MEASUREMENT OF SEEDBED COMPRESSION
AS RELATED TO
COTTONSEED GERMINATION AND SEEDLING EMERGENCE

by

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TABLE OF CONTENTS

TABLE OF CONTENTS--Continued

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS--Continued

LIST OF TABLES

ABSTRACT

Obtaining good cotton stands is economically important, but has always been a major problem in cotton production. Compaction of the seedbed is a major factor in the functional performance of planting equipment. If the soil pressures exerted on the seed can be used to predict germination and seedling emergence, the measurement of these soil pressures would be of value in the design and testing of planting equipment.

A small "seed-type" cell was designed and constructed which enabled measurement of soil pressures at seed level in response to forces applied at the soil surface. The cell was used in a laboratory study of seed germination and seedling emergence. The measurements revealed unexpected micro-variations in soil pressure distribution. These micro-variations prevent making predictions of germination and seedling emergence from the measured soil pressures at seed level.

Applied average surface pressure is more reliable in predicting emergence than the measured soil pressures by the "seed-type" cell. An increase in surface pressure reduced seedling emergence, but a high soil moisture level helped seedlings overcome the detrimental effect of high surface pressures.

INTRODUCTION

General Discussion

Obtaining good cotton stands has always been a major problem in cotton production. High rates of cotton seed are normally planted. After emergence the plants are thinned to the desired plant population. In Arizona, planting rates are usually about twice that of the desired final stand. This practice is intended as insurance for good stands, but even this does not prevent skips in the field.

The planting operation is a critical one because stands are dependent on this operation. The necessity of obtaining good stands is obvious because bare farm ground cannot provide income. Production costs must also be kept a minimum to yield profits. Planting in Arizona costs approximately $1.75 per acre. This figure does not include seed cost which is approximately $2.00 per acre. Thinning to the desired plant population costs approximately $4.50 per acre. Each additional operation adds to production costs, therefore, it is desirable to eliminate unnecessary operations. If the desired plant population could be obtained from the initial planting operation, thinning would be unnecessary thus reducing production costs approximately $4.50 per acre.

Statement of Problem

Planting machines have been developed to place seeds in the soil. The row crop planters open a furrow in the seedbed, drop the seed, and cover the seed with soil in one operation. Since there are several methods of achieving this operation, many planter variations and combinations of components are available. Various attachments may be used in combination with planters and are sometimes considered an integral part of the planter.

Fertilizer units are usually attached and used for fertilizer placement during the planting operation. Narrow seed press wheels are usually used on cotton planters to press the seed into the soil before it is covered. Press wheels can be attached to the planter to firm the soil above the seed. In Arizona, disk hillers are sometimes attached to the planter behind the surface press wheel to form a hill of soil 4 to 6 inches deep above the seed. Removing this cap before the cotton seedlings emerge is a critical operation and adds an additional machine coverage of the field.

The functional operation of the planter is of interest to everyone concerned with crop production. The designers of tillage equipment should design implements that will form a seedbed which will not hinder planter performance. The farmer should use this equipment in the best possible way to prepare for the planting operation. Information is vitally needed about the physical requirements of the seedbed so that designers and operators can achieve top functional performance of their machines.

The degree of compaction of the seedbed is a major factor in controlling the performance of planting equipment. Compaction from tractor and implement traffic during operations previous to planting can cause poor planter performance. Compaction caused during the planting operation can prevent seedlings from emerging. The degree of compaction can be largely controlled by farmers and designers of farm machinery. To intelligently control the degree of compaction when planting, the desirable seedbed environment for each crop must be known.

Methods of determining this desirable seedbed environment need to be established. A method of measuring seedbed compression is especially needed since it is a controlling factor of many interrelated factors. This method should provide a means to evaluate the functional performance of planting equipment in field tests.

Previous Studies

Previous seedling emergence studies have revealed some of the factors for consideration in making an emergence study.

Soil Particle Size. Yoder (43) planted cotton in small nonduplicated plots where the soil was prepared in various clod size combinations. The combination of approximately 50 per cent granules one-eighth to one-fourth inch diameter and the rest smaller, gave earlier emergence than other combinations. The per cent emergence did not appear to be affected except by clod sizes greater than 2 inches in diameter. However, the per cent survival at maturity was reduced in soil composed of combinations of 50 per cent clod size diameter two to four inches, 25 per cent clod size diameter one to two inches, 13 per cent clod size diameter one-half to one inch, and the remaining per cent smaller clod sizes.

Synthetic Soil Conditioners. Jamison (22) found that the addition of synthetic soil conditioners increased cotton seedling emergence. Crust strength was reduced at similar apparent specific gravity, consolidation decreased under a given applied pressure, and aggregate stability increased when synthetic soil conditioners were used.

Pressure and Compaction. A "mechanical seedling" was used by Morton and Buchele (27) to study energy requirements for seedling emergence. As the mechanical seedling was forced upward through a three inch layer of soil, the energy expended was measured. A hydraulic press was used to apply surface loads to a Brookston sandy loam soil containing 12, 16, and 20 per cent moisture. The emergence energy was found to increase directly with seedling diameter, compaction pressure, and length of drying time. High compaction pressures caused a greater increase in emergence energy requirements than the lower compaction pressures during the same drying period. When compaction pressures were applied at seed level, the maximum emergence energy requirement was less than when compaction was applied to the surface.

Stout, Buchele, and Snyder (37) studied the effect of applying different loads to the surface of a soil under simulated field conditions. They used a hydraulic press to load the soil composed of an undisturbed core of Sims subsoil beneath a layer of Sims sandy clay topsoil. Each layer was eight inches deep and kept in a chamber maintained at a temperature of 60°F. A five mile per hour wind was kept blowing across the surface, and radiant heat was applied by lamps.

Loads greater than one-half pound per square inch, when applied to the soil surface, usually suppressed emergence of corn, sugar beet, and bean seedlings. When applied at the seed level, loads of five and ten pounds per square inch improved emergence.

