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Response of cottonseed to direct-current glow discharge

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To the Graduate Council:

I am submitting herewith a thesis written by John L. Goodenough entitled "Response of cottonseed to direct-current glow discharge." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Biosystems Engineering.

John J. McDow, Major Professor

We have read this thesis and recommend its acceptance:

R. B. Stone Jr., Smith Worley, Zachary A. Henry, Richard S. Krowicki

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

August 1, 1968

To the Graduate Council:

I am submitting herewith a thesis written by John L. Goodenough, entitled "Response of Cottonseed to Direct-Current Glow Discharge." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Engineering.

John J. McDow
Major Professor

We have read this thesis and
recommend its acceptance:

Smith D. Worley, Jr

Russell B. Stone

Zachary A. Henry

Richard S. Krowski

Accepted for the Council:

Hilton A. Smith
Vice Chancellor for
Graduate Studies and Research

RESPONSE OF COTTONSEED TO DIRECT-CURRENT GLOW DISCHARGE

A Thesis
Presented to
the Graduate Council of
The University of Tennessee

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

by
John L. Goodenough
August 1968

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ABSTRACT

This study was conducted to determine the effects of direct-current glow-discharge treatment, current intensity, exposure time, and energy generated during treatment on the early and total germination of Empire WR cottonseed. Germination counts were made at 2, 3, 4, 7, and 12 days. Three-minute glow-discharge treatments at 30-150 milliamperes and 6-minute treatments at 30-95 milliamperes significantly improved early germination. Current intensities of 100-150 milliamperes for 6 minutes decreased both early and total germination. Multiple regression was calculated using germination as the dependent variable and energy, energy^2, seed temperature, seed temperature^2, moisture loss during treatment, and moisture loss^2 as the independent variables. In this regression the coefficient of determination for energy and energy^2 accounted for 91 percent of the variability in early germination and 92 percent of the variability in total germination

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CHAPTER I

STATEMENT OF THE PROBLEM

Many electrical treatments have been applied to living organisms as scientists have attempted to discover the effects of electric energy. Researchers have applied electric energy in various ways. One method is to pass electricity directly through the organism. A second is to place the organism in an electric or magnetic field. A third method involves the use of an electric discharge. This method subjects the material alternately to both electric and magnetic fields. It bombards the seeds with ions and electrons. Recombination energies of photons indicate that the energy lies principally in the ultraviolet region (5). Seeds have been treated with radio frequency, infrared, visible, and ultraviolet energy. Both beneficial and detrimental results have been reported.

The glow discharge or gas-plasma treatment has been used in recent years to treat various crop seeds. The researcher easily can control the parameters of current, time of exposure, excitation frequency, and pressure. A nearly unlimited number of combinations of parameters are possible. Many combinations have been used. These have usually involved currents of 0 to 120 milliamperes (ma), 3-minute treating times, frequencies from 60 Hertz (Hz) to 20,000 Hz, and pressures of 3 millimeters (mm) of mercury (Hg). A more limited number of tests have been run at other lengths of treatment times and pressures. Very little work has been reported when using direct current (DC) energy.

The DC glow discharge enabled the researcher to observe various regions of the glow discharge, such as the cathode dark space and the positive column. With alternating current (AC), the electrodes change from anode to cathode at the excitation frequency, and the glow discharge regions are masked as they also change at the excitation frequency. The purpose of this study, as described in this thesis, was to determine the effects of current, time, and energy on the early and total germination of cottonseed when using DC glow discharge.

Many glow discharge treatments on seeds have been made. The large number of combinations of parameters makes it impossible to conduct an experiment in which all parameters are considered simultaneously. Thus, if the effect of more than one parameter, such as current and time, could be evaluated by a single parameter, such as energy, considerable savings in time and money could be realized. This savings could then be applied to the investigation of economical methods of improving field germination of seeds.

I. OBJECTIVES

The objectives of the study were:

1. To determine the effects of DC gas-plasma radiations on the early and total germination of machine-delinted cottonseed.
2. To determine the effect of current intensity on early and total germination of machine-delinted cottonseed.
3. To determine the effect of exposure time on the early and total germination of machine-delinted cottonseed.
4. To determine the effect of quantity of electromagnetic energy on the early and total germination of machine-delinted cottonseed.

The resources required to complete the investigation were provided by the Agricultural Engineering Division (AE), Agricultural Research Service (ARS), United States Department of Agriculture (USDA), the Agricultural Engineering Department, and The University of Tennessee Computing Center. The seed treating and germination equipment were provided by AE, ARS, USDA. The Agricultural Engineering Department furnished laboratory space, and along with The University of Tennessee Computing Center, computational facilities for the analysis of data. A detailed description of equipment and procedure is included in Chapters III and IV. All resources were located at The University of Tennessee, Knoxville, Tennessee.

CHAPTER II

REVIEW OF LITERATURE

The effect of electromagnetic radiation on seeds, plants and plant materials has long been of interest to many researchers. A wide variety of treatments and treating techniques have been used, each researcher striving to investigate the effects of some type of electrical or electromagnetic treatment. The electromagnetic spectrum showing the approximate ranges of radiations from radio waves to gamma rays is shown in Figure 1 (14).

Briggs (3), conducted research in low frequency radiation during the period from 1907-1918. He used a charged network over the growing plants to change the electrical state of the surrounding atmosphere. The potential of the charged network varied from 30,000 to 60,000 volts with atmospheric current of 0.1 to 1 ma per acre. In both field and laboratory experiments he found no significant effects on plant growth.

Work on corn was reported by Ginsburg and Cholet (8), but the results showed no significant differences between the treatments and the controls. Treatments were run at frequencies from 500 Hz to 220 KiloHertz (KHz). Exposures were from 2 to 7 hours at voltages of 1,200 to 20,000 volts

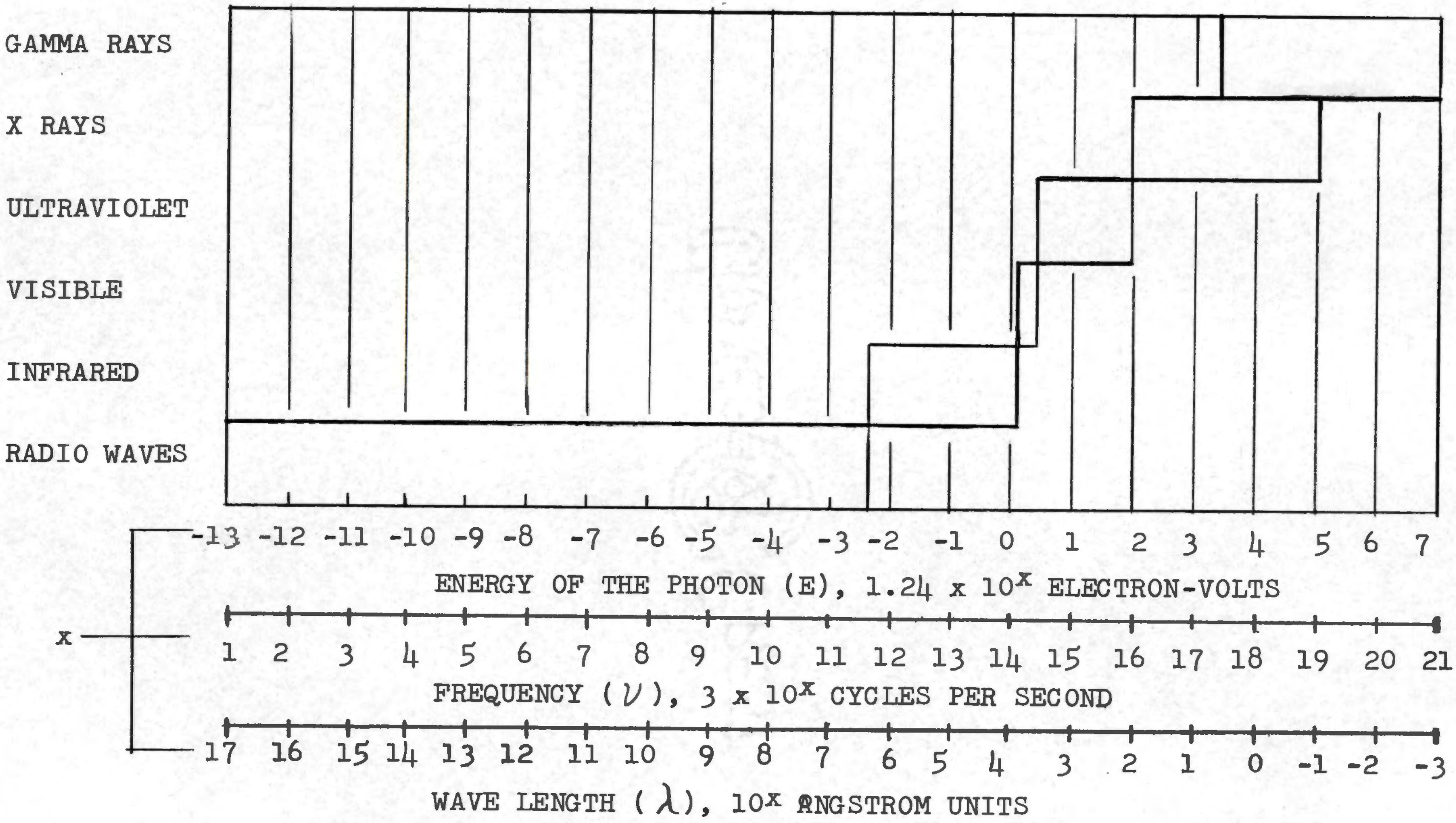

Figure 1

Electromagnetic Spectrum Showing Approximate Ranges of the Radiation per centimeter (cm). Also reporting on corn germination were Nelson and Walker (16). Corn seeds were exposed to radio-frequency irradiation at 40 MegaHertz (MHz) for 5 seconds. These showed a significant increase in germination over the control at 2 days. Carrots, onions, beets, lettuce, and tomatoes were irradiated with radio-frequency and infrared radiation by Jonas (11). Germination rate was increased by the radio-frequency treatments and was dependent on the voltage gradient, power and energy input, and seed temperature. The infrared radiation produced smaller increases in the rate of germination. Rincker (18) used infrared heat treatments to reduce the number of hard seed in alfalfa, sweet clover, and red clover. The irradiation was applied by a 110 volt 250 watt, infrared bulb at a temperature of 220 degrees Fahrenheit (^{O}F). He found that a hard seed of alfalfa and red clover could be made permeable by applications of properly regulated dry heat. However, the hard seeds of sweet clover did not respond the same as the hard seed of alfalfa and red clover to identical heat treatments. The hard-seed content of alfalfa was reduced by radio-frequency irradiation by Nelson and Wolf (17). The seeds were irradiated at a frequency of 39 MHz and at a field intensity from 2.5 to 5.3 kilovolts per inch. The moisture content of alfalfa varied from 2.1 to 15.6 percent. There was an optimum treatment level determined for each variety at a particular combination of field intensity and seed moisture content. Results from these optimum treatments showed a significant decrease in the number of hard seed with a corresponding increase in early germination when compared to the control seed. The seed at a lower moisture content could be exposed to a higher field intensity without damage than could the seed at high moisture content. This was reported to have been caused by the higher rate of heat conduction in the high moisture seed. Nelson verified these results in later research (14, 15, 16).

