	1 = yes
D3	Plant desiccated	0 = no
ET	Exposure time	sec
E1	1st exposure	sec
E2	2nd exposure	sec
I	Single or double exposure	1 = single 2 = double
ID	Sequence	–
ILT	Initial leaf temperature	MV*
L	Leaf length	in
LN	Leaf number	–
L1	Initial leaf count	–

Symbol	Identification	Units
L2	Leaves remaining after one week	-
L3	Number dead leaves remaining after one week	-
MA	Leaf area for moisture loss (one side)	in^2
ML	Total moisture loss	grams
MLT	Maximum leaf temperature	MV
PH	Plant height	in
RH	Relative humidity	%
TM	Time to maximum leaf temperature	sec
TM1	Time to 1st peak leaf temperature	sec
TM2	Time to 2nd peak leaf temperature	sec
TM3	Time between peak leaf temperatures	sec
T1	1st peak temperature	MV
T2	2nd initial leaf temperature	MV
VP	Velocity pressure	in. H_2O**
W	Leaf width	in

*MV referenced to 0.0°C

**Measured in center of 12 in diameter duct

TABLE XIV

ORIGINAL DATA FOR EACH TREATMENT IN SERIES A

ID	BAR	RH	DB	AT	ET	MA	ML	L1	L2	L3
1	29.90	75	92	250	2.0	0.0	0.0	12	3	0
2	29.91	77	97	300	5.0	14.12	0.0077	5	0	0
3	29.91	77	98	450	2.0	4.40	0.0380	4	0	0
4	29.91	77	100	500	3.0	5.52	0.0634	5	2	2
5	30.05	75	85	500	5.0	8.72	0.2709	9	3	3
6	30.05	75	85	300	5.0	8.88	0.0785	8	2	2
7	30.05	78	91	250	4.0	11.44	0.1022	12	0	0
8	30.05	77	88	500	2.0	11.56	0.1359	9	0	0
9	30.03	78	91	200	2.0	0.0	0.0	13	13	0
10	30.03	78	92	200	3.0	12.04	0.0224	11	8	0
11	30.03	79	93	400	3.0	10.68	0.0721	4	1	1
12	30.03	80	93	350	5.0	5.68	0.0824	9	8	8
13	30.03	79	94	400	4.0	8.00	0.1243	8	3	3
14	30.05	76	83	400	3.0	6.48	0.0787	8	0	0
15	30.05	77	84	350	4.0	4.48	0.0555	7	3	3
16	30.05	77	84	250	3.0	3.24	0.0187	10	7	0
17	30.05	77	90	300	3.0	4.56	0.0383	7	5	5
18	30.05	77	90	300	2.0	6.56	0.0624	10	4	4
19	30.05	77	92	400	2.0	7.12	0.0349	14	5	5
20	30.05	77	95	200	2.0	7.80	0.0064	10	10	0
21	30.06	78	97	400	1.0	8.24	0.0328	11	7	7
22	30.06	78	96	400	5.0	10.16	0.1798	9	5	5
23	30.06	78	96	200	5.0	9.36	0.0218	11	7	7
24	30.06	79	97	400	4.0	7.92	0.1219	9	7	7
25	30.06	79	97	300	2.0	7.32	0.0577	10	0	0
26	29.97	74	86	400	5.0	3.48	0.0837	12	8	8
27	29.97	77	99	450	1.0	8.72	0.0594	10	2	2
28	29.97	77	98	350	2.0	12.50	0.0502	8	5	5
29	29.97	75	87	500	2.0	8.64	0.0870	7	4	4
30	29.97	78	99	250	1.0	9.80	0.0198	8	8	0
31	29.97	75	90	450	4.0	1.28	0.0394	4	4	4
32	29.97	77	90	400	2.0	0.0	0.0	18	3	3
33	29.97	76	91	350	5.0	7.84	0.1055	11	4	4
34	29.97	78	98	200	4.0	11.32	0.0178	8	5	0
35	29.97	77	96	500	4.0	6.68	0.1794	13	11	11
36	29.97	77	98	450	5.0	0.0	0.0	10	9	9
37	29.97	78	98	200	1.0	8.16	0.0170	11	11	0
38	29.94	74	89	200	4.0	9.68	0.0617	7	7	7
39	29.94	74	87	500	5.0	7.68	0.2265	7	3	3
40	29.94	74	90	300	1.0	5.88	0.0158	8	8	0
41	29.94	74	92	200	3.0	12.80	0.0501	13	12	0
42	29.94	74	93	250	5.0	2.60	0.0193	12	0	0
43	29.94	74	94	200	1.0	14.08	0.0214	10	10	0
44	29.94	75	94	350	3.0	8.04	0.1087	12	0	0

TABLE XIV (Continued)

ID	BAR	RH	DB	AT	ET	MA	ML	L1	L2	L3
45	29.94	76	98	200	5.0	10.80	0.0520	9	5	5
46	29.94	73	88	450	3.0	10.72	0.1475	9	5	5
47	29.94	75	98	350	3.5	9.32	0.1190	11	5	5
48	29.94	76	99	350	1.0	12.72	0.0211	10	6	6
49	29.94	76	100	400	1.0	15.50	0.0321	12	9	0
50	29.90	75	88	350	3.0	13.52	0.1006	12	3	3
51	29.90	74	83	450	1.0	15.88	0.1572	11	10	10
52	29.90	75	88	250	2.0	4.21	0.0138	10	8	3
53	29.90	75	89	300	4.0	13.36	0.1256	7	4	4
54	29.90	74	89	250	1.0	11.28	0.0166	12	12	0
55	29.90	75	89	350	1.0	17.20	0.0463	14	13	0
56	29.90	74	90	250	3.0	11.88	0.0240	12	8	7
57	29.90	73	90	350	2.0	0.0	0.0	5	4	4
58	29.90	74	84	500	1.0	14.60	0.0135	10	9	9
59	29.90	73	90	300	3.0	13.32	0.1027	10	3	3
60	30.20	71	81	300	1.0	13.80	0.0462	11	9	0
61	30.20	71	81	250	4.0	15.04	0.1069	16	14	14
62	30.20	71	83	300	4.0	16.04	0.0651	6	6	6
63	29.90	75	86	500	1.0	0.0	0.0	11	9	0
64	29.90	75	87	500	3.0	10.40	0.1858	12	7	7
65	29.90	74	87	450	4.0	10.96	0.1727	7	6	6
66	30.20	72	83	450	3.0	7.24	0.0703	7	6	6
67	30.20	73	85	450	5.0	5.12	0.1033	12	10	10
68	30.20	73	85	500	4.0	0.0	0.0	8	8	8
69	30.20	73	86	450	2.0	13.92	0.0806	10	4	4
70	30.20	72	83	250	5.0	0.0	0.0	10	5	5
71	30.20	73	86	500	2.0	13.40	0.1133	10	4	4
72	30.00	74	89	350	4.0	7.40	0.0727	9	7	7
73	30.00	72	91	300	5.0	9.52	0.1056	9	8	8
74	30.00	73	91	200	2.0	8.52	0.0148	13	11	0
75	30.00	72	90	450	4.0	9.56	0.1805	12	12	12
76	30.00	73	90	350	1.0	0.0	0.0	8	6	5
77	30.00	72	90	450	5.0	12.50	0.2929	10	9	9
78	30.00	73	91	200	5.0	19.12	0.0355	14	14	14
79	30.06	70	87	200	3.0	9.04	0.0040	9	9	3
80	30.06	72	89	250	3.0	14.92	0.1042	8	8	8
81	30.06	69	79	450	2.0	15.60	0.0779	10	5	5
82	30.06	69	79	500	1.0	13.84	0.0287	9	9	9
83	30.06	70	80	500	3.0	10.60	0.1913	14	12	12
84	30.06	71	82	450	1.0	18.00	0.0203	10	10	10
85	30.06	72	83	500	2.0	5.72	0.0603	10	6	6
86	30.06	72	90	300	2.0	5.32	0.0115	8	6	6
87	30.06	72	90	250	3.5	10.20	0.0320	10	9	9
88	30.05	72	90	200	1.0	16.72	0.0091	10	10	0
89	30.05	73	91	400	3.0	6.24	0.0646	10	6	6
90	30.05	73	81	300	4.0	11.48	0.0578	12	11	11
91	30.05	73	92	200	2.0	3.96	0.0182	10	10	0
92	30.05	73	92	200	1.0	8.84	0.0027	11	11	0

TABLE XIV (Continued)

ID	BAR	RH	DB	AT	ET	MA	ML	L1	L2	L3
93	30.06	72	85	400	3.5	4.32	0.0527	14	9	9
94	30.02	72	86	350	2.0	11.84	0.0665	10	1	1
95	30.06	72	85	500	4.0	14.36	0.3364	8	8	8
96	30.02	69	81	450	5.0	10.44	0.2387	14	14	14
97	30.02	69	82	350	5.0	6.48	0.0676	12	5	5
98	30.02	72	88	250	1.0	7.60	0.0117	9	9	0
99	30.02	71	90	400	2.0	0.0	0.0	12	6	6
100	30.00	72	90	300	3.0	8.04	0.0552	11	5	5
101	30.00	72	92	400	2.0	11.76	0.0513	12	2	2
102	30.02	68	80	500	4.0	11.00	0.2127	7	7	7
103	30.00	73	92	300	4.0	8.00	0.0527	11	0	0
104	30.02	69	82	450	3.5	0.0	0.0	13	10	10
105	30.02	69	82	400	5.0	5.96	0.0773	11	10	10
106	30.02	69	84	400	5.0	3.16	0.0744	11	11	11
107	30.00	72	92	250	2.0	5.24	0.0066	11	10	0
108	30.02	70	86	500	1.0	10.08	0.1170	12	5	5
109	30.00	72	92	250	1.0	0.0	0.0	13	13	0
110	30.00	72	92	200	4.0	6.56	0.0048	12	9	9
111	29.94	68	79	250	4.0	15.56	0.0520	18	9	9
112	29.94	68	79	350	3.0	7.60	0.0608	10	4	4
113	29.94	72	83	500	5.0	7.20	0.2165	12	10	10
114	29.94	69	80	250	5.0	10.00	0.0513	16	4	4
115	29.94	73	85	500	5.0	4.48	0.1455	13	12	12
116	29.94	69	80	300	1.0	11.12	0.0035	8	8	0
117	29.94	69	80	200	4.0	0.0	0.0	6	6	0
118	29.94	73	86	500	3.0	4.88	0.0708	14	6	6
119	29.94	70	81	200	5.0	10.32	0.0041	17	14	0
120	29.94	71	82	350	3.5	13.88	0.1024	13	1	1
121	30.00	71	83	300	2.0	14.60	0.0565	17	9	5
122	30.00	72	85	350	2.0	6.72	0.1205	13	5	5
123	30.00	73	85	250	3.0	8.12	0.0142	10	9	9
124	30.00	73	86	250	5.0	7.40	0.0735	12	7	7
125	30.00	74	87	300	1.0	8.12	0.0040	10	10	0
126	30.00	74	87	350	5.0	9.24	0.1546	16	11	11
127	30.00	74	88	300	5.0	7.28	0.1089	14	3	3
128	30.00	75	89	350	1.0	7.84	0.0105	12	11	5
129	30.05	75	92	400	1.0	12.64	0.0496	10	4	4
130	30.05	76	94	450	3.0	0.0	0.0	12	12	12
131	30.05	76	95	450	2.0	2.92	0.0414	6	6	6
132	30.05	76	93	350	3.0	4.80	0.0530	13	5	5
133	30.05	76	93	200	3.0	5.08	0.0005	8	8	0
134	30.05	76	93	300	3.0	0.0	0.0	19	16	16
135	30.06	76	94	450	3.0	3.04	0.0708	14	14	14
136	30.06	77	94	400	3.0	5.20	0.0612	10	10	10
137	30.05	77	93	450	1.0	6.60	0.0272	13	0	0
138	30.05	77	93	250	2.0	12.32	0.0296	10	0	0
139	30.05	76	94	400	1.0	5.00	0.0149	9	0	0
140	30.06	76	93	400	4.0	0.0	0.0	16	15	15