Heath (19) studied the effect of soil consolidation on the growth of cotton by using a track-type tractor to compress field plots of a medium red loam soil at Barberton, South Africa. The compressed plots showed a somewhat higher and earlier germination than the loose plots. There was no significant difference in germination or emergence between the compressed and normal plots, but growth and root development were reported to be more favorable after soil consolidation.

The effects of various roller treatments on a sandy loam range soil where crested wheatgrass was sown were studied by Hyder and Sneva (21). Their results revealed that rolling to firm the seedbed provided advantages in moisture retention, rate of seedling emergence, seedling growth, survival, lateral root distribution, and the occurrence of root hairs near the surface. Heavy rolling above the seed was undesirable because it restricted emergence and aeration.

Triplett and Tesar (40) applied loads in 0, 3, 6, and 12 pounds per square inch intensity to the soil surface above alfalfa seed which was planted at four different depths. They showed that depth, compaction, and their interaction had a highly significant affect on soil moisture and seedling emergence.

A greenhouse experiment to determine the effects of reduced soil air space on growth of tomatoes was conducted by Flocker, Vomocil, and Howard (13). They compressed Yolo fine sandy loam, Salinas clay loam, and Sacramento clay soils using a hydraulic press to load each one-fourth of the soil as the container was filled. Their results showed that compressing the soil increased the time required for seedling emergence, and that percentage germination was increased up to a certain soil density, at which point further compression reduced germination. Growth curves indicated that the maximum rate of growth occurred at different plant ages depending on soil air space. Optimum air space for maximum plant height was calculated to be 40 per cent for Salinas clay loam soil, 35 per cent for Yolo fine sandy loam soil, and 26 per cent for Sacramento clay soil.

In a field study of the effect of soil compaction on tomatoes and potatoes, Flocker, Timm, and Vomocil (12) found that soil compaction which was applied by a loaded truck did not significantly reduce tomato yields. Potato yields and quality were both adversely affected by compaction treatment.

Van Doren (42) found that corn yields were affected when compacted by 40 pounds per square inch wheel-tractor load. He attributed 80 per cent of the difference in the corn yields to stand differences caused by poor planter operation on a rough seedbed and poor seedling emergence. The compaction treatment caused the rough seedbed and an adverse effect on plant growth to which Van Doren attributed the other 20 per cent difference in yields.

Crust Strength. Surface crusting is a serious problem affecting the emergence of some seedlings in some soils. Hanks and Thorp (17) have concluded that the modulus of rupture is a good measure of crust strength as related to seedling emergence of wheat and similar plants. Richards (33) studied the modulus of rupture on a fine sandy loam soil and shows how crusting affected bean emergence. When the modulus of rupture was 108 millibars, no decrease in bean emergence was noticed, but at a modulus of rupture of 273 millibars, there was no bean emergence. Carnes (6) also recognized the importance of crust strength and suggested that the soil should be packed below the seed in order to give the seedling a firm footing for penetrating the surface crusts.

Bowen (4) used small balloons buried in the soil to measure physical impedance. His results show how physical impedance changes with time and its effect in decreasing cotton seedling emergence. These measurements have considerable merit in interpreting seedling environment.

Oxygen. Buckingham (5), using the kinetic theory of gasses, expressed the diffusion of gas in the soil as a function of free pore space in the relation:

(1) $D = KS^2$

Where:

D is the diffusion constant

K is a proportionality factor

S is the free pore space.

The diffusion process accounts for the major exchange of air between the soil and atmosphere.

This relation has been used in studying the effect of oxygen on seedling emergence. Hanks and Thorp (18) found that the germination of wheat decreased as the oxygen diffusion rate decreased. Bowen (4) obtained similar results with cotton.

Moisture. Moisture is probably the most important single factor governing germination of seed. McGinnies (25) reported that increased moisture stress delays germination of range grass seed. Hanks and Thorp (18) found that the rate of emergence of soybeans, grain sorghum, and wheat was directly related to the soil moisture content.

Temperature. Temperature influences the germination of seeds, and affects each crop differently. Recommendations for soil temperatures are given for most crops and regions. Cotton seeds need a temperature of 58°F to start germination. A soil temperature of 65°F or higher is recommended before planting cotton.

Summary. Of the many factors that influence speed and completeness of germination and seedling emergence, temperature, moisture, oxygen, and physical impedance are of most concern. The interaction of the factors is important also. Since compaction by surface loads either directly or indirectly influences all of these factors, its importance is recognized. There is a need for interpreting the effect of compaction on the emergence of seedlings. Emergence has been generally correlated with surface loads. Interpretations in this manner must assume that the loads result in a uniform pressure being exerted at seed level. This is highly improbable in field operations. Since it is not apparent that this method of interpreting seedling emergence is readily adaptable to field studies, further investigation is needed to develop a method to correlate seedling emergence with seedbed compression.

Scope of Thesis

It is the purpose of this thesis to present a method to measure pressures in the seedbed and to determine if these measurements can be used to evaluate per cent germination and seedling emergence. A small device has been developed and tested in a laboratory study of the affect of soil compression by surface loads on cotton seedling emergence.

SOIL COMPRESSION

Theoretical Pressure Distribution

Several attempts have been made to develop methods of predicting soil reaction to pressure. Most of these are based on mathematical stress-strain relations.

<u>Boussinesq Solution</u>. Spangler (36) presents the widely used Boussinesq equations which were developed as a theoretical approach to estimating earth pressures. Boussinesq obtained the solution for an idealized elastic, homogenous, isotropic mass of material which extends an infinite distance laterally and downward from the point of application of the load on a horizontal boundary surface. When properly applied, these equations and the modifications of these equations may be used as guides for determination of stresses in the soil.