Researchers for many years have investigated the effect of electrical discharges on oils. Thomas, et al. (26) reported the reactions of hydrocarbons in electrical discharges. They described work on olefins, ethylene, acetylenes, and many others. Boelhouwer, et al. (2) stated that "The possibility of transforming linseed oil and other drying oils into polymerization products of a completely different chemical structure, depending on the applied polymerization process, opens new possibilities for their manufacture." They also found that the Voltolization of linseed oil brings about a polymerization product absolutely different from that of thermally or catalytically polymerized linseed oil. Whiteley (33) reported on Voltolization as applied to commercially liquid-phase reactions. The liquid flows between vertical electrodes which carry opposite charges. A rarified atmosphere of some gas is maintained (most of their work was done at 40 mm Hg). A glow discharge is established, and the liquid is recycled between the electrodes until the desired product is obtained. The electrical power required to affect a given degree of reaction was measured. The most obvious effect was that of the marked increase in viscosity. The overall reactions were much more complex than simple polymerization. Voltolizing petrolatum and wax yielded lubricating oil additives such as pour inhibitors and viscosity index improves. Other products formed were polybasic acids, high-molecular weight alcohols, esters and ketones, and polymerized drying oils. Boelhouwer, _et al_. (2) also found that glow discharges in hydrogen or nitrogen atmospheres at low pressures produced mineral oils and fatty oil which had a considerable increase in viscosity. They reported this was probably because of polymerization of the starting material.

Many reports have described beneficial effects of the glow discharge. Polymerization of oil may produce many new exciting and very valuable compounds. But to the farmer who is interested in a good stand of his crop whether he plants early or late, the beneficial effects for him will come when the reported early germination is shown as early emergence in the field, which in turn may lead to higher yields. This might be a reality in years of wet springs, when the farmer must plant late, or when an early emerging crop would yield a crop before an early frost. The use of glow discharge on seeds was started in 1954 by Brown, Stone, and Andrews (4). Using a frequency of 60 Hz, several types of seeds were irradiated. One common effect noticed on most seeds was that the rate of water uptake increased. Corn which was exposed to a limited amount of radiation germinated faster and more uniformly in a petri dish of free water than did the control. In all cases the seeds were killed if the radiation was made sufficiently intense.

There was a significant increase in the 2-day germination at all radiation levels over the control seed for Empire WR cottonseeds which were exposed to the glow discharge plasma. Excitation frequency was 60 Hz; the pressure was 3 mm of Hg for 3 minutes. Four-day germination counts showed no significant increase over the controls but there was significant increase in the radical development of the irradiated seed over the control seed. The highest intensity level of irradiation produced germination which was significantly lower than the controls. This treatment was intense enough to kill most of the seed.

Webb, et al. (31) found that acid-delinted seed treated with the glow discharge showed nonsignificant increase in germination over an acid-delinted control. Rapid water uptake was noticed on seed with linters. A later study reported stimulative effects of earlier germination and earlier radical development (32). In this study all glow discharge treatments showed significantly greater early germination after 2 days than did the controls. Controls germinated 1 percent compared to 67 percent for the best treated samples. There was no significance in early germination due to current or frequency effects alone. There was no beneficial total germination, but some treatments showed significantly lower germination than the control. All glow discharge treatments produced significantly longer and heavier radicals after 4 days than the control samples. The length and weight of the treated seed radicals were about two times the control samples. Although current alone did not show significant increase in early germination as the current level increased, there was a significant decrease in total germination. The frequency times current interaction was not significant at the 5 percent level.

The glow discharge treatment has also been used to treat cotton fibers, cotton yarn, cotton wax, rice bran and brown rice, milled rice, alfalfa, and other field seeds (30). Cotton fibers and cotton seeds were irradiated with a 60 Hz glow discharge by Stone (23). The treated cotton fibers were rough and stiff and absorbed water very rapidly. Electron micrographs showed broken surface areas on the cotton fibers and also showed evidence of primary wall cell damage. The wax on the cotton fibers had been degraded from the irradiation. The treated linters from fuzzy and machine-delinted cottonseed sank immediately when dropped into a container of water, but the control seed still floated on the surface of the water 24 hours after placement. The acid-delinted cottonseed which were glow discharge treated absorbed water over the entire surface of the seed more rapidly than did the control seed. Glow discharge treated cotton yarn showed an increase in strength of 31 percent for yarn spun at an optimum twist (24). At the lowest twist tested, the irradiated yarn was 75 percent stronger than the control. The breaking strengths of the irradiated yarns at low twists were greater than the strength of the control at optimum twist.

Roseman, et al. (19) reported on the treatment of milled rice with glow discharge. The treated rice showed a marked increase in the amount of water that could be absorbed. The study showed that the maximum changes in hydration characteristics occurred with tube pressure at 2 mm of Hg and treating time at 5 minutes with current at about 175 ma for the Zenith variety and with current at 150 ma for Bluebonnet 50 rice. Between 2 to 8 mm of Hg pressure during treatment had no great effect upon the water absorptive capacity of the rice with a current range of 25 to 75 ma with 5 minute treating time. Also, increasing the treatment time over 45 minutes for Bluebonnet variety and 70 minutes for Zenith was insufficient in increasing the amount of water absorption. The glow discharge treatment was used on rice bran and brown rice to determine its effects on oil stability and on certain other physical properties of the petroleum ether solubles (20). The rate of free fatty acid development in the lipids of stored brown rice and in the stored bran separated from rice kernels was much slower in the glow discharge treated samples than in the controls. The irradiation profoundly changed the chemical and physical characteristics of rice oil from both stored brown rice and stored separated rice bran. Treatment increased the average molecular weight of the oil from irradiated rice bran and the oil was less saturated than that of the controls. Investigation included treatments using only heat and vacuum. These treatments revealed that the changes are affected specifically by the glow discharge treatment rather than by the coincidental heat-vacuum effect of irradiation.

Nelson, _et_ _al_. (15) compared infrared, radio-frequency, and glow-discharge treatments on alfalfa hard-seed reduction. All three treatments were about equally effective in reducing the hard-seed content and increasing early germination and emergence. The benefits of all treatments remained after 14 months in storage. Seedlings from all except over-exposed seed samples appeared normal. Water sorption, leachate solution conductivity, and oxygen uptake of seeds were increased about the same amount by the three types of treatments and were closer related to the degree of hard seed reduction.

I. THE GLOW DISCHARGE

The physical aspects of the glow discharge have been studied very extensively, so that most of the characteristics of discharge are known (26). When significant voltage is applied to two electrodes in an evacuated chamber at a pressure of from 0.01 to 100 mm Hg a glow discharge will occur. A commonly used pressure is 5 mm Hg. The voltage required varies from about 100 volts at the low pressure (26) upwards and depends on the pressure and composition of the gas in the discharge, electrode spacing, electrode configuration and other factors. The nature of the discharge is affected by applied voltage, frequency, configuration of the discharge chamber and electrodes, type and pressure of the gas, electrode material, external circuit conditions, and other factors (30).

Coffman (7) described the phenomenon of corona discharge. This compares closely with the way that the discharge is initiated in the glow discharge tube except that corona occurs at atmospheric pressure. The phenomenon starts with the few stray electrons that are always present in a gas because of cosmic rays or other background radiation. Applying a high voltage creates strong electric fields, and electrons are accelerated to the positive electrodes. Electrons strike gas molecules in their paths, from which they rebound with little loss of energy--like ping-pong balls rebounding from a bowling ball. Then they accelerate again. Occasionally by chance, a long enough path opens up for an electron so that when it finally hits a gas molecule it has enough energy to penetrate the molecular shield of orbiting electrons. Then one of two things can happen. The impacting electron may knock an orbital electron out of the molecule, leaving a positive ion and another free electron that can go on to strike another molecule. More often the impacting electron lifts an orbiting electron to an unstable, higher-energy orbit, creating an "excited" molecule. Soon the gas is full of electrons, positive ions, excited molecules, heat and light--in other words, corona. The whole process of corona build-up takes only 10^{-7} second, and it is repeated every time the electric field reverses. The excited molecules are unstable; they decompose spontaneously into free radicals. Free radicals are formed by electron impact. A radical is a molecular fragment that functions as a unit. Examples are single-hydrogen atoms H, methyl group CH_3, amino group NH_2, acetyl group, CH_3CO. These are extremely reactive. They usually exist as free radicals for fractions of seconds at most.

When the pressure in the discharge chamber is reduced to approximately a mm of Hg depending on the type of gas in the chamber, the discharge consists of alternate dark and light regions. Starting with the cathode the regions are as follows:

1. The Aston dark space.
2. The cathode glow, whose length depends on the gas and the gas pressure, in many cases completely masks the Aston dark space.
3. The cathode dark space was sometimes called the Crookes or the Hittorf dark space.
4. The negative glow, the brightest of the glowing regions, is quite long compared with the cathode glow.
5. The Faraday dark space.
6. The positive column, which fills most of the length of the discharge tube.
7. The anode glow.
8. The anode dark space.

The last two regions may or may not appear depending on the gas mixture, gas pressure, and on the value of the discharge current. The dark spaces are not absolutely the void of light, but they are only dark relative to the glowing region (5).

In this experiment the seeds were placed in the tube in the regions of the cathode dark space, the negative glow, the Faraday dark space and the positive column. Most of the seeds were in the region of the positive column, especially for the higher current level treatments. For this reason the writer included discussion only of these areas. The cathode glow is a region of highly positive ion density due to the electrostatic attraction of the negative electrode (cathode). The glow in this region is probably due to excitation of molecules by positive ion collision (26). The cathode dark space provides the major part of the voltage drop across the discharge tube and is called the cathode fall of potential or cathode drop (30). The cathode fall of potential is defined as the difference between the potential of the cathode and the potential in the gas at a distance "d" from the cathode where "d" is the thickness of the dark space. The voltage drop depends on the type of gas, the gas pressure, and the work function of the electrode material. The cathode fall is markedly affected by the pressure of gaseous impurities, and it increases nearly linearly with the work function of the cathode material. The maintenance of the discharge depends on the emission of electrons from the cathode. Cobine (5) reported that the gaseous mixtures caused irregular and inexpicable variations in the cathode drop. The cathode drop is almost independent of the current and pressure in a normal discharge (27).

The negative glow is usually the region of greatest luminosity (5, 26, 30). The voltage drop across this region is very small compared to that in the cathode drop. In it the electron, positive ion, and probably the excited molecule densities are highest (26). This region is caused by high-speed electrons coming from the cathode and ionizing the gas molecules. The negative glow is regarded as the seat of ionization which, by producing a supply of positive ions prevents the electrons from building up a space-charge, and thereby keeps the electric force in the glow very low (27). As the electrons travel across the negative glow, they lose energy until not enough energy is left to ionize or produce luminosity. Because of this slowing down of the electrons, there is no sharp boundary between the negative glow and the Faraday dark space. In the transition region from the negative glow to the Faraday dark space, the ionizing and excitation effect from electron collisions becomes less (5). The Faraday dark space resembles the cathode dark space, but the energy dissipation and potential drop are much less (26). In the main part of the Faraday dark space, the ionizing and excitation action of electrons are completely absent. The electric field reverses in the transition region between the negative glow and the Faraday dark space. The current to the Faraday dark space is a diffusion current of electrons and positive ions with the electron current to the anode predominating (5).