TABLE XV

ORIGINAL DATA FOR EACH LEAF INSTRUMENTED IN SERIES A

ID	LN	ILT	MLT	TM	L	W	D1	D2	D3
1	2	1.600	2.200	2.50	2.9062	3.6250	0	0	0
1	3	1.600	2.425	2.50	2.3438	3.0000	0	0	0
1	4	1.600	2.500	3.00	2.7812	3.6250	1	0	0
1	5	1.550	2.150	2.50	2.0000	2.5312	1	0	0
2	1	1.600	3.175	4.50	2.2500	3.3750	1	0	0
2	2	1.700	3.100	5.00	2.6250	3.9688	1	0	0
2	3	1.700	3.350	5.00	2.4688	3.0625	1	0	0
2	4	1.750	3.375	6.00	2.4688	3.5625	1	0	0
2	5	1.700	3.000	5.00	2.0312	2.8750	1	0	0
3	1	1.600	3.275	3.00	1.6250	2.4062	1	0	0
3	2	1.600	2.700	3.50	1.8438	2.3750	1	0	0
3	3	1.575	3.175	4.00	1.5938	2.2500	1	0	0
3	4	1.600	3.050	3.50	1.6875	2.2812	1	0	0
5	1	1.400	4.000	5.50	2.1250	2.5625	0	1	1
5	4	1.400	3.450	5.50	2.0000	2.6562	0	1	1
6	1	1.600	3.200	4.00	2.1250	2.7500	1	0	1
6	3	1.750	3.800	4.50	2.0938	2.7812	1	0	1
6	4	1.700	4.250	4.50	1.7500	2.0625	0	1	1
6	6	1.600	3.150	5.50	2.3438	2.7812	1	0	1
7	1	1.600	2.700	5.00	2.5312	3.2188	1	0	0
7	3	1.600	2.950	4.50	2.2812	2.8438	1	0	0
7	4	1.600	2.725	5.00	2.2500	2.9688	1	0	0
7	6	1.550	3.150	4.50	2.0000	2.5312	1	0	0
8	1	1.500	2.900	3.50	2.4688	3.2500	1	0	0
8	3	1.650	3.200	3.50	2.4688	3.0000	1	0	0
8	4	1.750	3.050	3.00	1.9062	2.2500	1	0	0
8	5	1.800	3.000	3.00	2.6562	3.2656	1	0	0
8	6	1.700	3.550	3.00	2.2500	3.0312	1	0	0
9	1	1.500	1.800	2.00	2.1250	2.8750	0	0	0
9	3	1.550	1.925	3.00	1.6875	2.7188	0	0	0
9	4	1.525	1.950	2.00	1.8750	2.1875	0	0	0
9	5	1.550	2.050	2.50	1.8750	2.7812	0	0	0
9	6	1.600	2.075	2.00	2.2500	2.9375	0	0	0
10	1	1.375	2.050	3.00	2.6875	3.6875	0	0	0
10	3	1.475	2.150	3.50	1.8750	3.6250	0	0	0
10	4	1.450	2.100	3.00	2.1250	3.0312	0	0	0
10	5	1.450	2.200	3.00	3.1250	3.9062	0	0	0
10	6	1.400	1.800	3.50	2.8750	3.4062	0	0	0
11	1	1.650	3.250	3.50	2.8750	3.3125	1	0	0
11	4	1.625	3.900	3.50	2.4375	2.9375	1	0	0
11	5	1.600	3.100	3.00	2.2188	2.6875	1	0	0
12	3	1.600	3.625	10.50	1.5000	2.1250	0	1	1
12	4	1.575	4.025	9.00	1.6875	2.5000	0	1	1
12	5	1.550	4.700	6.50	2.0000	2.5312	0	1	1

TABLE XV (Continued)

ID	LN	ILT	MLT	TM	L	W	D1	D2	D3
13	1	1.500	4.250	6.50	2.1250	2.5938	1	0	1
13	3	1.600	3.400	5.50	1.3750	1.5312	1	0	1
13	4	1.525	4.700	6.00	2.1250	3.0625	1	0	1
13	5	1.550	3.425	6.00	2.5938	3.0625	0	1	1
13	6	1.525	3.550	7.00	2.6250	3.2188	1	0	1
14	1	1.400	3.675	4.00	1.8750	2.3750	1	0	0
14	3	1.350	2.900	4.50	1.7812	2.2188	1	0	0
14	5	1.450	2.975	4.50	2.0625	2.6562	1	0	0
14	6	1.375	3.200	4.00	2.0312	2.5625	1	0	0
15	1	1.600	3.100	4.00	2.0625	2.8750	0	1	0
15	3	1.625	3.350	4.50	2.3750	2.9375	0	1	0
15	5	1.650	3.300	5.00	2.2188	3.0625	1	0	0
15	6	1.600	3.300	4.50	2.0000	2.6875	1	0	0
16	1	1.225	2.175	6.00	1.8125	2.4688	1	0	0
16	3	1.350	2.250	4.00	2.3125	3.1250	1	0	0
16	4	1.350	2.675	4.00	1.3750	2.5312	0	1	0
16	5	1.400	2.450	3.50	1.5938	2.3750	1	0	0
17	3	1.450	2.375	4.00	2.1875	2.8750	0	1	0
17	4	1.400	2.250	4.00	2.4375	3.2500	0	1	0
18	1	1.400	2.525	2.50	1.7500	2.3125	0	1	0
18	4	1.425	2.300	2.50	1.6250	2.3125	0	1	0
18	5	1.450	2.400	2.50	1.9062	2.2500	0	1	0
18	6	1.450	2.600	3.00	2.0000	2.7500	1	0	0
19	4	1.350	3.100	4.00	2.5312	2.9375	1	0	0
19	5	1.350	2.450	3.50	2.3750	3.3125	0	1	0
19	6	1.400	2.475	3.00	2.3125	2.8438	0	1	0
20	1	1.475	1.950	2.00	1.9375	2.3438	0	0	0
20	3	1.525	1.950	2.00	2.1250	2.2500	0	0	0
20	4	1.475	1.875	2.50	1.6875	2.1562	0	0	0
20	5	1.525	1.925	2.00	1.7500	2.9375	0	0	0
20	6	1.575	2.750	2.00	1.7500	2.3125	0	0	0
21	1	1.250	2.400	2.50	2.0000	2.6250	1	0	0
21	4	1.300	3.150	2.00	1.8750	2.3438	0	1	0
21	5	1.325	2.150	2.00	1.8750	2.2500	1	0	0
21	6	1.325	2.225	2.50	2.0000	2.5938	0	1	0
22	1	1.600	3.550	6.50	2.3750	3.1562	1	0	1
22	3	1.550	3.450	5.50	2.6250	3.5000	0	1	1
22	4	1.575	4.650	5.00	1.5000	2.1562	0	1	1
22	5	1.550	3.850	5.50	2.9375	3.5938	1	0	1
22	6	1.500	3.300	6.50	2.9375	3.5938	1	0	1
23	3	1.575	2.650	6.50	2.4375	3.1562	1	0	0
23	4	1.600	5.675	6.00	2.1250	5.7188	0	1	0
23	5	1.600	2.450	5.00	1.9375	2.5938	0	1	0
23	6	1.550	2.525	5.50	2.2500	3.1250	0	1	0
24	5	1.750	3.525	5.00	2.0000	2.7500	0	1	1
24	6	1.700	3.600	5.00	2.5000	2.8750	0	1	1
25	1	1.750	2.850	2.50	2.2500	2.8438	1	0	0

TABLE XV (Continued)

ID	LN	ILT	MLT	TM	L	W	D1	D2	D3
25	4	1.675	2.625	2.50	1.5000	1.8750	1	0	0
25	5	1.750	2.750	2.00	2.0000	2.6875	1	0	0
25	6	1.700	3.150	2.50	2.5000	2.8438	1	0	0
26	1	1.450	3.600	6.00	1.9375	2.8750	0	1	0
26	3	1.450	3.350	6.00	2.0625	2.5625	1	0	0
26	4	1.550	3.500	5.50	2.3438	3.1250	1	0	0
26	5	1.400	3.550	6.50	1.9375	2.5625	0	1	0
26	6	1.500	3.600	6.00	1.8750	2.6250	0	1	0
27	1	1.900	2.900	2.00	2.2188	2.3750	1	0	0
27	3	1.900	4.100	1.50	2.4062	2.8125	0	1	0
27	4	2.000	3.500	2.00	2.0000	2.9062	1	0	0
27	5	1.850	2.800	1.50	2.3750	3.0000	1	0	0
28	1	1.675	2.625	3.00	2.3438	1.7188	0	1	0
28	3	1.700	2.600	4.00	1.8750	2.7188	0	1	0
28	4	1.750	3.500	2.50	1.7500	2.0000	0	1	0
28	5	1.750	2.975	2.50	2.0000	2.5312	1	0	0
28	6	1.800	2.650	3.00	2.5000	2.8125	1	0	0
29	1	1.700	3.400	2.50	2.3750	2.6875	1	0	0
29	3	1.600	3.100	3.00	1.7188	1.9062	0	1	0
29	4	1.600	3.350	3.50	2.0625	2.5000	0	1	0
29	5	1.750	3.800	3.50	2.3438	2.8125	1	0	0
29	6	1.600	3.350	2.50	2.4375	3.0000	1	0	0
30	1	1.750	2.300	1.50	2.3125	2.9375	0	0	0
30	3	1.850	2.200	1.00	2.3750	3.3125	0	0	0
30	4	1.975	2.850	1.50	2.0000	2.6250	0	0	0
30	5	1.800	2.325	1.00	2.5625	2.9688	0	0	0
30	6	1.775	2.225	1.50	2.0625	3.0000	0	0	0
31	3	1.500	5.900	8.00	1.5000	1.6250	0	1	1
31	5	1.500	3.550	5.00	2.0000	2.8750	0	1	1
32	1	1.550	2.400	1.50	2.5000	3.0000	1	0	0
32	3	1.700	2.800	3.00	2.4375	2.8750	0	1	0
32	4	1.700	3.050	2.50	2.6250	3.2500	1	0	0
32	5	1.650	2.950	2.50	2.5625	3.6250	0	1	0
32	6	1.600	2.550	2.00	2.6562	3.3125	1	0	0
33	1	1.550	3.300	5.50	2.2500	2.7812	1	0	0
33	3	1.600	3.100	5.50	1.9062	2.6250	1	0	0
33	4	1.500	3.200	7.50	2.0625	2.7500	1	0	0
33	5	1.600	3.150	5.00	1.9375	2.3125	0	1	0
33	6	1.500	3.150	5.00	2.2500	2.7812	0	1	0
34	1	1.625	2.450	2.50	2.4375	3.2500	1	0	0
34	3	1.700	2.350	4.00	1.8438	2.7188	1	0	0
34	4	1.775	2.100	3.00	2.2500	2.9375	0	0	0
34	5	1.700	2.400	4.50	2.7500	3.3750	0	0	0
35	1	1.700	5.400	6.50	1.7500	2.4688	0	1	1
35	3	1.700	4.700	7.00	1.6875	2.0000	0	1	1
35	4	1.600	4.750	5.00	2.0000	2.4688	0	1	1
35	5	1.700	3.900	6.00	1.5625	2.1250	0	1	1

TABLE XV (Continued)

ID	LN	ILT	MLT	TM	L	W	D1	D2	D3
35	6	1.650	3.850	6.00	2.0625	2.5938	0	1	1
36	1	1.700	4.050	6.50	1.7500	2.7812	0	1	1
36	2	1.850	4.950	6.50	2.1250	2.7500	0	1	1
36	3	1.700	4.750	6.50	1.5938	2.1250	0	1	1
36	5	1.800	3.700	7.00	2.1562	2.7500	0	1	1
37	1	1.600	1.900	1.00	1.7812	2.7188	0	0	0
37	3	1.650	1.900	1.50	1.9375	2.5312	0	0	0
37	4	1.650	1.850	1.50	1.9062	2.6250	0	0	0
37	5	1.650	1.900	1.00	2.0000	3.0625	0	0	0
37	6	1.700	2.275	1.00	2.0000	2.8125	0	0	0
38	1	1.400	2.300	3.50	2.5312	2.8125	0	1	0
38	4	1.450	2.225	4.00	2.0625	2.5625	0	1	0
38	5	1.500	2.325	4.00	2.5312	2.7500	0	1	0
38	6	1.400	2.200	5.00	3.0000	3.2500	0	1	0
39	1	1.800	3.650	5.00	4.1250	4.2188	1	0	0
39	5	1.600	3.600	6.50	3.7500	4.7500	1	0	0
39	6	1.700	6.000	4.50	3.7500	4.7500	0	1	0
40	4	1.475	2.100	1.50	2.0000	2.6875	0	0	0
40	5	1.450	1.875	1.00	2.0000	2.3750	1	0	0
40	6	1.400	1.775	1.00	2.3750	3.0625	0	0	0
41	1	1.475	2.050	2.50	2.6250	4.0625	0	0	0
41	3	1.525	2.000	2.00	2.7812	3.7812	0	0	0
41	4	1.575	2.025	4.00	2.7500	3.7500	0	0	0
41	5	1.525	2.075	3.00	2.5938	3.5625	0	0	0
41	6	1.475	1.900	2.50	2.3438	3.0625	0	0	0
42	1	1.475	3.000	7.50	2.3750	3.1250	1	0	0
42	3	1.500	3.250	7.00	2.0000	2.5938	1	0	0
42	4	1.500	2.900	7.00	2.1250	2.8750	1	0	0
42	5	1.525	3.250	7.50	2.0312	2.7188	1	0	0
42	6	1.500	2.650	7.50	2.0000	2.9688	1	0	0
43	4	1.500	1.800	1.50	3.0625	3.0000	0	0	0
43	5	1.500	1.725	1.00	2.8125	2.5000	0	0	0
43	6	1.500	1.675	1.00	2.7500	2.9688	0	0	0
44	3	1.700	3.200	4.50	2.6250	3.5000	1	0	0
44	4	1.750	3.250	3.50	2.6875	3.5312	1	0	0
44	5	1.750	3.500	3.50	2.2500	2.9688	1	0	0
44	6	1.700	3.100	3.00	2.3438	3.0625	1	0	0
45	1	1.450	2.375	6.00	3.3750	3.4375	0	1	0
45	3	1.600	2.500	5.50	3.0625	3.3750	0	1	0
45	4	1.550	2.375	6.00	2.7812	2.8125	0	1	0
45	5	1.600	2.400	6.00	3.0625	3.3750	1	0	0
45	6	1.625	2.325	6.50	2.6250	2.4688	1	0	0
46	1	1.600	3.150	4.00	3.1562	3.3438	1	0	0
46	3	1.550	3.300	5.00	3.2500	3.6250	0	1	0
46	4	1.650	4.000	4.50	3.2500	3.3438	1	0	0
46	5	1.700	3.350	5.00	2.7500	3.4062	1	0	0
46	6	1.500	3.300	4.50	3.2500	3.3438	1	0	0