The Boussinesq equations for the normal stresses shown in Figure 1 are as follows:

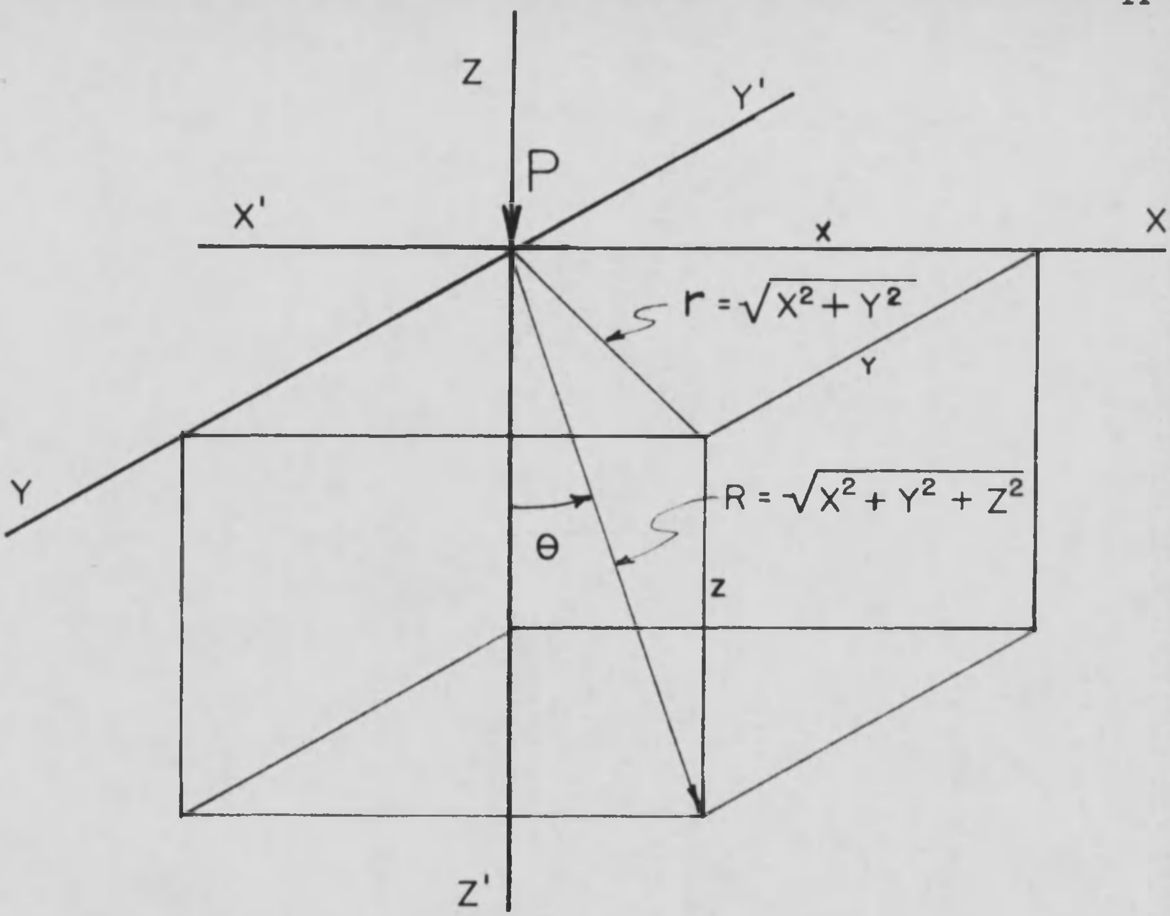
(2) $$\sigma_z = \frac{3PZ^3}{2\pi R^5}$$

(2a) $$\sigma_z = \frac{3P\cos^5\theta}{2\pi Z^2}$$

(3) $$\sigma_x = \frac{P}{2\pi}\left[\frac{3X^2Z}{R^5} - (1-2\nu)\left(\frac{X^2-Y^2}{Rr^2(R+Z)} + \frac{Y^2Z}{R^3r^2}\right)\right]$$

(4) $$\sigma_y = \frac{P}{2\pi}\left[\frac{3Y^2Z}{R^5} - (1-2\nu)\left(\frac{Y^2-X^2}{Rr^2(R+Z)} + \frac{Y^2Z}{R^3r^2}\right)\right]$$

Where:



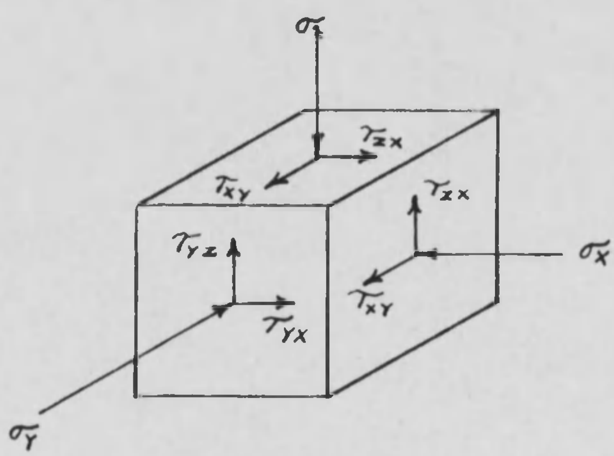


FIGURE 1. Boussinesq Diagram

P is the applied load.

Z is the depth to the point of stress determination below the boundary surface.

R is the radius from the point of load application to the point of stress determination.

θ is the angle that the radius makes with reference to the vertical load line.

r is the radius on the boundary surface from the point of load application to the projection of the point of stress determination.

ν is Poisson's ratio.