The positive column is a region of uniform ion density and energy unless the column is striated, in which case the energy and ion density vary with the striations (5, 26). The positive ion and electron densities are about 1/100 as great as the densities in the negative glow (26). Cobine (5) defines the positive column as "typical plasma having equal concentrations of positive ions and of electrons." The beginning of the positive column is very sharply defined and its length depends upon the gas pressure, the distance between electrodes, and the shape of the container in which the discharge is established. As the gas pressure is reduced the negative glow and the Faraday dark space will expand and the positive column will shorten. If the pressure is sufficiently reduced, the positive column will disappear completely. A similar effect is observed if the electrodes are moved together at constant gas pressure and constant current. The positive column decreases in length and finally disappears. Normally the positive column fills the major portion of the tube (5).

In the cathode dark space the high potential drop accelerates electrons according to the potential drop and the pressure in the discharge tube, since the number of molecules in the electron's path is dependent upon pressure. During this acceleration three types of collisions with molecules occur. (1) Elastic collisions; no energy lost or gained. (2) Ionizing collisions; a positive ion and electron result. (3) Activating collision; the quantum state of a molecule is raised. This energy may in turn be converted into vibrational energy (26). Thus, electrons receive most of their energy in the cathode dark space. As they move into the negative glow, electrons continue to lose energy in collisions. In the negative glow the electrons must complete the process of forming enough positive ions to maintain the discharge (26). From there the electrons diffuse towards the anode where they are neutralized by a diffusion of positive ions toward the cathode. The positive ions are produced by the incoming electrons and in the transition region between the positive column and the surface of the anode. There is a continual loss of electrons going on in the positive column caused by: (1) loss of by diffusion to the sides of the tube; (2) loss by a combination of electrons with neutral molecules to form negative ions; and (3) loss by combination of an electron with a positive ion to form a neutral atom (27). Some of the ions diffuse radially to the walls of the tube where they are lost by recombination with electrons. This diffusion of ions to the walls of the discharge tube can hinder the maintenance of the discharge (5). Since electrons and negative ions diffuse more rapidly in the tube than do positive ions, the outer boundary of the plasma becomes negatively charged and there is a net positive charge in the central portion of the plasma. This net positive charge increases the diffusion of positive ions.

The fundamentals of the glow discharge were summarized by Thomas (26).

1. The major portion of the chemical action takes place in the negative glow.
2. The reaction rate in the negative glow is independent of pressure within the limits of 0.2 to 20 mm.
3. The rate of reaction is proportional to the current.
4. Reactions in the negative glow have a zero or negative temperature coefficient. In synthesis (combination of two or more molecules) the rate of reaction is accelerated by the addition of the gas having the higher ionization potential and retarded by the addition of the gas with the lower potential.

In regard to the temperature in the glow discharge, Cobine (5) stated that the gas temperature is greater in the luminous parts than in the dark parts. The temperature of the gas in the positive column is seldom over 100°C, and this indicates that thermal ionization cannot be a factor in the maintenance of the conductance of the glow discharge.

The parameters considered in glow discharge treatment of cottonseed were current, length of treatment, frequency, and pressure. Webb (32) stated that during treatment the rate of outgassing from seed decreased as the treatment progressed. This change caused gradual change in the gas mixture in the radiation chamber. This would in turn change the ionization potential of the gas. Akerlof (1) reported that the amount of moisture lost during treatment in an evacuated tube is very important to the overall effects observed. To get comparable results, all physical conditions should be reproducable, such as (1) discharge power input conditions, (2) length of time exposure, and (3) previous history of seed. How quickly water gets to the seed coat at the chalazal region determines how soon a seed germinates (assuming other factors constant) (21). He found that naked cottonseed and acid-delinted cottonseed germinated 2 to 3 days earlier than fuzzy cottonseed. Thus the germination stimulating characteristic of the glow discharge may be that of hastening the movement of water to the chalazal region.

An explanation of the small amount of DC glow discharge investigation may be due to the following. It is harder to maintain a glow discharge with DC than AC. It is more dangerous because the voltage does not pass through zero, thereby raising the chance of injury from electrical shock.

In addition, special equipment in the form of a DC power supply must be available that will deliver sufficient voltage and current. This is relatively expensive to build and not readily available.

CHAPTER III

THE IRRADIATION SYSTEM

The irradiation system used for generating the glow discharge in this study was previously used by Webb (30), and Webb, Stone, and Pate (31). Modifications were made to excite the glow discharge with DC instead of AC as described by Webb (30). The vacuum system was the same except that a McLeod gage was added to provide monitoring of the electronic gage during each treatment. Webb calibrated the electronic gage separately. The apparatus is shown in Figures 2, 3, and 4.

I. THE ELECTRICAL SYSTEM

The DC power supply was a typical full-wave rectifier with a capacitor input pi filter such as those described by Hammond (10), Malmstadt (13), and Terman (25). It had output capability of 5000 volts and 150 ma. The AC line voltage to the power supply was adjusted by a motor-driven induction voltage regulator, which provided the fine current adjustment. The rated capacity of the regulator was to raise or lower the input voltage 56.5 percent. A variac was used for the initial current setting. Length of treatment was controlled by a time clock which was interconnected with a relay such that the