TABLE XV (Continued)

ID	LN	ILT	MLT	TM	L	W	D1	D2	D3
47	1	1.800	3.150	5.00	2.2500	2.3125	0	1	0
47	3	1.800	3.500	4.50	2.7812	2.7188	1	0	0
47	4	1.800	3.250	5.00	3.1562	3.3438	1	0	0
47	5	1.800	3.500	5.00	2.7500	2.8750	1	0	0
47	6	1.800	3.300	5.00	3.1250	3.1250	1	0	0
48	1	1.825	2.450	1.00	2.7500	2.8438	0	1	0
48	3	1.900	2.350	1.00	2.3750	2.5625	0	1	0
48	4	1.900	2.450	2.00	2.0000	2.0938	1	0	0
48	5	1.900	2.400	2.00	2.6250	2.4062	1	0	0
48	6	1.850	2.400	2.00	2.2500	2.5312	0	1	0
49	1	1.550	2.025	1.50	2.8750	2.5625	0	0	0
49	3	1.625	2.600	1.00	3.2812	3.5000	0	0	0
49	4	1.675	2.525	1.50	2.7500	2.9375	0	0	0
49	5	1.700	2.275	1.00	2.6875	2.9375	0	0	0
49	6	1.625	2.275	0.50	2.6875	2.9375	0	0	0
50	1	1.300	2.850	5.00	2.2812	3.2344	1	0	0
50	3	1.350	3.000	5.00	1.8750	2.8125	1	0	0
50	5	1.350	2.800	3.00	2.4062	3.2500	1	0	0
50	6	1.300	2.700	4.00	2.0312	2.5312	1	0	0
51	1	1.250	2.000	1.50	2.6250	2.9062	0	1	0
51	3	1.300	2.200	1.00	3.8125	3.8125	0	1	0
51	4	1.250	2.050	1.00	3.8125	3.8125	0	1	0
51	5	1.400	2.050	1.50	4.2500	4.5312	0	1	0
52	1	1.400	2.100	3.25	2.3438	2.9375	0	1	0
52	3	1.450	2.150	4.50	3.0625	3.5312	0	1	0
52	5	1.400	2.400	2.50	3.0000	3.5000	0	1	0
52	6	1.375	1.950	3.00	3.0000	3.1250	0	1	0
53	3	1.400	2.750	5.00	2.8750	3.1406	0	1	0
53	4	1.400	3.300	4.50	3.6875	4.1562	1	0	0
53	5	1.400	2.950	5.50	3.6875	4.1562	1	0	0
53	6	1.375	2.700	5.00	2.8750	3.1406	1	0	0
54	1	1.450	1.700	0.80	2.5000	2.6875	0	0	0
54	4	1.450	1.900	1.00	2.0000	2.5000	0	0	0
54	5	1.450	1.800	1.00	2.8750	3.2188	0	0	0
54	6	1.400	1.650	0.80	2.5625	2.7500	0	0	0
55	1	1.400	2.100	1.50	2.5625	3.0000	0	0	0
55	3	1.450	2.500	1.50	3.3125	3.3125	0	0	0
55	5	1.450	2.000	1.00	2.3750	2.6875	0	0	0
56	1	1.475	2.500	3.50	2.9062	3.2500	0	1	0
56	3	1.500	2.375	4.00	3.0000	2.2188	0	1	0
56	4	1.550	2.300	4.00	2.1875	2.2500	1	0	0
56	5	1.425	2.450	3.00	2.6875	2.5625	0	1	0
57	3	1.425	2.450	3.50	2.5938	3.5000	0	1	0
57	4	1.400	2.300	4.00	2.1875	2.6875	0	1	0
57	5	1.400	2.450	3.00	2.6875	3.5000	0	1	0
59	1	1.400	2.800	3.50	2.8750	2.7188	0	1	0
59	4	1.475	2.500	4.00	2.6875	2.5625	1	0	0

TABLE XV (Continued)

ID	LN	ILT	MLT	TM	L	W	D1	D2	D3
59	5	1.425	2.225	3.50	3.1250	3.2500	0	1	0
59	6	1.400	2.700	3.50	3.3438	3.5000	0	1	0
60	1	1.275	1.650	1.00	2.6250	2.4375	0	0	0
60	3	1.275	1.825	1.25	3.5938	4.0625	0	0	0
60	4	1.250	2.025	1.50	3.1875	3.0938	0	0	0
60	5	1.275	1.700	1.00	3.5938	4.0625	0	0	0
60	6	1.250	1.700	1.00	3.3438	3.4062	0	0	0
61	1	1.200	2.600	5.00	3.2500	3.5000	0	1	0
61	3	1.325	2.775	6.00	3.0625	3.3750	1	0	0
61	5	1.200	2.700	7.00	3.0000	3.1250	0	1	0
61	6	1.250	2.100	7.00	3.0000	3.4062	0	1	0
62	3	1.200	2.900	4.50	3.0000	3.1562	0	1	0
62	4	1.200	2.900	5.00	2.7500	3.0625	0	1	0
62	6	1.150	3.175	4.50	2.7500	2.6875	0	1	0
63	1	1.200	2.150	1.00	3.0000	3.4375	0	0	0
63	3	1.300	2.450	1.50	3.7812	4.1562	0	0	0
63	5	1.250	1.800	1.50	2.8750	3.0000	0	0	0
63	6	1.200	2.050	1.50	3.3750	3.7500	0	0	0
64	1	1.500	3.200	3.00	3.1562	3.4062	0	1	0
64	3	1.400	3.250	3.50	2.5625	2.6250	0	1	0
64	4	1.400	3.450	4.00	2.2188	2.1875	1	0	0
64	5	1.400	3.500	3.50	2.8438	2.9375	0	1	0
64	6	1.500	3.400	3.00	2.8750	3.1250	1	0	0
65	1	1.350	3.250	4.00	2.7188	2.8438	1	0	1
65	4	1.300	4.600	3.00	2.7656	2.9688	0	1	1
65	5	1.200	3.850	4.50	2.0938	2.1250	0	1	1
66	4	1.500	3.300	4.00	2.5000	2.7812	0	1	0
66	5	1.500	3.200	5.00	2.7500	3.4375	0	1	0
66	6	1.300	3.050	4.50	2.6875	3.3750	0	1	0
67	1	1.300	3.600	5.50	3.3750	3.6250	1	0	0
67	4	1.400	3.300	5.00	2.8750	3.1875	0	1	0
67	6	1.500	3.400	5.00	3.5000	3.7500	1	0	0
68	1	1.400	3.600	5.00	1.8750	3.5000	0	1	1
68	3	1.300	3.500	4.50	3.2500	4.0000	0	1	1
68	4	1.400	3.800	5.50	3.2500	4.0000	0	1	1
69	1	1.200	2.550	3.50	2.6875	3.0000	1	0	0
69	4	1.300	3.450	2.00	3.6562	4.0625	0	1	0
69	6	1.200	2.900	2.50	3.6875	3.8750	0	1	0
70	1	1.350	2.600	4.50	3.1562	3.8750	0	1	0
70	3	1.300	2.275	3.50	3.6250	4.0000	0	1	0
70	5	1.400	3.075	6.00	3.6875	3.9062	1	0	0
70	6	1.325	2.700	6.00	3.6875	3.9062	0	1	0
71	1	1.400	3.150	3.00	3.3438	3.7500	0	1	0
71	4	1.400	2.750	2.50	2.6250	2.5000	1	0	0
71	5	1.500	3.600	2.50	3.0000	3.0000	1	0	0
72	3	1.350	3.250	4.00	2.1250	2.0938	1	0	0
72	4	1.400	3.750	4.00	2.0000	2.1250	0	1	0

TABLE XV (Continued)

ID	LN	ILT	MLT	TM	L	W	D1	D2	D3
73	3	1.400	5.100	5.00	3.4375	3.7812	1	0	0
73	4	1.400	5.150	5.00	3.5625	3.8750	0	1	0
73	6	1.500	5.050	5.50	3.4062	3.4375	1	0	0
74	3	1.375	1.900	2.50	2.5000	2.6250	0	0	0
74	4	1.375	2.000	1.50	2.1562	2.1875	0	0	0
74	6	1.350	1.850	2.00	2.8125	3.0000	0	0	0
75	1	1.800	3.750	4.00	3.3750	3.5000	0	1	0
75	3	1.700	3.400	4.50	3.9375	4.0000	0	1	0
75	4	1.900	3.500	4.00	3.9375	4.0000	0	1	0
75	6	1.900	3.400	5.00	3.0312	2.8750	0	1	0
76	3	1.625	2.125	1.50	1.2969	2.4688	0	0	0
76	4	1.700	2.300	1.00	2.7188	2.5156	0	1	0
77	1	1.800	4.400	3.00	2.7500	3.0312	0	1	1
77	3	1.600	4.100	5.50	2.6250	2.3438	0	1	1
77	4	1.800	3.700	5.50	2.5000	2.6250	0	1	1
77	6	1.800	3.600	4.50	3.0000	2.9062	0	1	1
78	3	1.400	2.450	6.00	3.5000	4.0000	0	1	0
78	4	1.400	2.375	5.50	3.3750	3.5312	0	1	0
78	6	1.350	2.150	6.00	2.6875	3.3125	0	1	0
79	4	1.375	1.950	2.50	3.5312	3.7500	0	0	0
79	6	1.300	1.775	3.00	4.1250	4.9688	0	0	0
80	2	1.650	2.700	4.50	3.2812	3.6719	0	1	0
80	3	1.700	2.700	3.50	3.4062	4.0000	0	1	0
80	4	1.600	2.475	4.50	3.7500	4.1562	0	1	0
81	1	1.400	3.600	3.00	3.6250	3.6562	0	1	0
81	2	1.500	3.500	2.75	3.4062	3.9375	0	1	0
81	3	1.300	3.600	2.50	3.6250	3.6562	0	1	0
81	6	1.400	3.200	1.50	3.4062	3.3750	1	0	0
82	2	1.200	2.500	1.25	3.2188	3.3125	0	1	0
82	4	1.250	2.500	1.25	2.7500	3.0625	0	1	0
82	6	1.100	2.200	1.00	3.2500	3.1875	0	1	0
83	3	1.700	3.550	3.50	2.2500	3.0000	0	1	1
83	6	1.600	3.250	3.50	2.6250	3.0625	0	1	1
84	2	1.600	2.100	2.00	3.8750	4.6875	0	1	0
84	3	1.800	2.400	1.50	3.8750	4.6875	0	1	0
84	4	1.800	2.500	2.00	3.5000	3.7812	0	1	0
84	6	1.700	2.350	1.50	3.6562	3.9375	0	1	0
85	3	1.300	3.500	2.75	3.0000	2.6250	1	0	0
85	4	1.500	3.450	2.00	3.3438	3.3750	0	1	0
85	6	1.300	3.600	2.00	3.7812	3.7188	0	1	0
86	3	1.425	2.500	3.50	2.5000	2.4375	0	1	0
86	4	1.375	2.800	3.00	2.0938	2.2031	0	1	0
86	6	1.350	2.300	2.25	1.7500	2.0625	0	1	0
87	3	1.375	2.550	5.00	2.6875	2.4688	0	1	0
87	4	1.400	2.675	3.50	2.8438	3.0781	0	1	0
87	6	1.375	2.375	4.50	1.7969	1.5938	0	1	0
88	1	1.350	1.675	1.00	2.8125	3.0625	0	0	0

TABLE XV (Continued)