Using a value of 0.5 for Poisson's ratio, equations (3) and (4) reduce to:

$$(5) \qquad \sigma_X = \frac{3PX^2Z}{2\pi R^5}$$

$$(6) \qquad \sigma_Y = \frac{3PY^2Z}{2\pi R^5}$$

Modified Boussinesq Equations. With n used to denote concentration factor and obtained from experimental evidence, the equations are:

$$(7) \qquad \sigma_Z = \frac{(n-2)\,P\,Z^{(n-2)}}{2\pi R^n}$$

$$(7a) \qquad \sigma_Z = \frac{(n-2)\,P\cos^n\theta}{2\pi R^n}$$

These equations have been utilized in studying the "Pressure Bulb" formed by connecting points of equal stress beneath a surface load. Walter Soehne (35), using the Boussinesq equations as modified by

O. K. Froehlick, has given the fundamentals of pressure distribution under tractor tires.

Doner's Law of Compression. Doner (11) developed theoretical laws in terms of the cohesive force of moisture films and the coefficient of internal friction, or shear, between average particles. He expressed the law of compression as:

$$\frac{T - T_m}{T_o - T_m} = e^{-K'W} \tag{8}$$

Where:

T is the height of a column of a medium under any particular pressure.

T_m is the minimum thickness attainable without crushing.

T_o is the thickness of the layer when $W = 0$.

k' is a function of moisture content.

w is pressure.

It must be remembered that these pressures are estimated and are only as accurate as the medium approximates that upon which the equations are based.

Observed Pressure Distribution

Confined Fragmented Soils. Nichols (28) studied the resistance to compression of confined fragmented soils and found two phases of reaction to pressure within the range of his study. One phase consisted of a rearrangement or collapse of the fortuitous structure formed when putting the soil in the container. The second phase consisted of the resistance to rearrangement produced by cohesion and internal friction. The latter phase involves structural rearrangement of interlocking particles after contact is made between the soil particles of the mass.

Nichols and Reaves (29) continued this study and found that pressure-compression curves followed equations of the general form $y = ae^{bx}$,

where:

y indicates the amount of compression.

x indicates the pressure.

a and b are constants.

The relationship between pressure and compression was $\frac{dy}{dx} = KY$ which means that the amount of compression was proportional to the amount of initial compression. They reported that their measurements conformed to Doner's basic mathematical theory of compression.

<u>Arch Action</u>. Arch action is distinguished from compression in the following way. Compression is the reduction in volume by a compressive force whereas arch action is the tendency of a soil to distribute a compressive force, or sometimes called a vectoring out of pressure action.

Nichols and Reaves (29) have studied arch action by visual and measured methods. One of their visual studies utilized the plaster-cast method. Layers of soil were separated by fine aluminum leaf thus permitting change in shape and density of the layers to be obtained and cast. Another method permitted observation of the path of moving particles as traced on a glass coated with levigated aluminum. Arch action was also evaluated by using lucite cylinders in measuring the relationship of the pressure transmitted through the soil mass to that applied to the surface. They concluded that arch width is influenced largely by the friction and interlocking of particles with cohesion a secondary factor.

Chancellor and Schmidt (7) have taken X-ray photographs of lead balls arranged in a rectangular pattern in a soil box 28" x 3½" x 18". Pressures were applied to the soil at the edge of the box by rectangular pistons three and six inches in length representing half-load widths to determine reaction of particles to one side of the center. These photographs reveal that the pattern of soil movement is circular and that as the load is impressed deeper in the soil, particle movement extends farther out from the point of loading. Interpretations are given to these actions in terms of broadening, flattening, and maximum shear.

Factors Affecting Soil Reaction to Pressure

Cohesion and friction are the primary factors controlling soil reaction to pressure. There are many factors that influence cohesion and friction. The interaction of these factors makes it virtually impossible to isolate them individually. The factors must be studied in relation to their influence upon each other.

Moisture. Proctor (3) devised a test to determine the moisture content that will give maximum density at a given expenditure of energy. The Proctor density test shows that with a given amount of compaction energy, as the moisture content is increased, the dry density increases to a maximum and then decreases. He theorized that the moisture acts as a lubricant which reduces the frictional resistance between soil particles thus increasing the density of the soil for a given applied force until the soil voids become filled at the maximum dry density. The additional moisture then prevents increasing density because the compaction effort cannot remove the excess moisture.

Soil Structure and Texture. Soil aggregation is the grouping together of a number of primary particles forming a secondary unit. The arrangement of the primary and secondary units is defined as the soil structure. An indication of the structure may be obtained from porosity and apparent specific gravity determinations. The degree of aggregation and the arrangement can greatly influence the behavior of the soil when loads are applied to the surface.

Texture is used to denote the size characteristics of the soil particles. Several classification charts have been developed according to the grading of soils. The textural triangle developed by the U. S. Bureau of Public Roads is widely used in classifying soils of different particle size percentage into one of ten textural groups. Soils of each textural group react differently to pressure.

Type and Nature of Load. The type of load applied to the soil is known to affect soil patterns. Soil reacts differently to static loading than to live loading. Vibration and length of time load is applied can also influence the arrangement of soil particles.

Load intensity is important in determining soil reactions. It has been observed by Benkelman and Lancaster (3) that resistance offered to penetration of a circular bearing block into a cohesive soil varies inversely as the diameter of the block; while, for a granular soil, it varies more directly as the diameter of the block.

Summary

Theoretical laws of soil pressure distribution can only be used as estimates of pressures. This is because these laws are derived by making assumptions about the soil medium. Observed pressure distribution studies show that these estimates can be useful, but cannot precisely predict soil reaction to loading because of the interaction of the factors influencing these reactions. This points to the need of measuring environmental pressures when making studies involving loading the soil surface over planted seeds.

SOIL PRESSURE MEASUREMENT

There are many methods and devices for measuring pressures within the soil. The majority of the measuring devices have been designed and used by engineers to measure soil pressures beneath foundations, highways, or airfield runways. "Soil pressure cell" is the term used to identify the measuring devices which are placed in the soil.

Problems of Pressure Measurement

Arch action is a major obstacle in obtaining accurate measurements of pressure within soil. It is believed that the arching effect caused by frictional and cohesive forces of one soil particle acting on another particle prevents accurate pressure measurement. Since there are infinite shapes, sizes, and arrangements of the soil particles, the difficulty in resolving the force action is apparent.