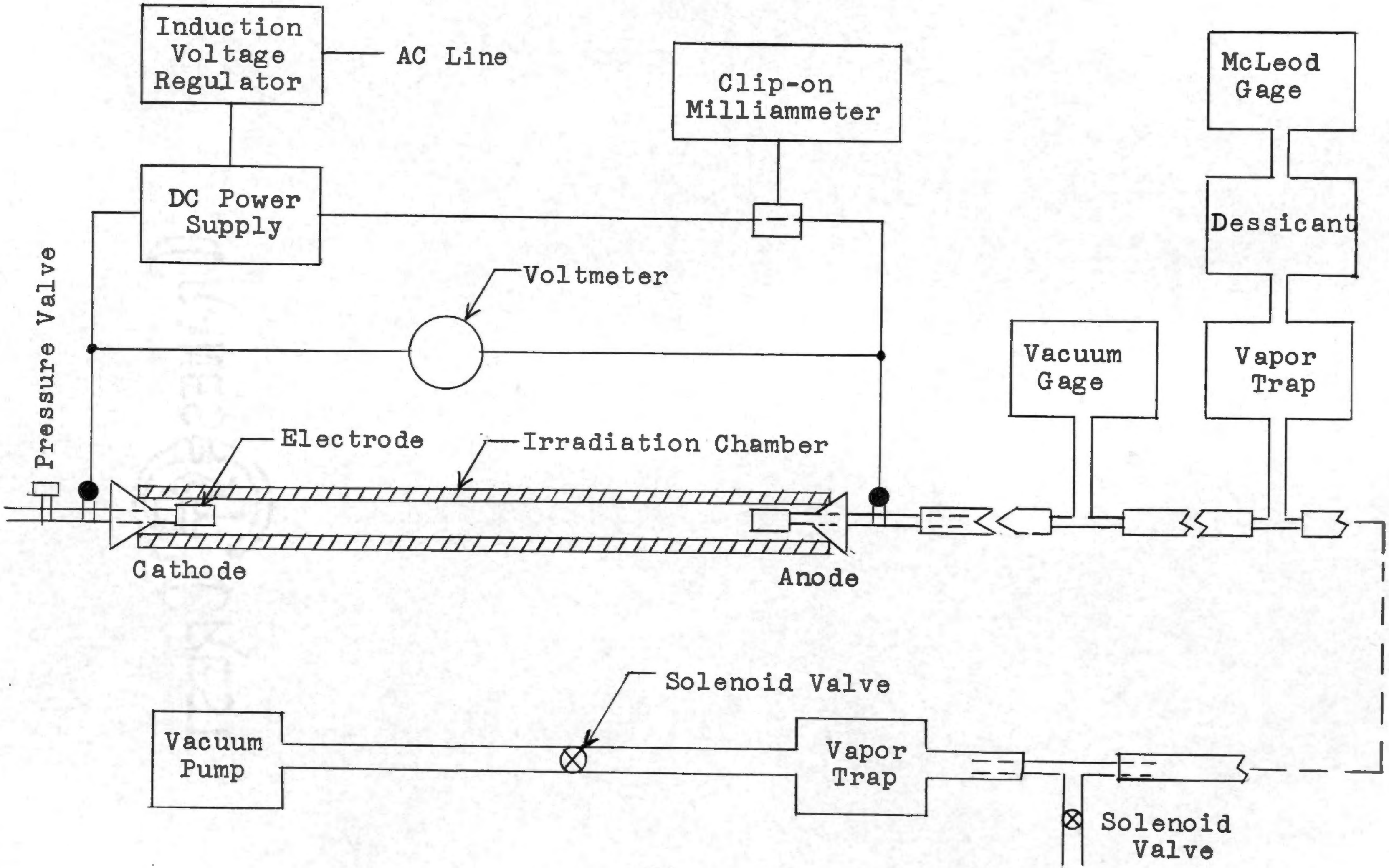

Figure 2

Block Diagram of the Irradiation System

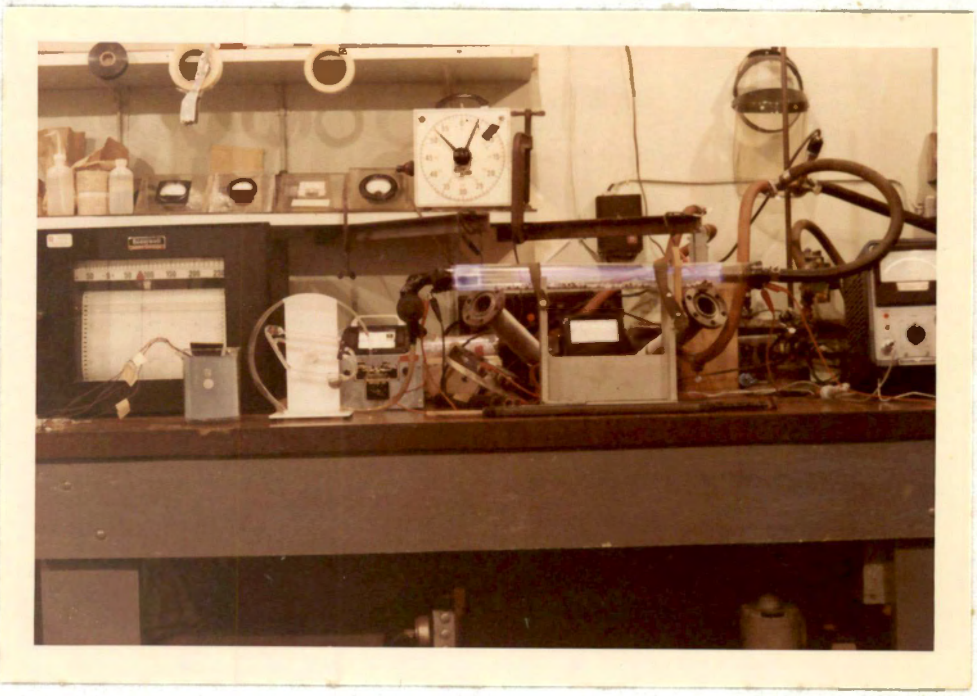

Figure 3

The Irradiation System

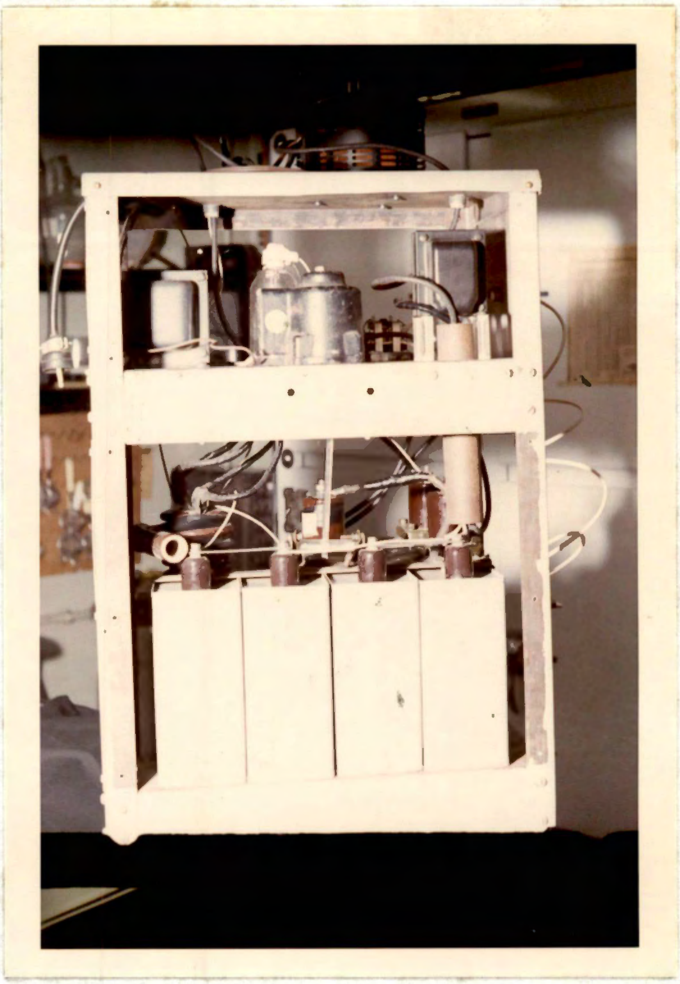

Figure 4

The Power Supply

current could not be turned on unless the clock was on. The sequence of equipment operation for a treatment was:

1. Clock set to desired treating time plus 1 minute.
2. Heater circuit to power supply rectifier tubes energized.
3. Variac turned up to roughly the desired current (one minute after the clock was turned on).
4. Voltage regulator adjusted to obtain desired reading on the clip-on milliameter.
5. Pressure checked with vacuum gage.
6. Voltage readings taken with voltmeter.
7. Additional current, pressure, and voltage checks made as described in Chapter IV.
8. Clock shut voltage off at end of treatment, and returned the tube to atmospheric pressure.
9. Variac returned to zero.

The filter capacitors in the power supply were capable of retaining a heavy charge. A shorting bar mechanism discharged the capacitors whenever the power was turned off. This provided considerable protection from severe electrical shock. The power supply was also equipped with thermal overload protection.

CHAPTER IV

EXPERIMENTAL PROCEDURES

The experimental design was chosen to satisfy the objective of this study. The limitations of the treatment and germination facilities determined the ranges of current and time which were used. This chapter covers the experimental design, the treatment procedure, the germination procedure, the collection of data, and the statistical analysis.

I. EXPERIMENTAL DESIGN

The experimental design was a randomized complete block design with a factorial arrangement of treatments. There were 25 current levels and two treating times. The current levels ranged from 30 to 150 ma in 5 ma steps. The two treating times were 3 and 6 minutes. All treatments were made with DC at 2 mm Hg pressure. Three control treatments were included in each replication. The first two were checks on the 6- and 3-minute evacuation, respectively. The third was taken directly from the seed supply. This made a total of 53 treatments per replication. The experiment was replicated four times using 100 seeds per replication. This provided 400 seeds per treatment, which satisfied the official germination rules (28).

II. TREATMENT PROCEDURE

The treatment procedure consisted of an orderly procedure of seed handling and glow discharge treatment. A 400-seed sample was counted and weighed. From this sample it was estimated that 8.3 pounds of seed were required for the experiment. A can containing about 11 pounds was chosen. The seed was Empire WR cottonseed, 1964 crop, which had been stored in a closed metal can in the USDA seed storage unit at a condition of 40°F and 50 percent relative humidity (R.H.). The sample was left out in the laboratory overnight to let it come to room temperature.

The 11-pound sample was mixed well. After mixing, the seeds were placed back into the can, which was opened only for drawing samples. Four 25-seed samples for moisture content before treatment were removed and stored in plastic bags. The seeds were moved quickly during weighing and moisture sampling so that the moisture content would not change appreciably. Two 30-gram (gm) samples were treated making 60 gms for each treatment.

Each 30 gm sample was placed in the center 16 inches of the treating chamber. This meant that most of the seeds were in the positive column during treatment, but some were in the cathode dark space. The seeds were spread with a wooden rod to form a single layer. The chamber was evacuated for one minute before the glow discharge was turned on. Fans were directed at the electrodes throughout the treatment process.

The current was monitored frequently during treatment. The pressure was checked several times during each treatment with a thermocouple vacuum gage. A McLeod gage was used to calibrate the thermocouple gage. When the thermocouple gage indicated that the pressure was no longer at 2.0 mm Hg, the pressure was checked with the McLeod gage. If more than 0.1 mm Hg error was found, the pressure was adjusted. The McLeod gage is shown in Figure 5.

The current was checked several times the first 30 seconds and at least once a minute thereafter. It was also checked whenever pressure adjustments were made, as lowering the pressure increased current, and vice-versa. Current adjustments were made whenever the indicated value was 1 ma in error.

The treatment time was regulated by a time clock. Since the current was turned up from zero at the beginning of each glow discharge treatment, usually 5 to 10 seconds were required before the desired current adjustment was obtained. Usually none or only a slight decrease in pressure was required at the beginning of a treatment. As the seed outgassed during treatment, the pressure decreased slightly, and

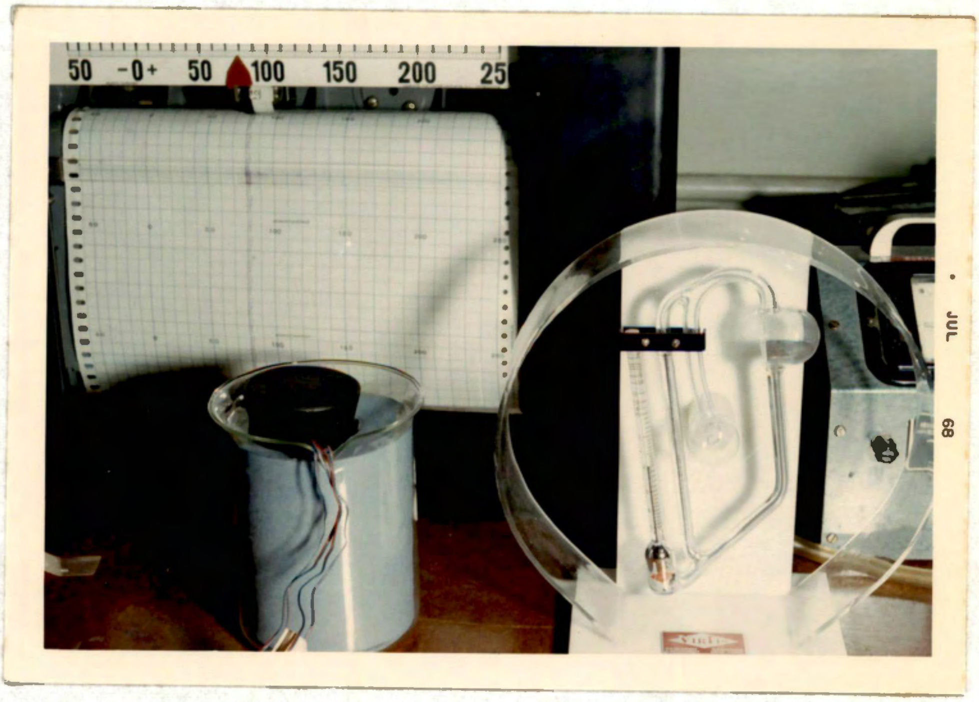

Figure 5

The McLeod Gage and The Seed Temperature Measuring Apparatus the pressure was adjusted accordingly. This was usually not necessary for the 3-minute treatments.

At the end of any treatment, the time clock shut off the current, closed the solenoid valve to the vacuum pump, and opened the solenoid valve between the treating chamber and room. This allowed the tube to come to atmospheric pressure. A recording potentiometer was used to measure temperature. As soon as the tube could be opened, the sample was raked into an insulated container (Figure 6). Four thermocouples were thrust into the sample, and the temperature measurement was made. The potentiometer recorded temperature while the next sample was loaded and during the initial 1-minute pump-down (Figure 5). This gave 1.5 to 2 minutes in which the temperature of the seed mass was recorded. The average of four thermocouple readings was used as the sample temperature after treatment.

After each temperature measurement, the sample was placed in a plastic bag. The bag was closed until the next 30-gm sample was completed. Both 30-gm samples were mixed well. The bag was then tightly sealed and saved for moisture sampling and germination testing.

III. GERMINATION PROCEDURE

The germination procedure consisted of seed preparation, handling, conditioning, and planting and germination

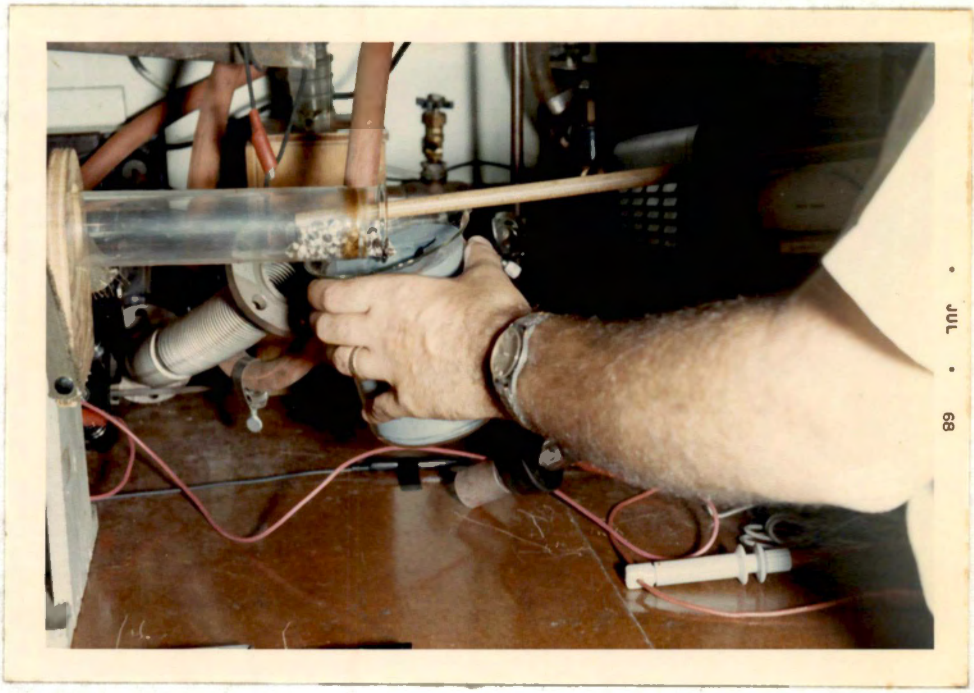

Figure 6

A Treated Sample Being Taken Into The Insulated Container Just Prior to Seed Temperature Measurement conditions used for the experiment. Seeds were prepared for planting as follows. The two 30-gm samples which comprised a treatment were mixed well. Then two 25-seed samples were quickly sealed in plastic bags for the moisture tests. Four additional 25-seed samples were carried along with the treated samples for moisture content at planting. Four samples of 100 seeds from each treatment were placed in labelled envelopes for the germination test. These were counted 50 at a time with a vacuum seed head. Broken and cracked seeds which were noted were removed from the samples. The four envelopes of 100 seeds were placed in a plastic bag until all germination samples were counted. The envelopes of germination samples were removed from the plastic bags and placed in the seed storage unit at 40°F and 50 percent relative humidity for 40 1/2 hours.