ID	LN	ILT	MLT	TM	L	W	D1	D2	D3
88	3	1.400	1.700	1.00	2.4844	2.8906	0	0	0
88	4	1.375	1.725	1.00	3.3906	3.3906	0	0	0
88	6	1.325	1.600	2.00	3.4844	3.6094	0	0	0
89	1	1.500	3.125	3.50	2.4062	2.5156	0	1	0
89	2	1.500	2.850	3.00	2.6875	3.0000	0	1	0
89	3	1.550	3.100	3.50	2.3438	2.0156	1	0	0
89	6	1.500	2.975	3.50	2.3281	2.2969	1	0	0
90	1	1.575	3.100	8.00	2.3750	2.2969	0	1	1
90	2	1.550	3.350	8.00	2.8281	3.1250	0	1	1
90	4	1.450	3.400	6.00	2.6719	2.2188	0	1	1
90	6	1.500	3.450	7.50	3.0312	3.1562	1	0	1
91	1	1.300	2.025	2.00	2.3594	2.2344	0	0	0
91	3	1.325	1.900	2.00	2.3281	2.2812	0	0	0
91	4	1.350	2.025	1.75	3.1094	2.4219	0	0	0
91	6	1.300	1.875	2.25	2.2812	2.2188	0	0	0
92	3	1.425	1.875	1.50	2.6406	3.5781	0	0	0
92	4	1.400	1.850	1.50	3.2031	3.8750	0	0	0
92	6	1.400	1.775	1.75	2.0156	3.6406	0	0	0
93	1	1.850	3.300	3.50	2.4375	2.8281	0	1	1
93	2	1.700	3.550	4.00	3.2500	3.3906	1	0	1
93	3	1.800	3.550	4.50	2.9375	3.2812	1	0	1
93	4	1.950	3.400	4.50	2.9219	2.7031	1	0	1
93	6	1.700	3.000	3.50	3.1250	3.5312	1	0	1
94	2	1.350	2.400	3.50	3.2344	3.5156	1	0	0
94	3	1.375	2.325	2.25	3.1250	3.3125	1	0	0
95	2	1.850	3.400	5.00	3.5625	4.0469	1	0	1
95	3	1.700	4.350	3.00	3.6719	3.7344	0	1	1
95	4	1.600	4.200	4.50	3.1250	3.4219	0	1	1
95	6	1.700	3.300	4.50	2.6875	3.0312	0	1	1
96	1	1.600	3.800	7.50	2.1250	2.5000	0	1	1
96	2	1.400	3.550	5.50	2.7344	3.0469	0	1	1
96	3	1.500	3.700	6.50	2.8750	3.2656	0	1	1
96	4	1.600	4.050	5.50	2.6250	3.1875	0	1	1
97	2	1.400	2.800	5.00	4.7812	5.3125	0	1	0
97	3	1.500	2.850	5.50	4.7812	5.3125	0	1	0
97	6	1.400	2.400	4.00	4.1250	4.4219	0	1	0
98	2	1.500	2.000	1.00	2.8125	2.8594	0	0	0
98	3	1.550	1.950	1.00	2.0625	2.0938	0	0	0
98	5	1.500	1.900	1.50	2.1094	1.9062	0	0	0
99	2	1.250	2.650	3.00	3.7500	4.3438	0	1	0
99	3	1.450	2.600	3.00	4.3438	4.8125	0	1	0
99	5	1.300	2.400	3.00	3.6719	3.9375	1	0	0
100	2	1.425	2.650	4.00	2.6719	3.3750	0	1	0
100	3	1.475	2.575	4.00	2.0000	2.7656	1	0	0
100	5	1.450	3.100	5.00	2.6250	3.1562	1	0	0
101	2	1.450	2.600	3.00	2.1875	2.7031	1	0	0
101	3	1.500	2.850	2.50	2.6094	3.0469	1	0	0

TABLE XV (Continued)

ID	LN	ILT	MLT	TM	L	W	D1	D2	D3
101	5	1.475	2.650	2.50	2.6406	2.9531	1	0	0
102	1	1.600	3.400	5.00	3.1562	4.0000	0	1	0
102	2	1.500	3.650	5.00	3.9219	5.0000	1	0	0
102	4	1.500	5.400	4.50	3.9219	5.0000	1	0	0
102	6	1.500	3.400	5.00	3.9219	5.0000	0	1	0
103	2	1.400	3.025	5.00	3.2188	3.2969	1	0	0
103	3	1.450	2.750	4.00	3.0469	3.3438	1	0	0
103	5	1.500	2.400	5.50	3.5156	3.7188	1	0	0
104	1	1.600	3.200	3.00	2.4688	2.7812	0	1	0
104	3	1.600	2.700	2.50	3.5156	2.8281	1	0	0
104	4	1.700	3.650	2.00	3.2344	3.3750	1	0	0
104	6	1.600	4.400	3.50	3.2031	3.5781	1	0	0
105	2	1.700	3.700	5.00	2.8594	3.4375	0	1	1
105	3	1.700	3.600	4.50	2.3750	2.4062	0	1	1
105	4	1.800	3.500	5.50	3.0000	3.3594	0	1	1
105	6	1.600	3.400	5.00	3.2344	3.5469	0	1	1
106	2	1.600	3.500	6.00	2.3438	2.7344	0	1	1
106	3	1.600	3.700	6.00	2.9219	3.3438	0	1	1
106	4	1.600	4.150	6.00	2.3438	2.3125	0	1	1
106	6	1.750	3.500	5.50	2.1875	2.1719	0	1	1
107	2	1.500	2.250	2.50	2.7188	3.0469	0	0	0
107	3	1.500	2.100	3.00	2.1406	2.6875	0	0	0
107	5	1.475	2.050	2.50	2.1875	2.4062	0	0	0
108	1	1.400	2.200	1.20	2.2344	2.1094	0	1	0
108	2	1.400	2.300	2.00	3.8281	3.7969	0	1	0
108	3	1.500	2.750	1.60	2.1875	2.5000	1	0	0
108	6	1.400	2.600	1.40	3.2656	3.8281	0	1	0
109	2	1.350	1.750	1.50	2.4844	3.9531	0	0	0
109	3	1.350	1.900	1.25	1.2812	3.5000	0	0	0
110	2	1.350	2.350	5.00	2.8750	3.0156	0	1	0
110	3	1.375	2.100	4.00	2.9688	3.3438	0	1	0
110	5	1.400	2.375	4.00	3.1406	3.4688	0	1	0
111	1	1.250	2.200	7.00	3.2188	3.6719	0	1	0
111	2	1.225	2.650	5.00	3.8438	4.2188	0	1	0
111	3	1.275	2.575	5.00	3.8438	4.2188	0	1	0
111	5	1.275	2.450	5.50	3.8438	4.2188	0	1	0
112	1	1.500	2.375	4.00	3.5781	3.7031	0	1	0
112	2	1.475	2.625	4.00	3.5625	3.7812	1	0	0
112	4	1.500	3.150	4.50	3.4688	3.7188	1	0	0
113	1	1.800	3.800	5.50	3.0000	3.8125	1	0	1
113	2	1.400	3.650	7.00	3.1562	3.6875	0	1	1
113	3	1.550	3.700	7.00	3.4375	4.0000	0	1	1
113	5	1.800	5.000	5.00	3.8750	4.1719	0	1	1
114	1	1.425	2.875	5.50	2.0938	2.7812	1	0	0
114	4	1.425	2.975	6.00	2.0625	2.9062	1	0	0
114	5	1.400	2.300	5.50	1.7500	2.6406	1	0	0
115	1	2.200	3.900	5.00	2.4375	2.7188	0	1	1

TABLE XV (Continued)

ID	LN	ILT	MLT	TM	L	W	D1	D2	D3
115	2	2.000	3.850	6.00	3.0625	3.2969	0	1	1
115	4	2.300	4.400	5.50	2.6875	3.1562	0	1	1
115	5	2.000	4.000	6.00	2.6562	3.0938	0	1	1
116	1	1.300	1.800	1.00	2.6250	2.6875	0	0	0
116	4	1.400	1.900	1.50	3.0469	3.3906	0	0	0
116	5	1.400	1.825	1.00	3.0781	2.8906	0	0	0
117	2	1.250	2.175	4.50	4.0469	4.1875	0	0	0
117	3	1.275	1.975	5.00	3.4375	3.5312	0	0	0
117	4	1.300	2.250	4.50	4.5000	4.6875	0	0	0
117	5	1.250	2.175	5.00	4.5000	4.6875	0	0	0
118	2	1.400	3.300	3.00	2.8750	2.9688	1	0	0
118	3	1.500	3.550	3.00	2.2344	2.4844	1	0	0
118	4	1.550	3.500	3.50	2.9375	3.3906	1	0	0
118	5	1.550	3.800	2.50	2.6250	2.8125	1	0	0
119	1	1.250	1.750	4.00	3.2656	3.5469	0	0	0
119	2	1.200	2.375	5.50	3.2344	3.6406	0	0	0
119	3	1.200	2.250	6.00	3.2500	3.7812	0	0	0
119	5	1.200	2.150	6.50	3.3750	3.9531	0	0	0
120	1	1.450	2.800	4.50	2.6875	3.0000	0	1	0
120	3	1.400	3.000	4.50	2.3750	2.5781	1	0	0
120	4	1.500	3.000	5.50	3.0781	3.6094	1	0	0
121	1	1.550	2.525	2.50	2.8125	2.9844	0	1	0
121	2	1.500	2.200	3.00	3.1719	3.6094	0	0	0
121	5	1.525	2.075	1.50	3.3281	3.8594	0	0	0
122	1	1.675	2.800	3.50	2.9844	3.2344	0	1	0
122	5	1.500	2.500	3.00	2.7812	2.3438	0	1	0
123	1	1.500	2.100	4.00	3.0625	3.0469	0	1	0
123	2	1.500	2.300	3.50	4.2031	4.6719	0	1	0
123	3	1.550	2.575	3.00	3.6562	4.0781	0	1	0
123	5	1.500	2.300	2.50	4.2031	4.6719	0	1	0
124	1	1.575	2.625	5.50	2.8281	2.6094	0	1	0
124	2	1.475	2.975	5.50	2.5625	2.2656	1	0	0
124	3	1.525	3.025	6.00	3.1562	3.5312	0	1	0
124	5	1.500	3.050	5.00	2.9062	3.1094	1	0	0
125	1	1.475	1.975	4.00	3.0312	3.2344	0	0	0
125	5	1.425	1.825	4.00	2.9375	3.2969	0	0	0
126	2	1.500	2.950	4.50	2.7656	3.4688	1	0	1
126	3	1.650	3.775	4.00	2.7031	3.3438	1	0	1
126	5	1.600	3.300	6.00	3.1250	3.3281	1	0	1
127	1	1.700	2.900	6.00	3.0938	2.7969	1	0	0
127	3	1.675	3.450	5.50	3.4531	3.7656	1	0	0
127	5	1.625	3.350	4.00	3.3906	3.9062	1	0	0
128	2	1.450	1.950	1.50	2.7188	2.6406	0	1	0
128	3	1.525	2.125	1.50	3.2031	3.6250	1	0	0
128	5	1.600	2.050	1.50	2.7031	3.1719	0	1	0
129	2	1.550	2.100	1.00	2.6719	2.9219	0	1	0
129	3	1.700	2.450	1.00	2.6406	2.7656	0	1	0

TABLE XV (Continued)

ID	LN	ILT	MLT	TM	L	W	D1	D2	D3
129	5	1.650	2.250	2.50	3.0469	3.2969	1	0	0
130	2	1.950	3.550	3.50	2.5469	2.7344	0	1	1
130	3	2.000	3.750	3.50	2.2656	2.2031	0	1	1
131	2	2.000	3.450	2.50	2.6250	2.9688	0	1	1
131	3	2.000	3.700	2.50	2.3281	2.2969	0	1	1
131	5	1.900	3.300	3.00	2.9062	3.2031	0	1	1
132	2	1.700	3.300	3.00	2.7344	2.8906	1	0	0
132	3	1.775	3.150	3.50	2.7812	3.0938	1	0	0
132	5	1.800	3.100	4.00	2.7031	2.8750	1	0	0
133	1	1.550	2.125	3.00	3.3594	3.5469	0	0	0
133	2	1.500	2.150	3.00	3.1250	3.8281	0	0	0
133	3	1.550	2.000	3.00	3.2188	2.4531	0	0	0
133	5	1.525	1.950	3.00	2.7500	2.8438	0	0	0
134	2	1.575	2.750	2.50	2.1875	3.7500	0	1	0
134	3	1.700	2.500	2.00	3.0938	3.8281	0	1	0
134	5	1.625	2.600	3.00	2.6719	4.0469	0	1	0
135	2	1.900	3.650	4.00	1.9688	2.0156	0	1	1
135	3	1.800	3.950	3.50	1.9531	2.1719	0	1	1
136	3	2.000	3.300	3.00	2.6719	2.9531	0	1	1
136	5	2.000	3.800	3.50	2.9688	2.4531	0	1	1
137	1	1.875	2.450	3.50	2.7344	3.1719	1	0	0
137	2	1.700	2.425	3.00	3.0469	3.4219	1	0	0
137	3	1.900	2.600	2.00	3.0625	3.3438	1	0	0
137	5	1.800	2.800	2.00	2.4844	2.7500	1	0	0
138	1	1.750	2.525	3.50	2.4688	2.2812	1	0	0
138	3	1.750	2.625	2.50	2.2969	2.7812	1	0	0
138	5	1.675	1.825	3.00	2.5156	2.7812	1	0	0
139	2	1.850	2.500	1.50	2.2969	2.3438	1	0	0
139	3	1.900	2.625	1.50	2.5156	2.5781	1	0	0
139	5	1.850	2.600	2.00	2.3281	2.2969	1	0	0
140	2	1.950	3.500	4.50	2.2969	2.6406	0	1	1