Some early investigators theorized that the measuring device should be rigid (10, 16). There should be no movement of the measuring device away from the soil. More recent investigators (3, 8, 23) have disagreed with this and have set forth the idea that a cell more rigid than the soil indicates pressures greater than those present in the soil, and a cell more compressible than the soil indicates pressures less than those in the soil. This infers that a measuring device must possess in itself the same elastic properties as those of the surrounding soil. It must deform in all directions to the same extent as the soil. The problem of designing a pressure cell with properties conforming to either the former or latter theories is obvious.

Pressure Cell Designs

Pneumatic Cell. Goldbeck and Smith (16) developed a cell based on the rigid pressure measuring theory. When his cell is subjected to soil pressures, a diaphragm moves about 0.0003 inch and makes electrical contact with a rigid stop. Compressed air is then used to lift the diaphragm from the rigid stop and break the electrical contact. The required air pressure is assumed to be equal to the soil pressure acting on the surface of the cell. Goldbeck (15) has later suggested that if a device is to indicate true soil pressures, it must possess in itself the same elastic properties as those of the surrounding soil.

Torque Cell. Huntington and Luetzelschwab (20) developed a pressure cell operating on the friction principle. A friction disc is placed between two diaphragms, and when pressure is applied to the surface of one of the diaphragms, the torque required to turn the friction disc is increased. Torque is applied and measured by means of a string and spring balance pulled at a uniform rate.

While measuring grain pressures with the torque cell, they found that moving the cell away from the grain as little as 0.005 inch, assuming the original diaphragm position as a reference plane, resulted in a marked decrease in the pressure reading. When the cell was pushed back to its original position, the pressure reading was much greater than the original value. This demonstrates arch action of a granular material and shows how it can significantly affect pressure measurements in the medium. The slight movement of the cell apparently allowed some change in force action of the particles near the cell and throughout the medium.

Strain Gage Cells. Cooper and Nichols (9) developed a Type A soil pressure cell which they later modified. This modified cell has four SR-4 type A-18 strain gages located on a diaphragm such that two gages register compressive stress and two register tensile stress when the diaphragm is subjected to a uniformly distributed load.

McMahon and Yoder (26) made a similar cell using only two strain gages on the diaphragm. This gage has a diameter of one inch and a thickness of three-eighths of an inch.

Redshaw (32) used a special rosette type foil resistance strain gage to make a cell one inch in diameter and one-fourth inch thick. These special gages, placed on the inner surface of both diaphragms, covered almost the entire area of the diaphragm.

Personnel at the Waterways Experiment Station, Vicksburg, Mississippi (8), have studied pressure cell operation. They developed a cell which uses oil to transfer pressure from a diaphragm subjected to soil pressures to a diaphragm with strain gages attached. This method provides uniform pressure action on the measuring diaphragm, but the measurements are affected by variations in oil density resulting from temperature changes.

Summary

These pressure cells measure the reaction of a flat diaphragm to soil particles pressure action. Pressure is assumed to act uniformly over the surface of the diaphragm. Since it is known that soil particles move in an approximate circular path beneath wheel or similarly applied loads (7), and because the study of cotton seed planted in the soil is of primary interest, it is speculated that a small cell having size, shape, and characteristics approximating that of seeds will prove valuable in studying the environmental pressures in the seedbed. This small cell would be especially useful to indicate low pressures exerted on seeds during field and laboratory studies of planting equipment.

MINIATURE CELL

Pressure Cell Design

Electrical resistance strain gages provide an excellent opportunity in making pressure cells. The small, flexible wires used to connect the sensing unit to the indicator provide ease of placement in the soil and permit the sensing unit to move with the soil as it is compressed. Electrical methods of sensing pressures are also readily adapted to recording systems. Investigation revealed that segments of thin, spherical shells exhibit some characteristics that make them adaptable to a pressure cell measuring device.

Thin Shell. Timoshenko (39) discusses shells of a surface of revolution. Since the convergence of the series entering into the rigorous solution for the stresses in shells thin in comparison to the radius becomes slow, approximate methods of solution are given. Application of pressure to the outside surface of the shell causes expansion of the edge diameter. The equation for the edge displacement of a spherical shell subjected to a uniform normal pressure is:

$$\delta = \frac{P a^2 (1 - \nu)}{2 E h} \sin \alpha \quad (9)$$

where:

δ is the horizontal deflection.

p is the pressure.

a is the radius of the sphere from which the segment is taken.

h is the shell thickness.

α is the angle from the edge to the center of the segment.

E is Young's modulus of elasticity.

The dimensions and radius of curvature of the shell segments used to make up the external surface of the cell are limited by the space required for the internal mechanism. The thickness of the shell is dependent upon the material used, the pressure range, and the size of the shell.

Internal Mechanism. Electrical resistance SR-4 strain gages bonded to metal strips rigidly attached to the spherical segments permits the horizontal edge deflection of the shell to be interpreted in terms of external pressure on the cell. SR-4 electrical resistance strain gages are composed of conductors which exhibit the property of changing resistance to electric current flow when strained. With instrumentation, this change in resistance can be measured and correlated with stress, strain, pressure, or force. These SR-4 gages are made from special wire or foil bonded to a protective backing to allow cementing to the member to be strained. An SR-4 gage, cemented to the member, acts as an integral part of the member. Type A-19 gages were selected from the many available types and sizes because of their small size and low cost. The Type A-19 gage has a resistance of sixty ohms and a gage factor of 1.72.

The use of two or more active gages is one way to increase strain sensitivity. Strains of opposite signs must be accessible for gage placement before this method can be used. To obtain stresses of opposite sign in a member due to the edge expansion of the shell, metal strips were arched and attached to the shell. The curved beam theory may be used to visualize the formation of opposing stresses on opposite sides of the beam. A horizontal outward deflection, as indicated in Figure 2 will cause a tensile stress on the inner surface and a compressive stress on the outer surface. A strain gage is placed on each side of the arched strip at the peak of the arch.