The seeds were planted on 2 layers of germination grade blotting paper in plastic boxes. The boxes and blotting paper had been dipped in a water bath which contained 4.0 gm Ceresan M fungicide in 5 gallons of water. The blotters were rung through a clothes ringer to attempt to get a uniform amount of water on each blotter. Eight ml of water was added to each blotter. This amount saturated the blotters.

The germinator cycle was 20°C for 16 hours, then 30°C for 8 hours as given in the germination rules (28). This constituted 1 day as described for the emergence counts. The treatments were randomized within each replication by using table of random numbers given in LeClerg, et al. (12). Germinated seed were removed after each count to help cut down on mold and disease (28).

IV. DATA COLLECTION

Data was collected so that energy generated during treatment, seed temperature, seed germination, and seed moisture content could be obtained. The energy values were calculated as the product of voltage drop across the treating tube, the current through the tube, and the length of treatment. The voltage measurements were taken with a Simpson Model 260 volt-ohm-milliammeter. Readings were taken during the 3-minute treatments after 30, 90, and 150 seconds had elapsed. Readings were taken during the 6-minute treatments after 1, 3, and 5 minutes of treating time. The three values were averaged for each sample. The Simpson voltmeter was calibrated with Hewlett Packard 410c Vacuum Tube Voltmeter.

Treatment current values were made with a Hewlett Packard Model 428B which had been calibrated with a Weston Model 1370 secondary standard meter. In both the voltage and current calibration, readings were taken with increasing and decreasing values. These were averaged and plotted as the calibration curves. Calibrated values were read from these curves. The current and time values used to calculate energy were those in the treatment descriptions (Table I). Energy was calculated as the product of average voltage drop across the tube, treatment current intensity, and length of treatment.

Seed germination counts were made after 2, 3, 4, 7, and 12 days in the germinator. The official days for counting (28) are 4 and 12 days, with a 1-3 day permissible variation in the first count. In this experiment a 2-day count was necessary to see if the glow-discharge treatments showed the beneficial effect of AC glow discharge reported by Stone (23). The 3- and 4-day counts were taken to see how long the anticipated early germination effect persisted. The 7-day count was taken because it was thought that the samples might be too moldy by 12 days to make an accurate count. Radicles were counted as soon as they had emerged from the seed.

Seed moisture contents, percent dry basis, were obtained before and after treatment and before planting. Moisture loss was calculated as the difference in moisture before and after treatment. Empty drying cans were dried for 48 hours at 100°C before empty weights were taken. The dessicant was also dried. Cans were placed in the dessicator to bring them to room temperature before weighing. The cans

TABLE I

GLOW DISCHARGE TREATMENT CONDITIONS

Treatment	Current (ma)	Time (minutes)	Seed temperature (°F)	Moisture loss (percent)	Voltage (volts)	Energy (joules)
1	30	3	86	0.78	1,428	7,711
2	35	3	87	0.75	1,388	8,744
3	40	3	89	0.87	1,357	9,770
4	45	3	92	0.23	1,338	10,838
5	50	3	92	0.71	1,306	11,754
6	55	3	96	0.59	1,280	12,672
7	60	3	97	1.11	1,259	13,597
8	65	3	102	0.90	1,246	14,578
9	70	3	100	1.11	1,226	15,447
10	75	3	100	1.16	1,209	16,322
11	80	3	104	1.22	1,200	17,280
12	85	3	107	0.97	1,196	18,299
13	90	3	109	1.28	1,194	19,343
14	95	3	108	0.61	1,182	20,212
15	100	3	113	1.42	1,177	21,186
16	105	3	110	1.60	1,178	22,264
17	110	3	113	0.77	1,152	22,810
18	115	3	112	1.73	1,150	23,805
19	120	3	114	1.01	1,160	25,056
20	125	3	113	1.39	1,155	25,988
21	130	3	120	1.93	1,148	26,863
22	135	3	114	1.58	1,144	27,799
23	140	3	119	1.23	1,134	28,577
24	145	3	123	1.30	1,129	29,467
25	150	3	128	1.82	1,125	30,375
26	30	6	95	1.70	1,416	15,293
27	35	6	99	1.03	1,390	17,514
28	40	6	101	1.79	1,346	19,382
29	45	6	103	1.11	1,304	21,125
30	50	6	106	1.39	1,290	23,220
31	55	6	109	1.59	1,263	25,007
32	60	6	108	2.39	1,244	26,870
33	65	6	110	2.11	1,238	28,969
34	70	6	114	2.33	1,226	30,895
35	75	6	115	1.42	1,192	32,184

TABLE I (continued)

Treatment	Current (ma)	Time (minutes)	Seed temperature (^{o}F)	Moisture loss (percent)	Voltage (volts)	Energy (joules)
36	80	6	116	1.74	1,203	34,646
37	85	6	120	1.65	1,187	36,322
38	90	6	120	1.81	1,175	38,070
39	95	6	120	1.66	1,175	40,185
40	100	6	129	1.94	1,158	41,688
41	105	6	133	1.01	1,157	43,735
42	110	6	133	2.21	1,147	45,421
43	115	6	137	1.89	1,140	47,196
44	120	6	136	2.15	1,130	48,816
45	125	6	141	2.19	1,130	50,850
46	130	6	140	2.24	1,121	52,463
47	135	6	143	2.75	1,112	54,043
48	140	6	143	2.48	1,116	56,246
49	145	6	150	3.00	1,126	58,777
50	150	6	145	2.85	1,122	60,588
51	0	6	74	-0.04	0	0
52	0	3	73	0.29	0	0
53	0	0	80	-0.47	0	0

were weighed empty, with wet seed, and with seed after drying for 2 days at 94-96°C. Cans were left open during drying and closed when removed from the oven. The oven temperature was kept low to avoid evaporating oil (28). The cans were kept in the dessicator between weighing and drying periods to avoid moisture regain. A metal-utility tongs was used to move cans from the oven to the dessicator and from the dessicator to the balance. All seed samples were held in plastic bags during the interim between moisture conditioning and moisture determination. All weighing for moisture determinations was done on a Christian Becker analytical balance.

V. STATISTICAL ANALYSIS

The statistical analyses were in three parts: (1) Analysis of Variance, (2) Duncan's Multiple Range Test for separation of means, and (3) Regression Analysis. Analysis of variance betweeen means was performed on the factorial arrangement of (A) Currents, (B) Times, and (C) Replications. Multiple regression was used to find a mathematical relationship between percent germination and (1) energy, (2) temperature, and (3) moisture loss.

CHAPTER V

PRESENTATION AND INTERPRETATION OF THE EXPERIMENTAL DATA

Empire WR 61 cottonseed was treated with DC current, germinated, and germination counts made at 2, 3, 4, 7, and 12 days. The treatments were arranged so that the effects of current, time, and energy on the early and total germination could be evaluated. The reason for the early germination count was because it is important to get the crop out of the ground quickly, before dry weather might hinder plant development. Total germination is important in calculating the amount of seed necessary to sow to get the desired stand.

The treatment conditions are listed in Table I, page 38, as current, time (length of glow-discharge treatment), seed temperature (after treatment), moisture loss (during treatment), voltage (average drop across the tube), and energy (total developed during treatment). Pressure was 2 mm Hg for all evacuated treatments. Seed temperatures generally increased as current increased. Moisture loss was sometimes higher for the 6-minute treatments but did not seem to show a trend as current changed. Voltage drop across the tube decreased gradually as current increased, thus agreeing with theory (5). Energy increased linearly as current increased, as shown in Figure 7, for both the 3- and 6-minute treatments. Six-minute energy values were about twice as high as the 3-minute. The three control treatments included were all at 0 current, but one was evacuated at 6 minutes, one at 3 minutes, and one was taken directly from the seed supply.

The simple correlation coefficients (r), Appendix page 67, substantiated the visual observations. Energy was highly correlated with temperature (r = 0.9684). Thus, since the change in energy for either length treatment was due mainly to the change in current, it follows that seed temperature would increase as current increased. On the other hand, moisture loss showed lower correlation to energy (r = 0.8161), indicating about 40 percent of the variation was unaccounted for. The high correlations between percent germination and energy squared of 0.8680 at 2 days to 0.8042 at 12 days showed that energy squared provided a good estimate of cottonseed response. This was also indicated by the regression equations, pages 54 and 56.

Lines joining points on graphs indicate trends and should not be used to predict ordinate values for a given treatment.

I. EFFECTS OF DC GLOW DISCHARGE TREATMENT ON GERMINATION

The analysis of variance test showed significance at the 1 percent level among the germination means on every day