TABLE XVI

ORIGINAL DATA FOR EACH TREATMENT IN SERIES B

ID	BAR	RH	DB	AT	E1	D	E2	MA	ML	L1	L2	L3
1	30.40	32	75	400	2.50	4.00	2.25	0.0	0.0	10	1	1
2	30.40	32	73	250	2.40	4.00	2.25	6.84	0.0308	9	1	1
3	30.40	32	74	350	1.50	3.75	1.40	8.88	0.0285	10	2	2
4	30.40	32	74	300	2.30	4.00	2.30	7.04	0.0255	10	0	0
5	30.40	32	73	300	1.60	2.75	2.25	6.44	0.0299	10	3	3
6	30.40	32	74	300	2.00	3.90	2.00	7.44	0.0393	10	7	7
7	30.40	32	73	250	1.60	4.00	1.75	6.28	0.0209	10	5	5
8	30.40	32	73	250	2.00	2.50	2.25	11.20	0.0262	9	7	7
9	30.40	34	75	400	2.40	4.00	2.40	7.28	0.0820	8	1	1
10	30.40	34	75	300	1.40	2.50	1.60	8.44	0.0186	10	8	8
11	30.40	34	73	250	1.60	2.50	2.00	8.92	0.0250	10	5	5
12	30.40	34	72	250	2.25	4.00	2.50	13.40	0.0200	12	8	8
13	30.40	34	73	250	1.25	2.50	1.50	0.0	0.0	12	12	7
14	30.40	34	73	400	1.90	2.50	2.10	3.96	0.0517	10	2	2
15	30.00	32	70	400	2.00	2.50	2.25	7.92	0.0630	10	4	4
16	30.00	32	68	350	1.40	2.50	1.75	9.64	0.0511	10	9	9
17	29.96	34	76	300	1.40	3.50	1.50	0.0	0.0	11	2	2
18	29.96	34	74	250	2.00	2.60	2.50	3.64	0.0099	10	2	2
19	29.96	34	74	400	1.25	3.75	1.10	0.0	0.0	11	7	7
20	29.95	33	76	350	1.75	2.60	2.10	5.80	0.0501	13	3	3
21	29.95	33	77	400	2.40	2.60	2.50	5.44	0.0738	8	3	3
22	29.95	33	78	250	1.50	2.50	1.50	5.16	0.0305	10	3	3
23	29.95	33	78	350	1.40	2.50	1.50	5.08	0.0200	11	3	3
24	29.95	33	78	250	2.20	2.50	2.50	5.80	0.0182	12	3	3
25	29.94	38	72	300	2.25	4.00	1.40	10.00	0.0034	13	4	4
26	29.94	38	72	250	1.25	3.75	1.40	0.0	0.0	9	5	5
27	29.94	38	73	350	1.90	2.50	2.40	4.72	0.0165	9	3	3
28	29.94	39	73	300	2.50	2.50	2.50	2.84	0.0192	9	0	0
29	29.94	40	72	350	2.10	2.50	2.50	7.76	0.0720	9	4	4
30	29.94	40	73	250	1.90	4.00	1.70	10.52	0.0399	8	6	6
31	29.94	40	72	400	1.50	2.50	1.50	5.96	0.0317	9	7	7
32	29.96	41	74	400	2.10	2.60	2.50	0.0	0.0	8	5	5
33	29.96	37	76	250	1.40	3.90	1.50	5.28	0.0071	10	7	3
34	29.96	37	76	300	2.50	2.55	2.55	6.56	0.0465	10	1	1
35	29.94	37	76	400	1.25	2.50	1.50	4.84	0.0465	7	1	1
36	29.94	36	78	350	1.40	3.75	1.30	2.92	0.0125	7	0	0
37	29.94	36	78	400	2.00	3.75	2.00	3.08	0.0339	10	0	0
38	29.94	36	78	300	1.25	2.50	1.55	5.72	0.0270	12	3	3
39	29.96	36	78	350	2.10	4.00	2.30	7.20	0.0800	10	2	2
40	29.96	36	78	350	2.30	2.50	2.55	2.84	0.0292	8	2	2
41	29.93	47	76	400	1.25	3.75	1.40	8.20	0.0530	10	7	7
42	29.93	44	77	350	2.10	4.00	2.25	5.24	0.0491	10	8	8
43	29.93	41	77	300	1.75	2.50	2.00	6.20	0.0236	8	6	6
44	29.93	38	78	400	1.90	3.90	1.90	7.68	0.0313	10	6	6
45	29.93	37	78	300	1.75	4.00	1.90	0.0	0.0	10	1	1
46	29.93	35	78	350	1.80	4.00	1.75	4.96	0.0305	10	4	4
47	29.93	33	78	300	2.50	4.00	2.30	6.36	0.0378	10	5	5
48	29.93	32	78	350	1.80	3.75	2.00	5.72	0.0620	9	7	7

TABLE XVII

ORIGINAL DATA FOR EACH LEAF INSTRUMENTED IN SERIES B

ID	LN	ILT	T1	T2	MLT	TM1	TM2	TM3	L	W	D1	D2
1	1	0.95	1.95	1.95	3.05	4.50	2.50	4.50	2.906	2.781	1	0
1	3	0.95	2.40	1.15	3.48	5.75	3.25	3.25	3.625	3.750	1	0
2	1	1.05	1.81	1.80	2.49	4.00	3.25	6.25	2.875	3.687	0	1
2	2	0.95	1.75	1.75	2.45	4.75	3.00	5.75	3.500	3.375	1	0
2	3	1.05	2.28	2.14	3.12	3.00	3.00	7.75	3.750	3.687	1	0
3	1	1.06	1.98	1.94	2.85	3.00	2.00	5.25	3.437	3.844	1	0
3	2	1.00	2.02	2.02	2.85	4.00	2.50	4.00	3.375	3.687	1	0
3	3	1.08	1.90	1.15	2.42	5.75	3.25	3.25	3.406	3.937	0	1
4	1	0.90	2.55	2.40	3.35	3.25	2.75	5.75	3.375	3.375	1	0
4	2	1.00	1.96	1.95	2.70	4.50	3.25	5.75	3.000	3.406	1	0
4	3	1.07	2.40	2.35	3.20	3.75	2.75	5.00	3.625	3.062	1	0
5	1	1.02	1.88	1.88	3.28	4.50	3.20	3.20	3.250	3.125	1	0
5	2	1.10	1.75	1.75	2.90	5.00	3.00	3.00	2.781	3.125	1	0
5	3	1.06	1.70	1.70	2.82	4.50	3.00	3.00	2.750	2.968	0	1
6	1	1.00	1.74	1.74	2.40	3.00	2.50	6.00	3.000	3.375	0	1
6	3	1.01	1.74	1.74	2.42	5.00	3.75	5.50	4.250	3.562	0	1
7	1	0.96	1.80	1.80	2.24	4.50	2.50	2.50	3.250	3.625	1	0
7	2	1.02	2.02	2.02	2.68	3.50	3.00	5.00	3.750	3.250	1	0
7	3	0.98	1.92	1.92	2.61	4.25	2.10	2.10	2.906	3.750	0	1
8	1	1.00	2.05	2.05	2.68	3.00	2.75	4.25	3.406	3.437	0	1
8	2	1.04	2.01	2.01	2.72	3.25	3.00	4.50	2.312	2.500	0	1
8	3	1.01	1.94	1.94	2.65	4.25	3.60	3.60	3.343	4.062	0	1
9	1	0.95	2.05	2.05	3.02	4.50	4.75	4.75	4.000	3.250	0	1
9	2	0.96	1.98	1.98	3.15	4.00	4.50	4.50	2.719	3.062	1	0
9	3	0.98	2.24	2.24	3.30	4.50	4.00	4.00	2.125	2.219	1	0
10	1	1.04	1.98	1.98	2.84	2.00	2.25	3.50	3.594	3.531	0	1
10	2	1.10	1.60	1.60	2.10	3.00	3.50	4.50	3.406	3.625	0	1
10	3	1.14	1.88	1.75	2.32	1.30	3.00	6.00	3.000	3.812	0	1
11	1	1.10	1.60	1.60	2.26	3.60	3.90	3.90	3.906	4.375	0	1
11	2	1.02	1.62	1.62	2.40	2.50	3.50	3.50	4.437	3.906	0	1
11	3	1.15	1.75	1.75	2.20	2.00	3.25	5.50	2.500	2.312	0	1
12	1	1.15	1.80	1.75	2.38	3.50	3.50	8.50	3.000	3.312	0	1
12	2	1.15	1.75	1.75	2.50	3.00	4.00	8.00	3.625	3.375	1	0
12	3	1.15	1.80	1.80	2.42	4.00	3.00	4.50	3.375	3.875	1	0
13	1	1.05	1.48	1.48	2.00	2.00	2.25	4.25	3.000	3.750	0	1
13	2	1.06	1.39	1.39	1.78	3.90	3.75	3.75	2.844	3.156	0	0
13	3	1.10	1.50	1.50	1.82	4.00	4.00	4.00	3.062	3.719	0	0
14	1	0.95	2.42	2.42	3.45	5.00	3.75	3.75	2.750	2.625	0	1
14	2	1.00	2.45	2.45	3.58	5.75	3.25	3.25	2.156	2.406	1	0
14	3	1.04	2.65	2.42	3.48	4.50	3.00	4.75	2.719	2.875	1	0
15	1	1.02	2.60	2.60	3.50	3.00	2.50	2.50	3.312	3.500	0	1
15	2	0.98	1.85	1.85	3.21	2.50	3.50	3.50	3.812	3.500	0	1
15	3	1.00	2.14	2.14	2.90	4.00	3.00	3.00	3.687	3.500	0	1

TABLE XVII (Continued)

ID	LN	ILT	T1	T2	MLT	TM1	TM2	TM3	L	W	D1	D2
16	1	1.18	1.96	1.95	2.73	2.25	2.25	4.00	3.750	4.046	0	1
16	2	1.15	1.98	1.96	2.71	2.75	3.00	4.50	3.812	4.594	0	1
16	3	1.21	2.40	2.40	3.25	2.75	2.25	3.50	3.406	3.375	0	1
17	3	1.12	2.02	2.00	2.62	1.75	1.50	4.00	1.875	2.594	1	0
17	5	1.10	1.70	1.70	2.08	3.00	2.00	3.50	2.500	2.906	0	1
18	2	1.10	1.50	1.50	2.05	3.50	5.00	7.50	2.500	3.000	0	1
18	3	1.13	1.82	1.80	2.50	2.50	2.25	5.75	1.969	3.375	1	0
18	5	1.10	1.89	1.89	2.32	5.00	3.00	3.00	3.625	3.875	0	1
19	2	1.20	2.18	2.14	2.92	2.75	2.25	4.50	2.875	3.125	0	1
19	3	1.22	2.27	2.25	3.18	4.00	2.00	4.50	3.125	3.656	0	1
19	5	1.19	2.07	2.07	2.81	4.50	2.00	2.00	3.500	4.000	1	0
20	2	1.11	2.00	2.00	2.81	4.00	3.50	3.50	3.500	3.562	0	1
20	3	1.20	2.05	2.05	2.92	5.00	3.25	3.25	2.375	2.719	0	1
20	5	1.19	2.14	2.14	2.94	4.50	3.50	3.50	3.125	3.625	0	1
21	2	1.22	2.88	2.85	3.50	3.50	2.75	4.50	3.281	3.156	1	0
21	3	1.40	2.71	2.71	3.60	6.00	3.50	3.50	3.125	2.656	1	0
21	5	1.35	2.70	2.70	3.47	5.00	3.50	3.50	2.750	2.812	1	0
22	2	1.35	1.96	1.95	2.46	2.00	2.00	4.00	3.062	2.687	0	1
22	3	1.38	1.90	1.90	2.32	4.40	3.50	3.50	2.125	2.437	1	0
22	5	1.34	1.90	1.90	2.52	3.75	2.50	2.50	3.125	2.656	1	0
23	2	1.05	1.60	1.60	2.20	3.00	4.00	4.00	2.875	3.125	1	0
23	3	1.14	1.90	1.90	2.70	2.25	3.00	3.00	2.375	3.125	0	1
23	5	1.10	2.42	2.42	3.19	4.00	2.00	2.00	2.594	2.812	1	0
24	2	1.10	1.69	1.69	2.19	5.75	5.50	5.50	3.125	3.250	1	0
24	3	1.18	2.00	2.00	2.67	4.00	2.50	2.50	3.125	3.125	1	0
24	5	1.20	1.92	1.92	2.55	5.00	4.00	4.00	3.375	3.687	0	1
25	2	1.09	2.25	2.20	2.62	4.00	2.60	5.00	3.062	3.625	1	0
25	3	1.12	2.72	2.60	3.12	3.75	2.00	4.50	3.125	3.625	0	1
25	5	1.25	2.25	2.25	2.70	4.00	2.25	4.75	2.375	2.750	1	0
26	2	1.00	1.52	1.52	2.00	3.50	3.25	3.25	3.875	3.437	0	1
26	3	1.15	1.60	1.60	2.02	4.25	3.50	3.50	3.062	3.562	0	1
26	5	1.08	1.72	1.70	2.25	2.50	2.25	4.50	2.250	3.125	0	1
28	2	0.92	2.00	2.00	2.96	3.50	3.75	3.75	2.031	2.500	1	0
28	3	0.90	1.75	1.75	2.51	4.75	3.75	3.75	2.750	3.000	1	0
28	5	0.95	1.90	1.90	2.74	4.50	4.00	4.00	2.562	3.156	1	0
29	2	1.00	2.01	2.01	2.88	5.00	3.50	3.50	2.281	2.875	1	0
29	3	1.00	2.14	2.14	2.92	5.00	4.50	4.50	3.375	4.125	0	1
29	5	1.02	2.35	2.35	3.10	4.25	3.25	3.25	2.781	3.500	0	1
30	2	1.04	1.60	1.60	2.15	5.00	3.40	3.40	2.875	3.312	1	0
30	3	1.10	1.69	1.68	2.15	3.00	3.50	6.00	2.281	2.625	0	1
30	5	1.16	1.63	1.61	2.15	2.90	2.50	6.50	3.625	3.500	0	1
31	3	0.95	1.85	1.85	2.88	4.00	2.50	2.50	3.062	3.500	0	1
31	5	1.02	2.08	2.02	2.72	1.75	1.70	4.75	2.250	2.625	1	0
33	2	1.05	1.45	1.45	1.98	5.00	1.75	1.75	3.500	3.125	0	0