Instrumentation. The Wheatstone-bridge circuit is used to measure the small change in resistance of the SR-4 gages due to strain. The following relations are obtained by applying Kirchoff's law to the circuit shown in Figure 3 when the bridge is balanced and there is no current, I_g, flowing through the galvanometer:

(10) $I_1R_1 = I_2R_3$

(11) $I_1R_2 = I_2R_4$

where:

I is current.

R is resistance.

Solving the equations simultaneously, the relations in terms of resistance are:

(12) $\frac{R_1}{R_3} = \frac{R_2}{R_4}$.

If R_3 is a calibrated variable resistor and R_2 and R_4 are fixed resistors, R_1 can be accurately determined. The difference between the values

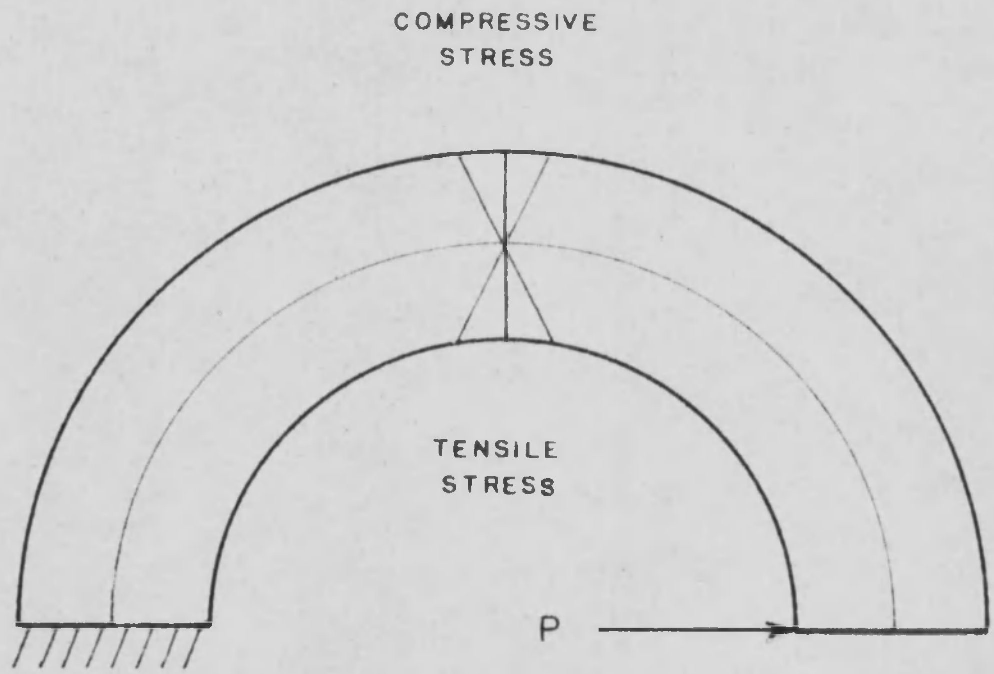


FIGURE 2. Curved Beam

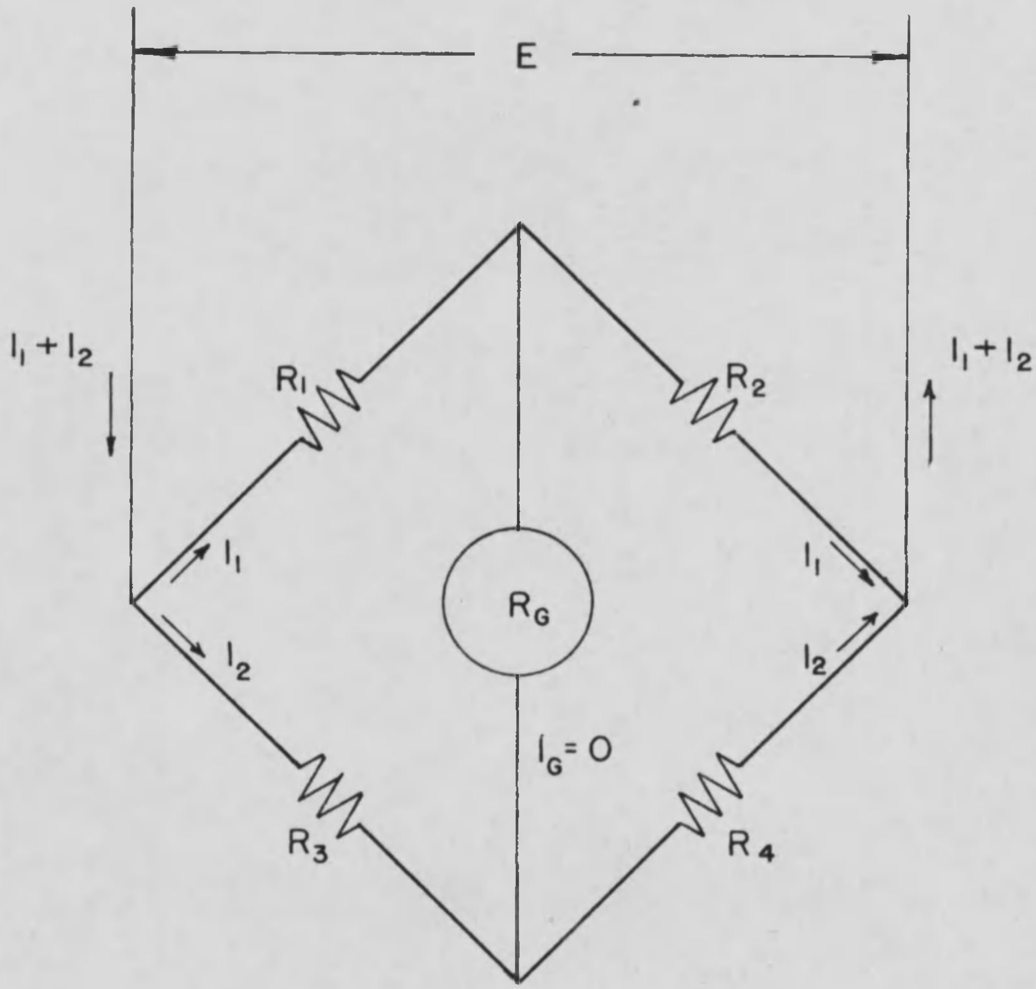


FIGURE 3. Wheatstone-Bridge Circuit

of R_1 before and after the application of a force is a function of the strain in the member.