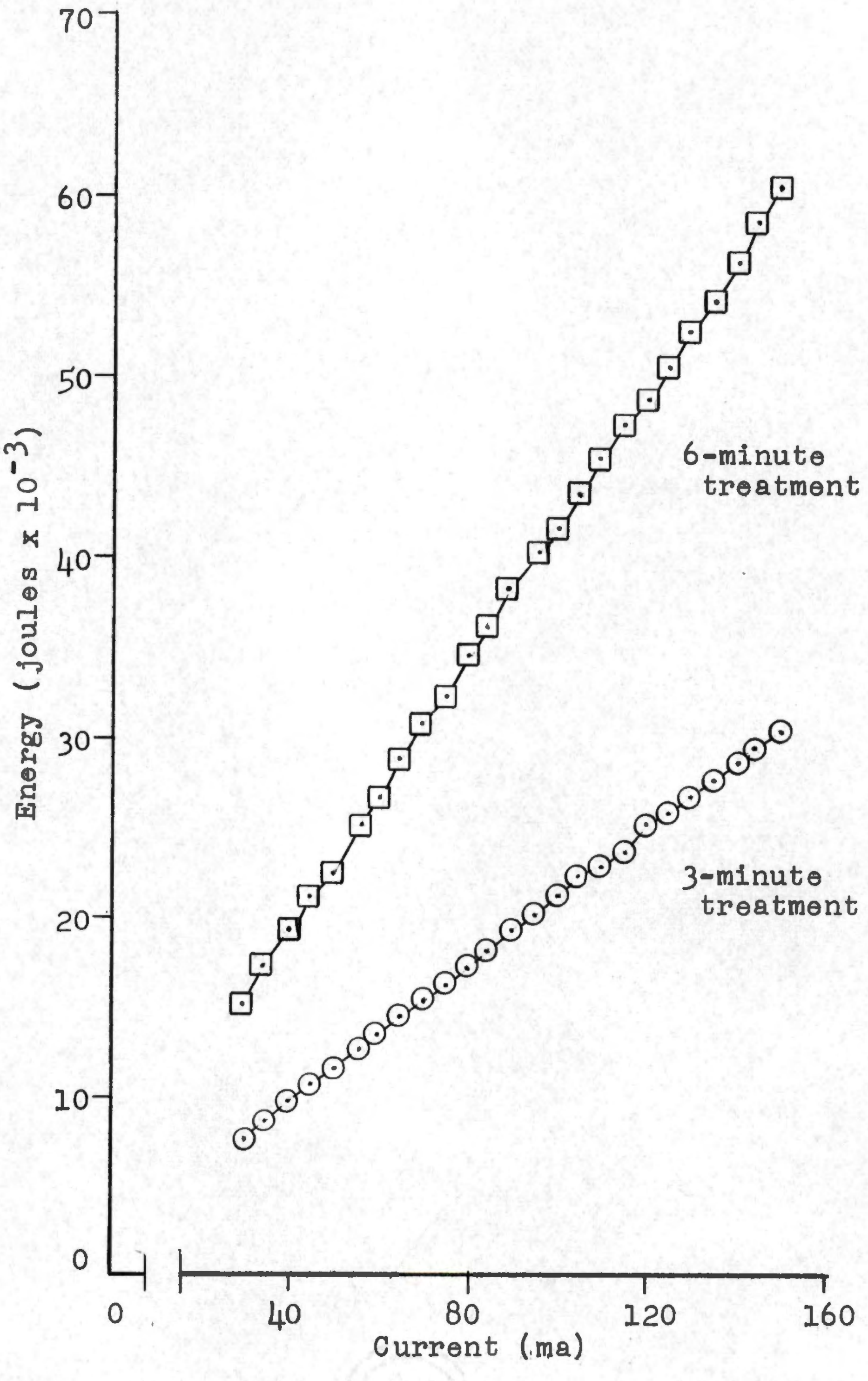

Figure 7

Energy Generated During Treatment

counted, (Appendix, page 68). The percent germination means after 2, 3, and 12 days are shown in Table II. The Duncan's Multiple Range Test results are included to separate the means at the 5 percent probability level. The 2-day percent germination results show 40 glow-discharge treatment means significantly higher than the controls. The 10 means not superior to the controls were from 6-minute treatments at 100 to 150 ma. There was no significance among the three control samples. The 3-day germination data show 31 glow discharge treatments significantly different than the control samples. At 12 days, three glow-discharge treatments were significantly higher than the control evacuated for 3 minutes. There were no glow-discharge treatments significantly above the other two controls. However, there were nine of the treatments at the higher energy levels that were significantly lower in germination than any of the control samples. These trends are similar to those reported by Webb (30).

II. EFFECTS OF CURRENT INTENSITY ON GERMINATION

The glow discharge at 30 and 90 ma is shown in Figures 8 and 9, respectively. Both figures show the long positive column with the adjoining Faraday dark space. As described by Cobine (5) the glow seems to cling to the cathode (left

TABLE II

MEAN PERCENT GERMINATION AFTER 2, 3, AND 12 DAYS IN THE GERMINATOR

	Means**					
Treatment*	2-day germination		3-day germination		12-day germination	
1	73	ab	85	ab	90	a
2	72	ab	84	a-c	88	ab
3	67	a-d	80	a-d	86	a-d
4	68	a-d	81	a-d	86	a-d
5	70	a-c	84	a-c	89	ab
6	64	a-e	80	a-d	83	b-d
7	62	b-f	81	a-d	88	ab
8	66	a-e	83	a-c	88	ab
9	60	b-f	76	c-e	83	b-d
10	76	a	85	ab	88	ab
11	68	a-d	82	a-d	88	ab
12	64	a-e	82	a-d	86	a-d
13	70	a-c	85	ab	89	ab
14	66	a-e	82	a-d	87	a-c
15	60	b-f	80	a-d	87	a-c
16	66	a-e	79	a-d	87	a-c
17	62	b-f	80	a-d	89	ab
18	65	a-e	80	a-d	84	a-d
19	67	a-d	82	a-d	87	a-c
20	61	b-f	80	a-d	84	a-d
21	63	a-e	80	a-d	84	a-d
22	66	a-e	82	a-d	86	a-d
23	67	a-d	81	a-d	88	ab
24	60	b-f	74	d-f	84	a-d
25	66	a-e	79	a-d	86	a-d
26	71	ab	85	ab	89	ab
27	73	ab	85	ab	90	a
28	66	a-e	80	a-d	86	a-d
29	69	a-c	84	a-c	88	ab
30	65	a-e	81	a-d	87	a-c
31	68	a-d	81	a-d	87	a-c
32	69	a-c	86	a	89	ab
33	68	a-d	84	a-c	90	a
34	66	a-e	79	a-d	87	a-c
35	64	a-e	81	a-d	88	ab

TABLE II (continued)

	Means**					
Treatment*	2-day germination		3-day germination		12-day germination	
36	71	ab	81	a-d	87	a-c
37	65	a-e	78	a-e	84	a-d
38	57	c-f	76	c-e	84	a-d
39	53	e-g	77	b-e	85	a-d
40	50	f-h	68	f-h	80	de
41	42	g-i	66	g-i	77	ef
42	55	d-f	71	e-g	81	c-e
43	42	g-i	63	h-j	76	ef
44	41	hi	60	i-k	72	fg
45	38	hi	54	kl	68	gh
46	38	hi	50	lm	65	h
47	24	jk	36	n	56	j
48	30	ij	44	m	57	j
49	14	k	25	o	44	k
50	15	k	27	o	42	k
51	40	hi	71	e-g	88	ab
52	34	ij	58	jk	83	b-d
53	38	hi	68	f-h	88	ab

*The conditions of treatment are listed in Table I.

**Means followed by the same letter are not significantly different at the 5 percent probability level.

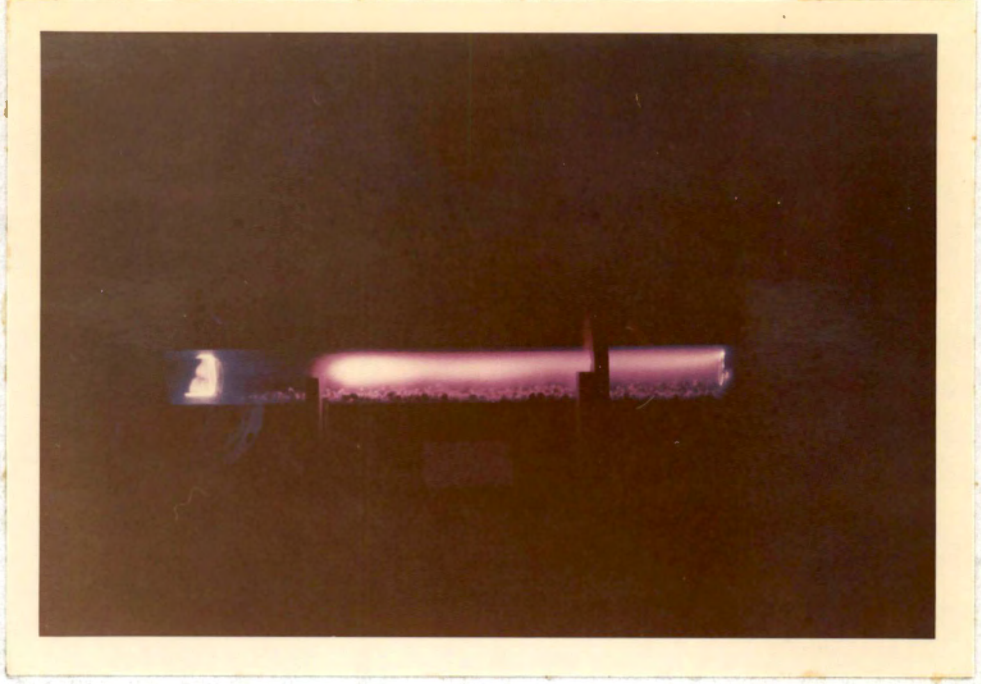

Figure 8

Glow Discharge With 30 Milliampere Current

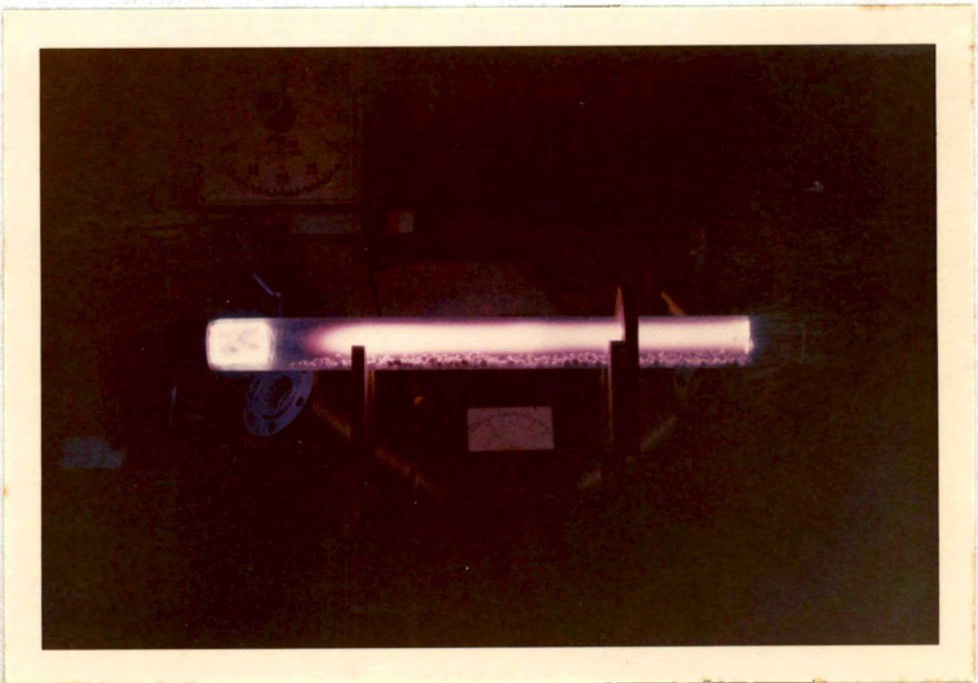

Figure 9

Glow Discharge With 90 Milliampere Current end) and with higher current more completely covers the cathode. The higher current displays a longer positive column, and more visible irradiation is apparent. It may also be noted that the seeds are below the regions of maximum intensity.

The analysis of variance test showed highly significant differences at the 1 percent level among current means at all days of germination (Appendix, page 69). A comparison between 2- and 12-day current means is plotted in Figure 10. The downward trend at the higher current levels is apparent at both days. The means and the separation of means via the Duncan's Multiple Range Test are given in Table III. For each of the 3 days the lower current means gave the highest germination with the high current means giving significantly lower germination. There was no significant difference among the 30-65 ma, the 30-90 ma, or the 30-110 ma means after 2, 3, and 12 days, respectfully.