TABLE XVII (Continued)

ID	LN	ILT	T1	T2	MLT	TM1	TM2	TM3	L	W	D1	D2
33	3	1.11	1.78	1.74	2.12	2.75	1.00	3.75	2.906	3.500	0	1
33	5	1.05	1.60	1.60	2.02	4.25	1.50	1.50	4.125	4.000	0	1
34	2	1.05	2.15	2.15	2.76	4.00	2.50	2.50	2.344	3.000	1	0
34	3	1.10	2.28	2.28	3.16	4.50	2.75	2.75	3.156	3.094	1	0
34	5	1.10	2.10	2.10	2.90	4.00	2.75	2.75	2.219	2.562	1	0
35	3	1.25	2.30	2.30	3.04	3.40	2.70	2.70	2.344	2.375	1	0
35	5	1.25	2.40	2.40	3.40	2.50	2.00	3.00	1.656	1.750	1	0
36	2	1.25	1.99	1.99	2.32	4.25	2.75	4.25	2.250	2.812	1	0
36	3	1.38	2.10	2.10	2.64	5.50	2.75	2.75	3.562	3.344	1	0
36	5	1.29	2.08	2.08	2.68	4.25	2.75	2.75	2.906	3.344	1	0
37	2	1.25	2.45	2.45	3.25	4.75	2.50	2.50	3.000	3.250	1	0
37	3	1.25	2.26	2.25	3.31	3.25	2.00	4.10	2.375	2.625	1	0
37	5	1.28	2.40	2.38	3.25	3.40	2.10	5.10	3.250	3.125	1	0
38	2	1.08	1.70	1.70	2.20	2.75	2.40	2.40	2.219	2.594	0	1
38	3	1.12	1.72	1.72	2.22	3.50	3.00	3.00	3.187	3.125	0	1
38	5	1.15	1.89	1.89	2.39	3.00	5.50	5.50	1.719	2.187	1	0
39	2	1.08	2.30	2.30	3.19	4.50	2.75	2.75	2.250	2.469	1	0
39	3	1.10	2.04	2.04	3.01	4.00	2.25	2.25	3.187	3.375	1	0
40	2	1.15	2.10	2.10	2.90	5.00	4.00	4.00	1.875	2.687	1	0
40	3	1.13	2.20	2.20	3.03	4.40	2.50	2.50	2.562	2.875	1	0
40	5	1.20	2.25	2.25	3.06	4.25	3.25	3.25	2.812	3.062	0	1
41	2	1.04	1.85	1.85	2.75	5.00	3.00	3.00	3.312	3.906	0	1
41	3	1.22	2.14	2.14	3.01	5.50	2.60	2.60	3.250	3.625	0	1
41	5	1.12	2.40	2.40	3.30	3.00	2.25	4.75	2.000	2.906	1	0
42	2	1.08	2.38	2.38	3.30	6.50	3.00	3.00	2.500	2.781	1	0
42	3	1.18	2.48	2.48	3.15	7.00	3.50	3.50	3.156	3.937	0	1
42	5	1.12	2.55	2.55	3.20	6.00	3.00	3.00	3.125	3.406	1	0
43	2	1.09	1.78	1.78	2.48	3.40	3.90	3.90	3.312	3.625	1	0
43	3	1.13	1.80	1.80	2.49	3.40	2.95	2.95	2.625	2.906	0	1
43	5	1.10	1.96	1.96	2.72	2.00	2.10	3.60	3.312	3.812	0	1
44	2	1.08	1.90	1.90	2.65	4.50	4.00	4.00	2.125	2.875	1	0
44	3	1.14	2.20	2.20	3.10	4.00	2.50	2.50	3.750	4.312	0	1
44	5	1.18	2.08	2.08	2.98	4.50	3.25	3.25	3.625	3.781	1	0
45	2	1.12	1.94	1.94	2.58	4.75	3.50	3.50	3.250	3.000	0	1
45	3	1.16	1.99	1.99	2.68	4.50	2.75	2.75	2.250	2.375	1	0
45	5	1.25	2.18	2.18	2.86	5.50	2.75	2.75	2.875	3.031	1	0
46	2	1.00	2.25	2.25	2.94	5.00	2.50	2.50	2.750	3.062	0	1
46	3	1.13	2.26	2.25	3.02	3.00	3.60	5.60	2.625	3.375	0	1
46	5	1.05	2.20	2.20	3.00	5.00	3.00	3.00	3.500	2.750	1	0
47	2	1.02	1.94	1.92	2.46	4.10	3.00	5.50	3.125	3.437	1	0
47	3	1.08	2.33	2.24	3.25	3.00	2.75	6.60	3.875	3.250	0	1
47	5	1.10	2.08	2.08	2.62	3.75	3.00	6.25	3.375	3.812	1	0
48	3	1.10	2.21	2.21	2.95	4.50	2.75	2.75	2.687	2.844	0	1
48	5	1.10	2.38	2.38	3.36	4.50	2.50	2.50	4.062	3.875	0	1

TABLE XVIII

ORIGINAL DATA FOR EACH TREATMENT IN SERIES C

ID	RH	DB	AT	ET	MA	ML	L1	L2	L3	I
1	28	75	400	2.00	0.0	0.0600	17	1	1	2
2	41	75	350	2.25	14.96	0.1880	15	10	5	2
3	47	74	300	4.00	10.00	0.0555	19	11	5	1
4	41	76	400	2.25	12.68	0.0839	14	10	7	2
5	40	72	400	2.50	9.48	0.1289	19	18	18	1
6	50	73	250	3.75	7.96	0.0250	15	13	11	2
7	28	75	300	3.75	11.04	0.0544	13	4	4	2
8	39	72	250	1.75	0.0	0.0	12	12	0	1
9	32	74	350	4.00	12.84	0.1239	16	3	3	2
10	32	74	300	3.50	0.0	0.0	12	8	5	1
11	31	74	350	4.00	6.96	0.0626	14	5	5	2
12	31	74	300	3.25	0.0	0.0	19	14	11	2
13	31	74	350	3.00	6.04	0.0038	6	2	2	2
14	28	74	250	3.00	15.08	0.0226	21	20	15	2
15	28	74	300	3.00	7.96	0.0631	24	10	10	2
16	28	74	350	2.75	8.72	0.1042	18	8	8	1
17	28	74	400	4.00	11.36	0.1934	20	2	2	1
18	29	74	250	1.75	7.24	0.0202	20	20	2	1
19	29	74	300	4.00	7.40	0.0700	21	11	11	2
20	29	74	400	2.75	11.20	0.1210	18	10	10	1
21	29	74	250	4.00	11.96	0.0611	18	9	9	2
22	29	74	400	3.00	0.0	0.0	9	6	6	2
23	29	74	350	3.15	10.64	0.0486	19	9	9	1
24	29	74	250	2.75	9.28	0.0078	16	15	14	1
25	29	71	250	3.75	6.28	0.0412	22	17	15	1
26	28	74	400	4.00	9.80	0.0998	20	4	4	1
27	28	72	350	1.75	8.40	0.0516	22	15	15	2
28	28	72	250	3.00	7.76	0.0242	14	11	10	2
29	28	72	350	2.00	7.28	0.0457	28	22	21	1
30	28	72	400	3.00	10.56	0.0742	16	8	7	2
31	28	73	400	2.75	8.96	0.0921	21	11	11	1
32	28	73	400	3.75	7.68	0.0926	19	11	11	2
33	28	73	300	1.75	4.96	0.0182	15	13	12	1
34	29	73	300	2.85	11.72	0.0608	17	8	8	1
35	29	73	250	2.50	9.28	0.0175	19	19	9	2
36	30	74	350	4.00	8.52	0.0981	22	12	12	1
37	32	71	350	3.65	5.56	0.0361	18	6	6	1
38	32	73	350	2.00	6.48	0.0227	17	13	12	1
39	32	73	250	2.75	6.60	0.0273	31	22	21	1
40	32	73	400	3.50	0.0	0.0	7	5	5	2
41	33	72	400	2.00	8.20	0.0341	26	21	21	1
42	33	72	300	2.00	13.32	0.0155	26	25	24	2
43	34	71	250	2.00	7.40	0.0134	15	15	8	2
44	34	71	300	2.25	9.00	0.0170	22	22	18	2
45	34	71	250	4.00	6.48	0.0154	19	17	17	1
46	35	72	350	3.00	9.48	0.0471	17	12	12	2
47	35	72	300	2.00	10.64	0.0129	20	19	14	1
48	35	74	300	4.00	5.28	0.0242	16	11	11	1