Since the thermal coefficient of expansion of the gage is usually different from that of the member to which it is attached, it is necessary to correct for the apparent strains resulting from temperature changes. This is best accomplished by using another gage as the R_2 or R_3 resistor. This gage can be either a "dummy" gage or another "active" gage. Dummy and active gages must be identical gages attached to identical materials subjected to identical thermal conditions. The additional active gage measures strains of sign opposite to the original R_1 gage. If a dummy gage is used, it is placed on a nonloaded member and measures only strain due to thermal changes.

The temperature compensation feature of using gages as the resistors is apparent when equation 12 is considered. If R_1 and R_3 are identical gages of equal resistance, the temperature change will cause equal resistance changes, ΔR_t, in both gages, and the bridge remains balanced, as shown below.

$$(13)\quad \frac{R_1}{R_3} = \frac{R_2}{R_4} = \frac{R_1 + \Delta R_t}{R_3 + \Delta R_t}$$

When the bridge is composed of more than one active SR-4 gage, the resistance of the individual gage will increase or decrease depending on whether the stress being measured is compressive or tensile. Utilizing this opposing reaction of the gages, the range in which strains may be detected is increased. The Wheatstone-bridge circuit for increasing strain sensitivity with four active gages is shown in

Figure 4. This method is not only effective for significantly increasing the strain sensitivity, but is simultaneously effective in temperature compensation.

Several instruments for indicating and recording strains are available from different companies. A Baldwin-Lima-Hamilton Type N. null-type, balance indicator was used for strain indication in this study.

Alternative Design

To compare the operation of the "seed shaped" cell to the operation of cells of previous designs, a small cell of the diaphragm type was made. It was necessary to cement the gages with the elements perpendicular to each other as shown in Figure 5. As long as uniform pressure acts on the cell, opposing strains are obtained in different regions of the clamped diaphragm. The pressure cell, shown in Figure 6, has an outside radius of one-half inch, a thickness of one-eighth inch, and a diaphragm thickness of 0.010 inch.

Pressure Cell Construction

After some testing of operational principles using watch glasses as the outside shell, shown in Figure 6, the construction of the cell was undertaken in its miniaturized form.

Thin Shell. A die set for pressing spherical segments was formed with an epoxy resin. The epoxy resin ingredients were mixed and placed in an indentation formed by partially drilling through a steel plate. A three-quarter inch diameter ball bearing coated with