III. EFFECTS OF LENGTH OF TREATMENT

Shortening the treatment time would be advantageous because of the increased volume of material which could be treated. The analysis of variance test showed significance between treatment times of 3 and 6 minutes on each day counted. Investigation of the means showed that in each case the 3-minute treatments were significantly superior to the 6-minute

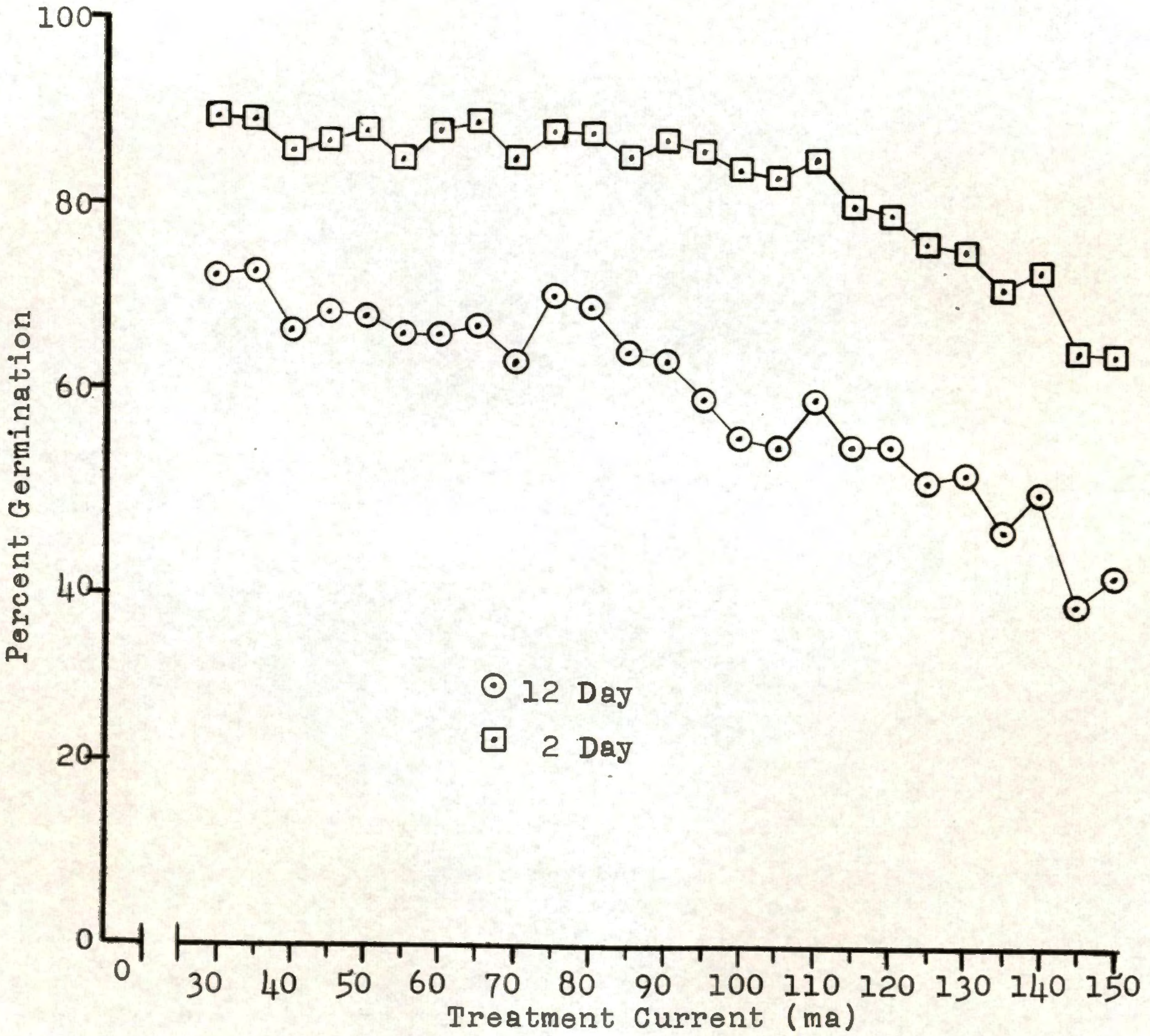

Figure 10

Effect of Current Intensity

TABLE III

MEAN PERCENT GERMINATION FOR EACH CURRENT LEVEL AFTER 2, 3, AND 12 DAYS IN THE GERMINATOR

Current (ma)	Means*					
	2-day germination		3-day germination		12-day germination	
30	72	ab	85	a	89	a
35	73	a	84	ab	89	a
40	66	a-d	80	a-d	86	a-c
45	68	a-c	82	a-c	87	ab
50	68	a-c	82	a-c	88	ab
55	66	a-d	80	a-d	85	a-c
60	66	a-d	84	ab	88	ab
65	66	a-d	84	ab	89	a
70	63	c-d	78	c-e	85	a-c
75	70	a-c	83	a-c	88	ab
80	69	a-c	82	a-c	88	ab
85	64	b-d	80	a-d	85	a-c
90	63	cd	80	a-d	87	ab
95	59	de	79	b-d	86	a-c
100	55	ef	74	e-g	84	bc
105	54	ef	73	fg	82	cd
110	59	de	76	df	85	a-c
115	54	ef	72	fg	80	d
120	54	ef	70	gh	79	de
125	50	fg	67	hi	76	ef
130	50	fg	65	ij	75	f
135	45	gh	59	k	71	g
140	49	fg	62	jk	73	fg
145	37	i	50	l	64	h
150	40	hi	53	l	69	h

*Means followed by the same letter are not significantly different at the 5 percent probability level.

treatments. These data are plotted in Figure 11 showing the trend of higher germination by the 3-minute treatments.

IV. EFFECTS OF ENERGY ON GERMINATION

The germination results showed a near constant response at the lower energy levels, both for the 2- and 12-day germination (Figure 12). At 2 days the second-highest energy (58,777 joules) had the lowest germination of 15 percent, while at 12 days the lowest germination was 42 percent at the highest energy level of 60,588 joules (Table I, page 38, and Table II, page 45). Contrasted to this, the highest germination at 2 days was 76 percent for treatment 10 (16,322 joules), and at 12 days was 90 percent for treatments 1, 27, and 33, with 7,711, 17,514, and 28,969 joules, respectively (Table I, page 38, and Table II, page 45).

Regression analyses were run, assuming percent germination to be a function of energy (E), energy squared (E^2), seed temperature (ST), seed temperature squared (ST^2), moisture loss (ML), and moisture loss squared (ML^2). The equations were put in the form given by Snedecor (22) as

$$\hat{Y} = \bar{Y} + (X_1 - \bar{x}_1) + (X_2 - \bar{x}_2) + \ldots + (X_n - \bar{x}_n)$$