TABLE XIX

ORIGINAL DATA FOR EACH LEAF INSTRUMENTED IN SERIES C

ID	LN	ILT	T1	T2	MLT	TM1	TM2	L	W	D1	D2	D3
1	1	0.75	1.30	1.25	1.70	1.50	1.50	3.3215	3.2500	1	0	0
1	2	0.75	1.00	1.00	1.30	1.50	1.25	3.6250	3.6250	1	0	0
1	3	0.80	1.05	1.05	1.20	1.50	1.25	3.0000	3.0938	1	0	0
2	1	1.45	2.02	2.00	2.62	2.00	1.50	4.4375	5.7500	0	1	0
2	2	1.35	1.95	1.95	2.40	3.50	2.00	3.7812	5.5000	1	0	0
2	3	1.50	2.10	2.10	2.52	4.00	1.25	3.5000	3.8750	0	1	0
3	1	1.15	0.0	0.0	3.58	5.50	0.0	2.9062	3.0625	1	0	0
3	2	1.17	0.0	0.0	2.75	6.00	0.0	3.1250	3.6250	1	0	0
3	3	1.25	0.0	0.0	2.45	6.00	0.0	3.3750	3.9688	1	0	0
4	1	1.25	2.22	2.22	3.05	3.00	1.25	3.9375	4.4062	1	0	0
4	2	1.08	1.88	1.88	2.68	3.00	1.75	3.8438	4.3750	1	0	0
4	3	1.22	2.12	2.10	3.77	1.75	2.00	3.2500	3.9688	0	1	0
5	1	1.85	0.0	0.0	3.80	5.00	0.0	3.9375	4.5625	0	1	1
5	2	1.67	0.0	0.0	3.18	5.00	0.0	3.9375	4.5000	0	1	1
5	3	1.73	0.0	0.0	3.22	4.25	0.0	3.0312	3.7500	0	1	1
6	1	1.08	1.75	1.75	2.75	2.50	2.00	3.0000	3.4375	0	1	0
6	2	1.15	1.77	1.77	2.85	3.00	2.00	3.5000	3.1562	1	0	0
6	3	1.17	2.70	2.45	3.10	2.25	2.50	3.9375	4.5000	0	1	0
7	1	1.15	2.43	2.40	3.65	2.00	2.50	2.8438	3.0000	1	0	0
7	2	1.05	1.90	1.90	2.55	4.00	3.00	3.3125	3.7500	0	1	0
8	1	1.25	0.0	0.0	1.77	3.75	0.0	4.3438	4.7500	0	1	0
8	2	1.22	0.0	0.0	1.80	2.50	0.0	4.4375	4.7500	0	0	0
8	3	1.25	0.0	0.0	1.88	2.75	0.0	3.3750	3.5000	0	0	0
9	1	1.12	2.07	2.07	2.65	7.00	2.00	3.8750	4.5000	1	0	0
9	2	1.20	2.20	2.20	2.82	7.00	3.00	3.0000	3.2500	1	0	0
10	1	1.25	0.0	0.0	2.30	5.50	0.0	3.8750	4.0000	0	1	0
10	2	1.15	0.0	0.0	2.65	2.75	0.0	3.9375	4.5000	1	0	0
11	2	1.10	2.10	2.10	2.95	3.25	2.50	3.6250	4.0000	1	0	0
11	3	1.20	2.05	2.05	2.88	4.75	3.00	3.3750	3.5000	1	0	0
12	1	1.05	1.80	1.78	2.98	1.00	2.25	3.2188	3.6406	0	1	0
12	2	1.00	1.72	1.72	2.60	4.00	2.00	3.0938	3.7656	1	0	0
12	3	1.07	1.70	1.70	2.28	5.00	2.50	3.4844	4.0312	0	1	0
14	1	1.25	1.75	1.75	2.15	5.50	3.00	3.1875	3.5000	0	1	0
14	2	1.25	1.70	1.70	2.02	3.00	2.25	3.7188	4.2344	0	1	0
14	3	1.25	1.70	1.70	2.10	3.00	3.50	2.7656	3.1719	0	1	0
15	1	1.00	1.55	1.55	2.50	4.75	3.50	3.5938	4.3906	0	1	0
15	2	1.18	1.75	1.75	2.25	6.25	2.50	3.5000	4.2188	0	1	0
15	3	1.25	1.95	1.95	2.50	4.00	3.00	3.7500	3.9531	1	0	0
16	1	1.68	0.0	0.0	2.92	3.50	0.0	3.2812	3.7031	0	1	0
16	2	1.70	0.0	0.0	2.75	3.00	0.0	3.0312	3.1719	1	0	0
16	3	1.70	0.0	0.0	2.55	3.50	0.0	3.5312	4.3438	0	1	0
17	1	1.60	0.0	0.0	3.00	5.25	0.0	2.8594	3.4531	1	0	0

TABLE XIX (Continued)

ID	LN	ILT	T1	T2	MLT	TM1	TM2	L	W	D1	D2	D3
17	2	1.60	0.0	0.0	3.10	5.00	0.0	3.2031	3.5312	1	0	0
17	3	1.50	0.0	0.0	3.90	4.50	0.0	2.9062	3.1875	1	0	0
18	1	1.22	0.0	0.0	1.75	4.00	0.0	3.0938	3.8750	0	0	0
18	2	1.28	0.0	0.0	1.70	4.00	0.0	3.2188	4.0000	0	0	0
18	3	1.30	0.0	0.0	1.90	3.50	0.0	3.8125	4.2500	0	0	0
19	1	1.20	2.10	2.05	2.60	3.50	2.00	3.2969	3.9531	0	1	0
19	2	1.05	1.67	1.67	2.40	2.50	2.50	3.0938	3.5938	0	1	0
19	3	1.10	2.15	2.05	3.10	2.25	2.25	3.1056	3.7812	1	0	0
20	1	1.43	0.0	0.0	3.35	3.50	0.0	2.9219	3.3281	0	1	0
20	2	1.35	0.0	0.0	2.75	3.50	0.0	3.7969	3.8125	1	0	0
20	3	1.40	0.0	0.0	2.63	4.50	0.0	3.0938	3.7500	0	1	0
21	1	1.10	0.0	0.0	3.35	6.00	0.0	3.2500	3.7812	1	0	0
21	2	1.20	0.0	0.0	3.75	8.00	0.0	2.7188	3.4844	1	0	0
21	3	1.18	0.0	0.0	3.42	7.00	0.0	3.1562	3.6250	0	1	0
22	1	1.20	2.30	2.30	3.15	4.25	2.50	2.8906	3.0938	0	1	0
22	2	1.10	2.10	2.10	2.87	4.00	2.50	3.3438	3.7031	0	1	0
22	3	1.10	1.90	1.90	2.65	4.50	2.50	3.3281	3.4688	0	1	0
23	1	1.35	0.0	0.0	3.20	3.50	0.0	3.2031	3.3281	1	0	0
23	2	1.37	0.0	0.0	2.90	4.00	0.0	2.7812	3.5469	0	1	0
23	3	1.35	0.0	0.0	3.50	3.50	0.0	3.1719	3.9844	0	0	0
24	1	1.40	0.0	0.0	2.23	4.00	0.0	3.2188	3.2812	0	1	0
24	2	1.33	0.0	0.0	2.17	3.50	0.0	3.2812	3.7188	0	1	0
24	3	1.35	0.0	0.0	2.10	5.75	0.0	3.5938	4.1406	0	1	0
25	1	1.30	0.0	0.0	2.22	3.50	0.0	3.5938	4.0000	0	1	0
25	2	1.32	0.0	0.0	2.10	5.00	0.0	3.8750	4.5000	0	1	0
25	3	1.30	0.0	0.0	2.40	3.00	0.0	3.7812	3.7500	0	1	0
26	1	1.30	0.0	0.0	3.05	4.00	0.0	3.8125	4.2500	1	0	0
26	2	1.25	0.0	0.0	3.30	5.25	0.0	3.2500	3.8750	1	0	0
26	3	1.55	0.0	0.0	3.70	4.00	0.0	3.3750	3.3750	1	0	0
27	1	1.05	1.80	1.80	2.40	3.25	1.25	3.2500	3.8750	0	1	0
27	2	0.95	1.65	1.65	2.15	2.50	1.50	3.2500	3.5000	0	1	0
27	3	1.10	1.70	1.70	2.50	3.00	1.00	3.9062	4.2188	0	1	0
28	1	1.18	1.60	1.60	2.10	2.50	2.25	3.4531	3.9531	0	1	0
28	2	1.10	1.50	1.50	1.95	1.50	2.75	3.2344	3.6719	0	1	0
28	3	1.10	1.60	1.60	2.15	2.50	3.00	3.2031	3.1406	0	1	0
29	1	1.20	0.0	0.0	2.20	2.50	0.0	3.2656	3.8438	0	1	0
29	2	1.10	0.0	0.0	2.10	3.00	0.0	3.1719	3.5469	0	1	0
29	3	1.10	0.0	0.0	2.35	2.75	0.0	3.5938	3.9688	0	1	0
30	1	1.10	2.10	2.10	3.10	2.50	1.75	3.2969	3.4219	1	0	0
30	2	1.10	2.20	2.20	2.80	4.00	1.25	3.3906	3.7969	0	1	0
30	3	1.10	2.48	2.48	3.17	4.00	1.75	3.4062	2.8438	1	0	0
31	1	1.40	0.0	0.0	3.30	3.50	0.0	2.7344	3.4219	0	1	0
31	2	1.40	0.0	0.0	3.20	2.75	0.0	3.4062	3.5938	1	0	0
31	3	1.50	0.0	0.0	3.20	3.75	0.0	2.7969	2.5781	1	0	0
32	1	1.25	2.40	2.40	3.15	5.00	2.75	2.6562	3.2812	1	0	0
32	2	1.20	2.32	2.32	3.20	5.00	3.00	2.3125	2.6094	1	0	0
32	3	1.25	2.30	2.30	3.20	4.25	2.75	3.2188	2.7969	0	1	0

TABLE XIX (Continued)

ID	LN	ILT	T1	T2	MLT	TM1	TM2	L	W	D1	D2	D3
33	1	1.40	0.0	0.0	2.00	3.50	0.0	2.8438	3.1094	0	1	0
33	2	1.25	0.0	0.0	2.45	2.00	0.0	2.8281	3.0469	0	1	0
33	3	1.30	0.0	0.0	2.30	2.00	0.0	2.9375	3.1250	0	1	0
34	1	1.35	0.0	0.0	2.98	7.25	0.0	3.7031	4.3281	0	1	0
34	2	1.30	0.0	0.0	3.05	6.00	0.0	3.0938	3.7188	0	1	0
34	3	1.40	0.0	0.0	3.20	6.00	0.0	3.1719	3.2188	1	0	0
35	1	1.15	0.0	0.0	1.90	3.00	0.0	3.9375	4.6719	0	1	0
35	2	1.15	0.0	0.0	2.00	3.50	0.0	3.1562	3.8438	0	1	0
35	3	1.10	0.0	0.0	2.53	2.50	0.0	4.0156	4.9062	0	0	0
36	1	1.35	0.0	0.0	3.20	4.00	0.0	3.0625	3.0000	0	1	0
36	2	1.30	0.0	0.0	3.00	5.50	0.0	2.6250	3.1250	1	0	0
36	3	1.35	0.0	0.0	3.07	6.50	0.0	2.8750	3.2500	1	0	0
37	1	1.10	0.0	0.0	2.55	4.50	0.0	2.6562	3.5000	0	1	0
37	2	1.00	0.0	0.0	2.42	5.00	0.0	3.3750	3.4688	1	0	0
37	3	1.10	0.0	0.0	2.82	5.00	0.0	3.1562	2.6250	0	1	0
38	1	1.08	0.0	0.0	2.10	3.50	0.0	2.7500	3.1875	0	1	0
38	2	1.22	0.0	0.0	2.15	3.25	0.0	2.6250	2.8750	0	1	0
38	3	1.30	0.0	0.0	2.60	2.75	0.0	2.8750	3.3750	0	1	0
39	1	1.28	0.0	0.0	2.30	3.50	0.0	3.0625	3.5000	0	1	0
39	2	1.20	0.0	0.0	2.05	3.25	0.0	2.3438	2.7500	0	1	0
39	3	1.20	0.0	0.0	2.03	3.50	0.0	2.9375	3.0625	0	0	0
40	2	1.13	2.45	2.45	3.60	3.25	2.25	3.3750	4.3750	0	1	0
40	3	1.20	2.20	2.20	3.00	3.50	2.50	3.6250	4.0000	0	1	0
41	1	1.40	0.0	0.0	2.90	2.75	0.0	3.6875	4.1250	0	1	0
41	2	1.20	0.0	0.0	2.55	2.50	0.0	3.4375	3.5625	0	1	0
41	3	1.40	0.0	0.0	2.65	3.50	0.0	2.6562	3.3750	0	1	0
42	1	1.27	1.90	1.90	2.38	3.00	1.50	3.3750	4.1250	0	1	0
42	2	1.20	1.70	1.70	2.15	3.00	1.25	4.0625	4.5000	0	1	0
42	3	1.20	1.70	1.70	2.17	2.50	1.50	3.7500	4.5000	0	1	0
43	1	1.18	1.65	1.65	2.00	2.50	1.00	3.4688	3.8750	0	0	0
43	2	1.18	1.60	1.60	1.90	2.75	1.00	3.3438	3.5000	0	0	0
43	3	1.13	1.70	1.70	2.07	3.75	1.75	3.0312	3.2500	0	0	0
44	1	1.10	1.70	1.70	2.17	2.50	1.50	3.6250	4.1250	0	1	0
44	2	1.00	1.50	1.50	1.93	2.75	1.50	2.7500	3.0938	0	1	0
44	3	1.00	1.65	1.65	2.30	2.75	1.50	3.2500	3.8125	0	1	0
45	1	1.10	0.0	0.0	2.55	4.50	0.0	2.8750	3.2500	0	1	0
45	2	1.00	0.0	0.0	2.05	5.75	0.0	3.5625	4.0000	0	1	0
45	3	1.15	0.0	0.0	2.40	6.25	0.0	3.3750	3.9688	0	1	0
46	1	1.00	1.90	1.90	2.60	4.50	2.50	3.0938	3.7188	0	1	0
46	2	0.90	2.05	2.05	2.88	3.75	1.75	3.2500	3.8438	0	1	0
46	3	0.97	1.70	1.70	2.37	4.00	3.00	3.3438	4.3438	0	1	0
47	1	1.05	0.0	0.0	2.07	4.00	0.0	2.7188	2.8438	0	1	0
47	2	1.00	0.0	0.0	1.80	4.75	0.0	3.0938	4.1250	0	1	0
47	3	1.10	0.0	0.0	2.10	3.00	0.0	3.3438	3.6250	0	1	0
48	1	1.05	0.0	0.0	2.50	6.00	0.0	2.7812	3.1250	1	0	0
48	2	1.00	0.0	0.0	2.65	5.50	0.0	2.5000	3.0000	0	1	0
48	3	1.15	0.0	0.0	3.25	4.75	0.0	2.5938	2.9375	0	1	0

TABLE XX

ORIGINAL DATA FOR EACH TREATMENT IN SERIES D

ID	BAR	RH	DB	AT	ET	MA	ML	VP	L1	L2	L3
1	29.55	38	77	350	3.25	4.68	0.0691	0.0715	27	4	4
2	29.55	38	77	350	3.50	0.0	0.0	0.0855	20	3	3
3	29.54	36	79	350	3.50	11.88	0.0797	0.0620	16	4	1
4	29.54	34	78	350	3.50	11.64	0.0893	0.0520	31	12	12
5	29.45	45	74	300	5.00	8.60	0.0749	0.0510	20	8	8
6	29.45	45	74	400	1.75	6.92	0.0469	0.0460	20	12	12
7	29.45	46	75	400	1.90	6.00	0.0437	0.0830	19	8	8
8	29.45	55	72	300	5.00	6.00	0.0518	0.0890	20	5	5
9	29.71	30	76	400	5.00	5.12	0.1072	0.0880	21	3	3
10	29.71	30	76	300	1.90	7.48	0.0217	0.0	28	26	26
11	29.71	30	76	400	4.75	4.44	0.1392	0.0	25	4	4
12	29.71	30	76	300	1.90	0.0	0.0	0.0450	23	20	10
13	29.74	31	74	400	5.00	0.0	0.0	0.0810	23	6	6
14	29.74	31	74	300	4.90	0.0	0.0	0.0920	13	6	6
15	29.74	32	75	400	1.75	8.00	0.0524	0.0820	28	14	14
16	29.74	32	75	300	1.85	4.56	0.0113	0.0820	23	20	14
17	29.66	31	74	400	5.00	4.24	0.0953	0.0490	31	1	1
18	29.66	32	74	400	1.85	5.32	0.0328	0.0	29	20	19
19	29.66	32	74	300	1.85	5.84	0.0350	0.0450	30	23	15
20	29.66	32	74	300	5.00	6.12	0.0632	0.0450	33	3	3
21	29.75	30	76	400	5.00	0.0	0.0	0.0800	30	2	2
22	29.75	30	76	300	5.00	0.0	0.0	0.0820	21	3	3
23	29.75	30	76	400	1.75	4.28	0.0242	0.0	31	21	21
24	29.75	30	77	300	1.75	8.00	0.0163	0.0	22	17	15

TABLE XXI

ORIGINAL DATA FOR EACH LEAF INSTRUMENTED IN SERIES D

ID	LN	ILT	MLT	TM	L	W	D1	D2	D3
1	1	1.15	2.68	3.00	3.1875	3.8438	0	1	0
1	2	1.10	2.90	4.25	3.0000	3.5000	1	0	0
1	3	1.10	2.78	3.75	3.5000	3.8750	1	0	0
2	1	1.20	2.92	3.75	3.7500	3.3750	0	1	0
2	2	1.30	2.40	4.00	3.0625	3.3438	1	0	0
2	3	1.20	2.45	5.50	2.8750	3.3125	0	1	0
3	1	1.20	2.85	4.00	3.6250	4.0938	0	0	0
3	2	1.40	2.85	3.50	3.3750	4.0625	1	0	0
3	3	1.20	2.77	5.50	3.2812	3.8750	0	0	0
4	1	1.35	2.82	5.00	3.4375	4.4062	0	1	0
4	2	1.20	2.60	6.50	3.3438	4.2812	0	1	0
5	1	1.20	2.80	5.00	2.9062	3.1250	0	1	0
5	2	1.10	2.88	6.50	3.0000	3.2500	0	1	0
5	3	1.10	2.88	6.00	3.8750	3.3750	1	0	0
6	1	1.20	2.70	3.50	3.0625	3.2812	0	1	0
6	2	1.05	2.70	2.50	2.6875	2.7500	0	1	0
6	3	1.10	2.45	3.50	2.7812	3.1562	0	1	0
7	1	1.10	2.37	4.00	2.8750	3.4688	0	1	0
7	2	1.08	2.17	2.25	2.7812	2.9688	0	1	0
7	3	1.12	2.68	3.75	3.0312	3.0000	1	0	0
8	1	1.15	3.15	6.50	2.7500	3.0625	1	0	0
8	2	1.12	2.80	6.50	2.3750	2.6562	1	0	0
8	3	1.25	2.80	6.00	2.6250	3.1250	0	1	0
9	1	1.45	3.22	6.25	2.9375	3.5938	1	0	0
9	3	1.20	4.45	7.50	2.3750	2.6250	1	0	0
10	1	1.20	1.98	5.00	2.8438	3.3438	0	1	0
10	2	1.20	2.15	4.00	3.1875	3.5000	0	1	0
10	3	1.22	2.48	2.25	3.0938	3.3125	0	1	0
11	1	1.30	3.25	6.00	3.2500	3.7188	1	0	0
11	2	1.40	3.75	6.50	2.8750	3.1562	1	0	0
11	3	1.30	3.38	7.00	2.5312	3.0000	1	0	0
12	1	1.10	1.85	5.00	2.8750	3.6875	0	0	0
12	2	1.10	2.05	2.00	2.8125	3.3750	0	0	0
12	3	1.10	1.90	5.25	3.0000	3.6875	0	1	0
13	2	1.25	3.80	5.75	3.2500	3.1250	1	0	0
13	3	1.40	3.20	6.50	3.5312	3.9375	1	0	0
14	1	1.20	2.97	7.25	4.0000	4.6875	1	0	0
14	2	1.30	3.22	6.00	3.8750	4.6250	1	0	0
14	3	1.20	2.80	5.50	3.7500	4.1562	0	1	0
15	1	1.25	2.85	2.25	3.1250	3.2500	0	1	0
15	2	1.15	2.62	2.25	3.5625	3.7188	0	1	0
15	3	1.30	2.50	3.25	3.2500	3.5000	0	1	0

TABLE XXI (Continued)

ID	LN	ILT	MLT	TM	L	W	D1	D2	D3
16	1	1.28	2.25	3.25	2.7500	3.1875	0	1	0
16	2	1.33	2.27	2.75	2.9375	3.1562	0	1	0
16	3	1.20	2.23	2.50	2.8750	3.4375	0	1	0
17	1	1.05	3.20	5.50	2.9688	3.1250	1	0	0
17	2	0.90	3.95	7.00	2.3750	2.6562	1	0	0
17	3	1.10	3.85	6.50	3.0000	3.2812	1	0	0
18	1	0.95	2.60	3.00	2.5000	2.9375	0	1	0
18	2	1.07	2.60	4.00	2.7812	3.0000	0	1	0
18	3	1.00	2.30	3.00	2.9375	3.3438	1	0	0
19	1	0.95	1.95	3.25	2.7188	3.2500	0	0	0
19	2	0.95	1.80	2.00	3.1250	3.3438	0	1	0
19	3	1.00	1.98	3.75	3.0000	3.3125	0	1	0
20	1	1.05	3.07	6.75	3.2812	3.1250	1	0	0
20	3	1.05	3.00	6.75	2.3750	2.8750	1	0	0
21	1	1.30	3.87	6.25	2.4062	3.0000	1	0	0
21	2	1.20	4.55	7.50	2.8438	3.2188	1	0	0
21	3	1.40	3.75	6.75	3.0312	3.3750	1	0	0
22	3	1.20	3.25	7.50	3.1250	3.5938	1	0	0
23	1	1.17	2.75	4.00	2.4062	2.9375	0	1	0
23	3	1.20	2.60	4.00	2.5625	2.7500	0	1	0
24	1	1.20	2.30	2.00	2.6875	3.8750	0	1	0
24	2	1.20	1.97	2.75	3.2812	4.1250	0	1	0

TABLE XXII

ORIGINAL DATA FOR EACH TREATMENT IN THE FIELD SERIES

ID	RH	DB	AT	ET	PH	L1	L2	L3
1	73	63	400	7.55	32	17	1	1
2	67	64	400	4.00	33	72	2	2
3	62	65	500	5.05	33	48	6	6
4	62	65	500	7.05	34	69	20	20
5	58	66	300	4.00	26	53	27	4
6	54	67	600	7.75	28	43	30	30
7	52	67	400	3.30	32	67	5	3
8	52	67	300	5.00	24	20	0	0
9	52	67	300	5.10	30	50	8	3
10	53	66	300	3.70	31	67	2	2
13	54	65	400	7.25	22	18	4	4
15	51	65	300	7.20	25	40	4	4
16	51	66	300	6.75	31	30	4	4
18	51	66	500	7.10	25	74	42	42
19	51	66	400	6.60	31	68	9	9
21	51	68	500	3.50	34	40	9	9
22	50	70	500	5.00	34	47	6	6
23	50	70	500	3.90	27	40	3	3
24	50	70	400	4.75	17	41	1	1

TABLE XXIII

ORIGINAL DATA FOR EACH LEAF INSTRUMENTED IN THE FIELD SERIES

ID	LN	ILT	MLT	TM	L	W	D1	D2
1	5	1.22	2.28	8.25	2.500	3.281	1	0
1	6	1.10	2.52	7.50	2.625	3.250	1	0
2	5	1.04	2.42	4.00	2.406	2.625	1	0
2	6	1.20	2.60	4.50	2.531	2.125	1	0
3	4	0.78	1.44	5.00	3.531	3.594	1	0
3	5	0.80	2.12	5.25	3.312	4.125	1	0
3	6	0.78	2.10	5.00	2.906	3.000	0	1
4	5	1.02	2.22	7.00	2.875	2.750	1	0
4	6	0.85	3.05	8.00	2.437	2.781	1	0
5	4	0.60	1.49	4.50	3.250	3.281	1	0
5	5	0.95	1.45	4.00	3.406	3.750	0	0
5	6	0.88	1.40	4.00	3.625	4.000	0	1
6	4	1.00	3.60	5.50	2.375	2.031	0	1
6	5	1.21	2.98	5.50	2.875	3.125	0	1
7	4	0.84	2.04	4.00	3.125	3.187	1	0
7	5	0.88	1.80	4.00	2.937	3.000	0	0
7	6	0.98	1.88	3.75	3.000	4.125	1	0
8	4	0.96	1.80	5.00	2.500	3.000	1	0
8	5	0.86	1.65	6.10	3.250	3.125	1	0
9	4	1.10	1.96	4.50	3.281	3.000	1	0
9	5	0.89	1.56	5.00	3.531	4.562	1	0
9	6	1.16	1.60	4.75	3.250	3.375	1	0
10	4	0.80	2.22	3.50	2.500	2.625	1	0
10	5	0.81	1.84	3.50	2.000	1.844	0	1
10	6	1.15	2.04	3.75	3.062	3.344	1	0
13	5	0.85	2.40	9.90	2.156	2.406	1	0
15	4	1.05	2.30	7.00	2.437	3.250	1	0
15	5	1.04	2.65	9.50	3.000	3.156	1	0
16	4	1.02	3.36	6.25	4.000	5.156	1	0
16	6	1.20	2.45	7.00	0.0	0.0	1	0
18	4	1.08	3.10	5.50	0.0	0.0	1	0
18	5	1.10	3.78	5.25	0.0	0.0	1	0
19	4	1.04	3.56	6.00	0.0	0.0	1	0
19	5	0.94	3.12	6.75	0.0	0.0	1	0
21	4	1.12	2.60	3.50	3.531	5.062	1	0
21	5	0.96	2.50	4.75	3.250	3.625	1	0
22	4	1.20	3.32	5.55	3.781	4.625	1	0
22	5	1.05	2.80	4.60	2.906	3.125	1	0
22	6	1.12	2.82	5.00	2.375	2.625	1	0
23	5	1.10	3.50	4.00	3.000	3.125	1	0
23	6	1.10	2.90	4.10	3.656	3.594	1	0
24	5	1.05	2.40	4.00	3.625	4.125	1	0
24	6	1.02	2.52	4.00	3.625	3.375	1	0

VITA

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Candidate for the Degree of

Doctor of Philosophy

Thesis: HEAT INPUTS TO COTTON PLANTS

Major Field: Agricultural Engineering

Biographical:

Personal Data: Born in Worland, Wyoming, November 5, 1938, the son of Vernon and Anna Bashford.

Education: Graduated from Worland High School, Worland, Wyoming in 1957; graduated from the University of Wyoming with a Bachelor of Science in Agricultural Engineering in 1963; received a Master of Science in Agricultural Engineering from the University of Arizona in 1966; completed the requirements for the Doctor of Philosophy degree at the Oklahoma State University in May, 1972.

Professional Experience: Graduate Assistant for the Agricultural Engineering Department, University of Arizona, 1964-1965; Graduate Trainee, Ford Motor Company, Birmingham, Michigan, 1966; Research Associate, University of Arkansas Agricultural Engineering Department, 1966 to 1969; Graduate Assistant, Oklahoma State University, 1969 to 1971.

Professional and Honorary Societies: Associate Member American Society of Agricultural Engineers; Associate Member of Sigma Xi; Member of Alpha Zeta; Registered Professional Engineer in Arkansas.