where $\hat{Y}$ = predicted value of the dependent variable

$\bar{Y}$ = mean of the dependent variable

X_1 = first independent variable

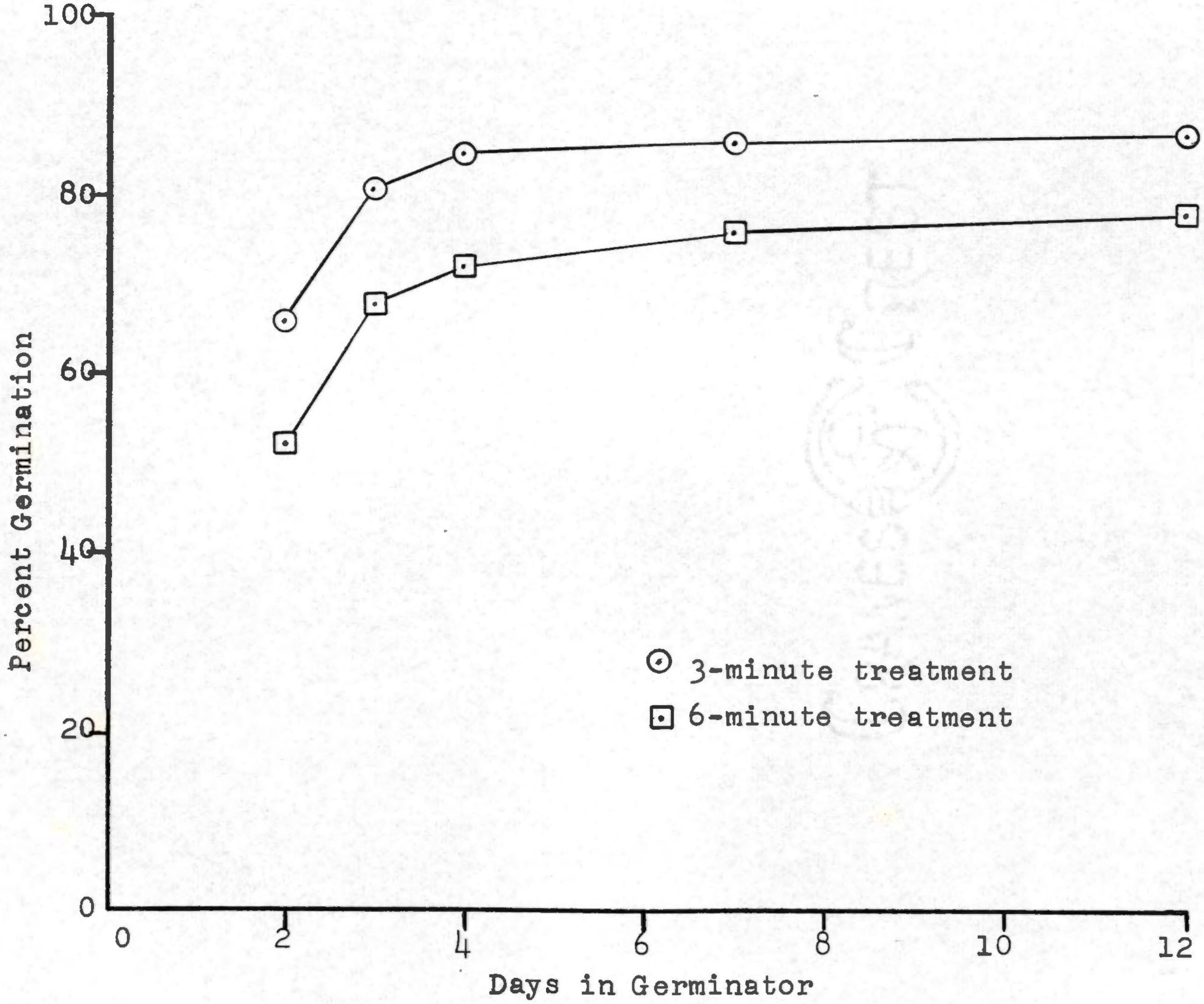

Figure 11

Effect of Length of Treatment

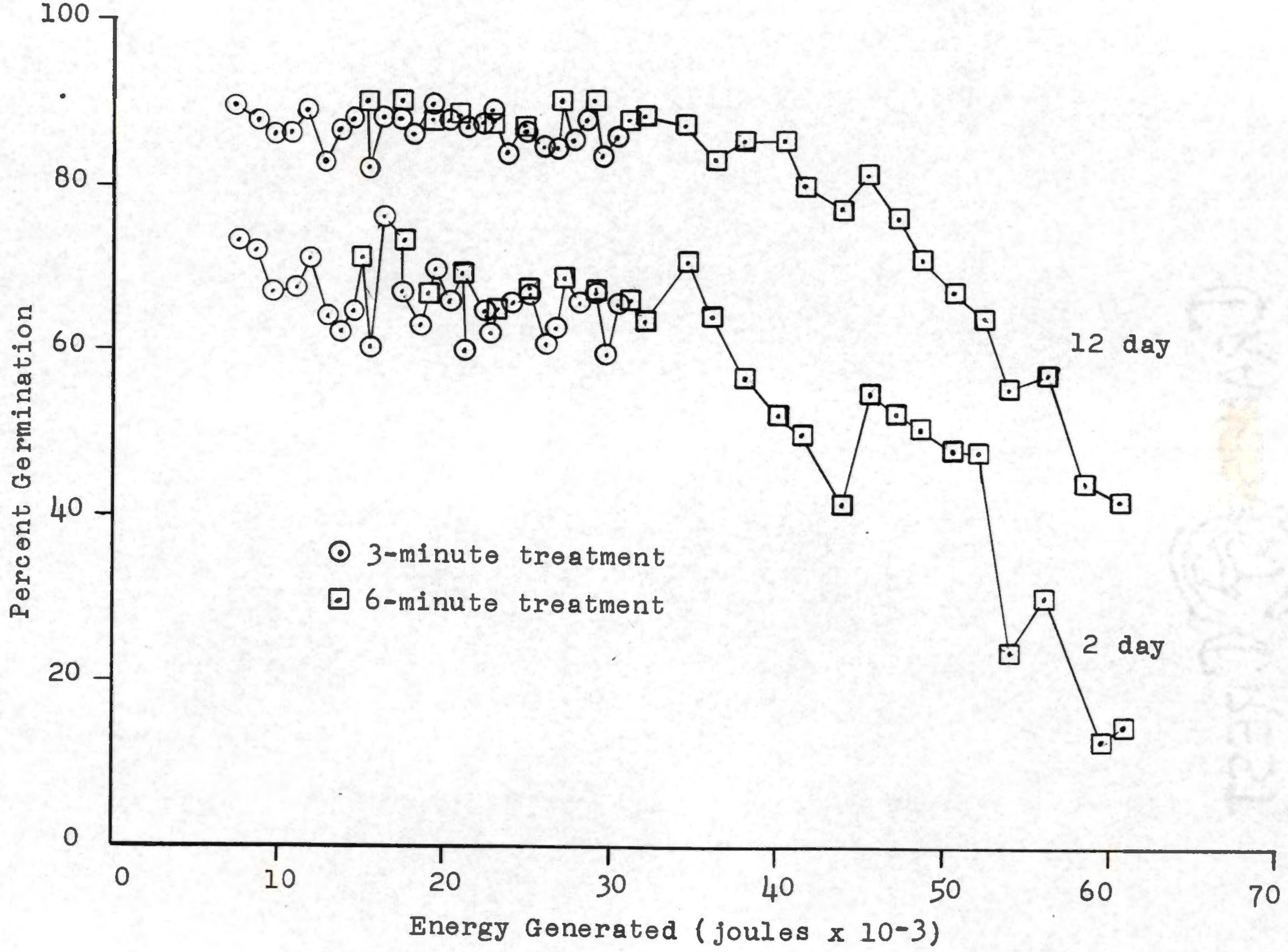

Figure 12

Effect of Energy

$\bar{x}_1$ = mean of the first independent variable
X_2 = second independent variable
$\bar{x}_2$ = mean of second independent variable
X_n = nth independent variable
$\bar{x}_n$ = mean of nth independent variable

In the curvilinear form, one or more X_i are transformed into quadratic or higher degree terms.

The equation for the regression of 2-day percent germination (P2) on E, E^2, ST, ST^2, ML, and ML^2 was

$$P2 = 98.8 + 0.00158E - 0.284 \times 10^{-7} E^2 - 0.529TE + 6.31ML - 1.85ML^2 .$$

Seed temperature squared (ST^2) was deleted because it did not contribute significantly to the prediction equation. The variables in the order they were entered into the equation, and their multiple R^2 values, and their increase in R^2, where R^2 represents the approximate percent of the total variation in P2 which was accounted for by all the variables in the equation at that point were shown in Table IV. The R^2 and the increase in R^2 values show that very little of the variation in P2 was accounted for by ML and ML^2. However, E proved to be very useful, in that E and E^2 together accounted for about 91 percent of the variation in P2. Temperature

TABLE IV

MULTIPLE R^2 VALUES FOR 2-DAY GERMINATION

Variable	R^2	Increase in R^2
E^2	0.8678	0.8678
E	0.9096	0.0418
TE	0.9313	0.0217
ML	0.9315	0.0002
ML^2	0.9331	0.0016

added 0.0217 to R^2, so that E^2, E, and TE together accounted for about 93 percent of the variation in P2.

The regression equation for 12-day germination (P12) was

$$P12 = 101.9 + 0.00163E - 0.259 \times 10^{-7} E^2$$

$$- 0.368TE + 6.72ML - 2.99ML^2.$$

The order of entry, R^2, and increase in R^2 for P12 was shown in Table V. Energy squared (E^2) and E together accounted for about 92 percent of the total variation. A comparison of the total variation in P2 and P12 accounted for by each combination of variables was made as follows: (1) E alone accounted for nearly 87 percent at 2 days but just 80 percent at 12 days; (2) E^2 and E together accounted for about 91 percent at 2 days and about 92 percent at 12 days; (3) E^2, E, and TE accounted for about 93 percent at 2 days and 94 percent at 12 days; (4) ML was added fourth at 2 days, but increased R^2 only 0.0002, while ML^2 was added fourth at 12 days, increasing R^2 by 0.101; and (5) ML^2 added to E^2, E, TE, and ML at 2 days increased R^2 by 0.0016, while ML was added to E^2, E, TE, and ML^2 at 12 days, increasing R^2 by 0.0036. Thus, the moisture loss data added very little to either P2 or P12.

TABLE V

MULTIPLE R^2 VALUES FOR 12-DAY GERMINATION

Variable	R^2	Increase in R^2
E^2	0.8036	0.8036
E	0.9226	0.1189
TE	0.9378	0.0153
ML^2	0.9480	0.0101
ML	0.9515	0.0036

CHAPTER VI

SUMMARY AND CONCLUSIONS

A wide variety of electrical treatments have been used on plants and plant materials. The glow-discharge treatment subjects material to electric and magnetic fields, and bombardment by ions and electrons. The energy lies principally in the ultraviolet range (5). The objectives of this experiment were to determine the effects of DC glow-discharge treatment, current intensity, exposure time, and energy on the early and total germination of Empire WR cottonseed. The experiment was conducted in the USDA-ARS-AE laboratory, at the Department of Agricultural Engineering, The University of Tennessee, Knoxville, Tennessee.

Empire WR 61 cottonseed, 1964 crop, was DC glow-discharge treated at 25 current levels (30-150 ma) and two exposure times of 3 and 6 minutes. Treating tube pressure was held constant at 2 mm Hg. Control samples were included at 6, 3, and 0 minutes evacuation at 2 mm Hg. Four replications of 100 seeds each were planted in a seed germinator at conditions of 20°C for 16 hours and 30°C for 8 hours. Germination counts were made at 2, 3, 4, 7, and 12 days.

Analysis of variance showed significance among the combination of 50 glow-discharge treatments and three controls, between the treating times, and among current intensities. These were highly significant at the 1 percent level on every day germination was counted. Duncan's Multiple Range Test at the 5 percent level showed significant increases in early germination of 40 treated samples. Three glow-discharge treatments showed significantly higher total germination (90 percent) than the control evacuated for 3 minutes (83 percent). No treatments showed total germination superior to the other two controls. Nine glow-discharge treatments showed significant decreases in total germination. Their total germination ranged from 42 to 77 percent.

Current intensity affected the germination at the current levels of 100-150 ma. The 30 ma treatment had 2- and 12-day germination means of 72 and 89 percent, respectively. However, the 150 ma treatment had means of only 40 and 64 percent on 2 and 12 days, respectively.

The 3-minute treatments were superior to the 6-minute treatments on every day germination counts were made. Early germination was 66 percent for the 3-minute and 53 percent for the 6-minute treatments. Total germination was 87 and 78 percent for the 3- and 6-minute treatments, respectively.

Least squares regression analysis showed that energy and energy squared together accounted for about 91 percent of the variation in the germination, and 92 percent of the variation in the total germination. Energy, energy squared, and temperature accounted for about 93 percent of the variability in early germination and nearly 94 percent of the variability in total germination.

I. SUMMARY OF RESULTS

1. Direct-current glow-discharge treatments stimulated the early germination of Empire WR 61 cottonseed by as much as 42 percent over a control sample.
2. Treatments of high currents (100-150 ma) and an exposure time of 6 minutes decreased early germination by as much as 26 percent and total germination by as much as 46 percent.
3. Energy was highly correlated with percent germination ($r = 0.8680$ at 2 days and 0.8042 at 12 days). Furthermore, energy and energy squared accounted for over 90 percent of the total variability in the germination data.
4. Water loss was determined not to be a good predictor of seed germination.

II. AREAS FOR FUTURE STUDY

1. Effect of exposure times from a few seconds to 3 minutes.

2. Effect of different regions in the treating tube on energy produced and germination.
3. Effect of germination conditions of temperature and moisture tension of substrata.
4. Effect of treatment pressure.
5. Effect of storage conditions before and after treatment--i.e., moisture content at treatment and planting.

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APPENDIX

TABLE VI

PARTIAL CORRELATION COEFFICIENTS

Variable	2 Day	3 Day	4 Day	7 Day	12 Day	Energy	Energy^2	Temperature	Temperature^2	Water Loss	(Water Loss)^2
2 Day	1.000	0.9774	0.9673	0.9597	0.9577	-0.8680	-0.9316	-0.8475	-0.8772	-0.6769	-0.7559
3 Day		1.000	0.9960	0.9917	0.9899	-0.8440	-0.9244	-0.8159	-0.8520	-0.6956	-0.7877
4 Day			1.000	0.9968	0.9950	-0.8288	-0.9151	-0.8005	-0.8381	-0.6977	-0.7910
7 Day				1.000	0.9993	-0.8104	-0.9014	-0.7782	-0.8166	-0.6812	-0.7807
12 Day					1.000	-0.8042	-0.8965	-0.7707	-0.8093	-0.6784	-0.7803
Energy						1.000	0.9778	0.9684	0.9723	0.8161	0.8219
Energy^2							1.000	0.9319	0.9509	0.7931	0.8330
Temperature								1.000	0.9971	0.7694	0.7679
Temperature^2									1.000	0.7725	0.7826
Water Loss										1.000	0.9743
(Water Loss)^2											1.000

TABLE VII

MEAN SQUARES FROM ANALYSES OF VARIANCE OF ALL MEANS

		Days in germinator				
Source	df	2	3	4	7	12
Treatments	52	914**	841**	725**	520**	469**
Replications	3	39	30	44	75**	49*
Error	156	63	24	17	16	15

**Indicates significance at the 1 percent level of probability.

*Indicates significance at the 5 percent level of probability.

TABLE VIII

MEAN SQUARES FROM ANALYSES OF VARIANCE OF CURRENT AND TIME MEANS

		Days in germinator				
Source	df	2	3	4	7	12
Currents I	24	808^{**}	811^{**}	724^{**}	500^{**}	448^{**}
Times T	1	8738^{**}	8463^{**}	6903^{**}	4675^{**}	4113^{**}
I X T	24	581^{**}	605^{**}	551^{**}	420^{**}	386^{**}
Replications R	3	28	27	31	61^{*}	40
I X R	72	51	18	13	13	13
T X R	3	241^{**}	66^{*}	31	23	40
Error	72	58	24	19	16	15

**Indicates significance at the 1 percent level of probability.

*Indicates significance at the 5 percent level of probability.

VITA

John L. Goodenough was born May 12, 1938 at Morrison, Illinois, the son of Elmer L. and Helen F. Goodenough. He attended Unionville Elementary School and Morrison Community High School. He received the State Farmer Degree in FFA, and served as sophomore class secretary and senior class president. Entering the University of Illinois in 1960, he received a Bachelor of Science with a major in Agricultural Engineering in 1965. He has been employed with the Agricultural Engineering Research Division, Agricultural Research Service, United States Department of Agriculture at Knoxville, Tennessee, from July 1965 to present. He entered the graduate school of The University of Tennessee the fall quarter, 1965. He expects to receive a Master of Science with a major in Agricultural Engineering in August, 1968.

He was married in 1958 to Marilyn Conner. They have two children, Michael, 9, and Machelle, 6.