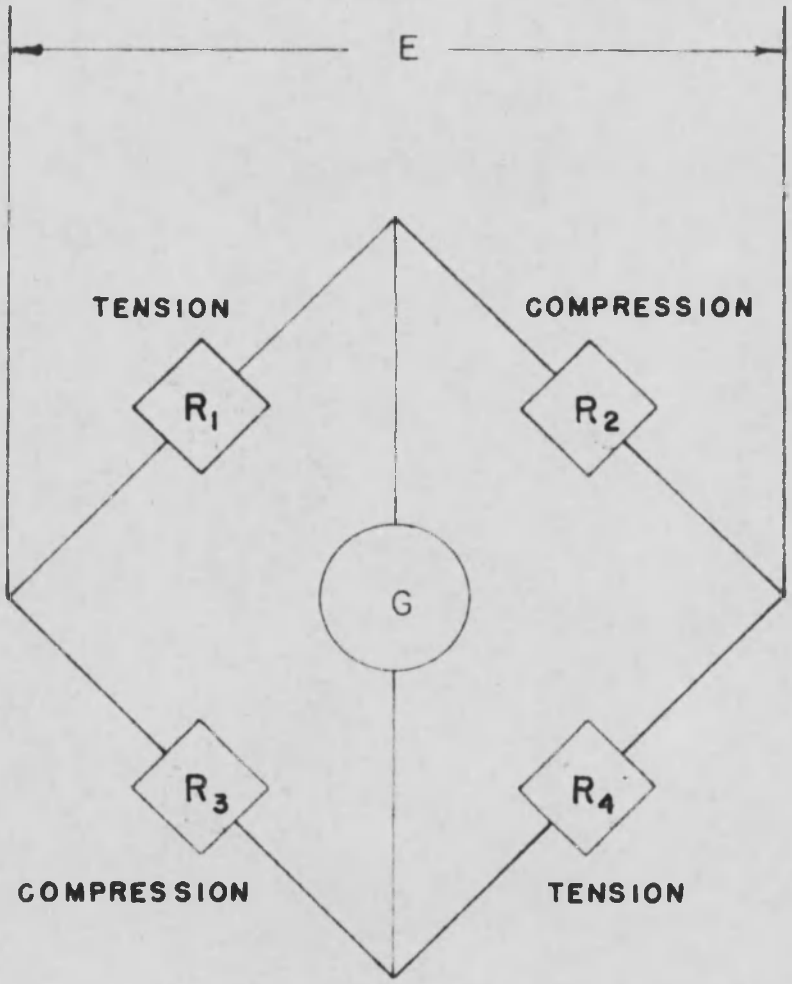


FIGURE 4. Four Active Arm Bridge

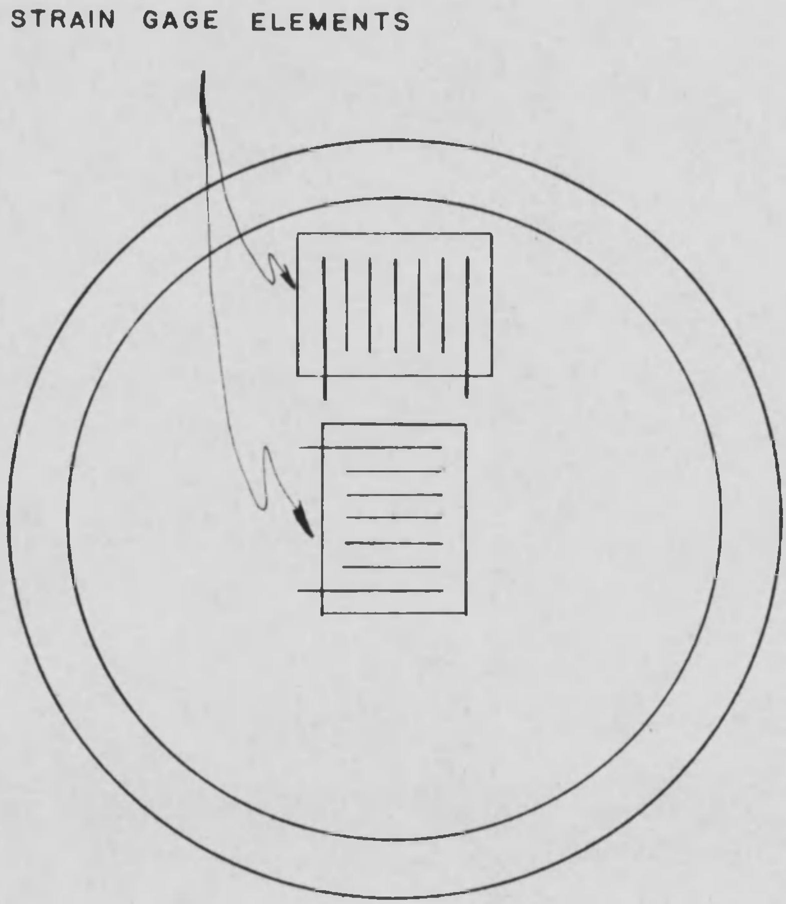


FIGURE 5. Strain Gage Placement on Diaphragm

FIGURE 6. Experimental Pressure Cells. The diaphragm type cell is shown in the upper right portion of the figure. The lower cells are made from watch crystals.

heavy oil was pressed into the epoxy resin to the desired depth measured by a micrometer. The bearing was removed after the epoxy resin had solidified, and the surface of the plate was smoothed by filing, leaving a smooth concave spherical mold. A smaller bearing was used as the male part to complete the die set. Segments of spheres were formed by pressing brass shim stock 0.005 inch thick into the die. The excess shim material was trimmed away from the partial sphere, and the edges were sanded down to a one-half inch radius. A high speed hand drill was then used to grind small slots and drill small holes to facilitate attachment of the internal mechanism. This provided an economical means of making the thin shells with reasonable accuracy and uniformity.

Arched Strips. Using the same method, another die set was made to form the tiny arched strips. The concave part of the die set was formed by pressing a portion of round three-quarter inch diameter steel shaft into epoxy resin. The male part of the die set was formed by cutting a segment from the shaft and soldering to a backing piece. The backing piece fitted into guides extending from the female part of the set to give proper seating when pressing the strips. Strips of brass shim stock 0.010 inch thick and 0.13 inch wide were "arched". The extra length left on the ends as shown in Figure 6, was removed in the final assembly.

Gage Attachment. The A-19, SR-4 strain gages were trimmed and cemented to the arched strips. They were placed at the center of the arch with one on the inside curvature and one on the outside curvature. Baldwin-Lima-Hamilton SR-4 strain gage cement was used in attaching the gages. The die with pieces of felt placed over the gages was used to apply pressure until the cement was partially dry. Number 30 flexible phonograph wire was used for leads. These wires were twisted with the strain gage leads and soldered as near the strip as possible.

A two active arm bridge was used on the first cells, but on the later cells, a four active arm bridge was formed by using two arched strips placed horizontally perpendicular to each other and arched away from each other. A miniature wooden jig held the arched strips securely while soldered connections were made with a small pencil type soldering iron.

Final Assembly. A holding clamp was fashioned from circular calipers by soldering small spherical segments to its tips. The arched strips were symetrically placed within the spherical segments and the unit clamped together. The arched strips were then soldered to the spherical segments exercising extreme care to prevent excessive heating in the unit. The extra material from the arched strips protruding from the cell not only permitted centering the arch, but helped conduct heat away from the SR-4 gages. After soldering, the excess of the strips was cut away, and the unit was shaped and smoothed with grinding bits in the high speed drill. The edges of the cell were then coated with strain gage cement to moisture proof the unit.

Calibration

The miniature cells were placed in rubber balloons and subjected to air pressure with the apparatus shown in Figure 7. Atmospheric pressure was maintained within the balloon thus allowing uniform pressure to act upon the cell. Air pressure was increased at various increments to 20 pounds per square inch and then released at various intervals. The cells used in the emergence study were calibrated before and after the study.

The first tests of the pressure cells did not agree completely with later tests. There was an increase in slope of the curve and a tendency of the zero reading of the cell to change. The reason for this was not evident, so zero indicator readings were stabilized by applying and releasing pressure several times before the cells were calibrated. When using the pressure cells with the four active arm bridge, it was necessary to reduce the indicator output to prevent heating of the SR-4 gages. This was accomplished by placing a 56 ohm resistor in the leads between the cell and the indicator.

In Figure 8, three different calibrations of a pressure cell show the curves to be the same straight line when applying and releasing pressure. This pressure cell possessed a four active arm bridge.

The calibration curves of the cells used in the emergence study are given in Appendix A. Pressure cells designated 1, 2, and 3 were made using the four active arm bridge. Pressure cell number 4 was the flat, diaphragm type cell used for comparison. Pressure cell number 5 had a two active arm bridge. These pressure cells are shown in Figure 9.

FIGURE 7. Pressure Cell Calibration Apparatus. Shown are calibration chamber, air supply tank, and mercury manometer.

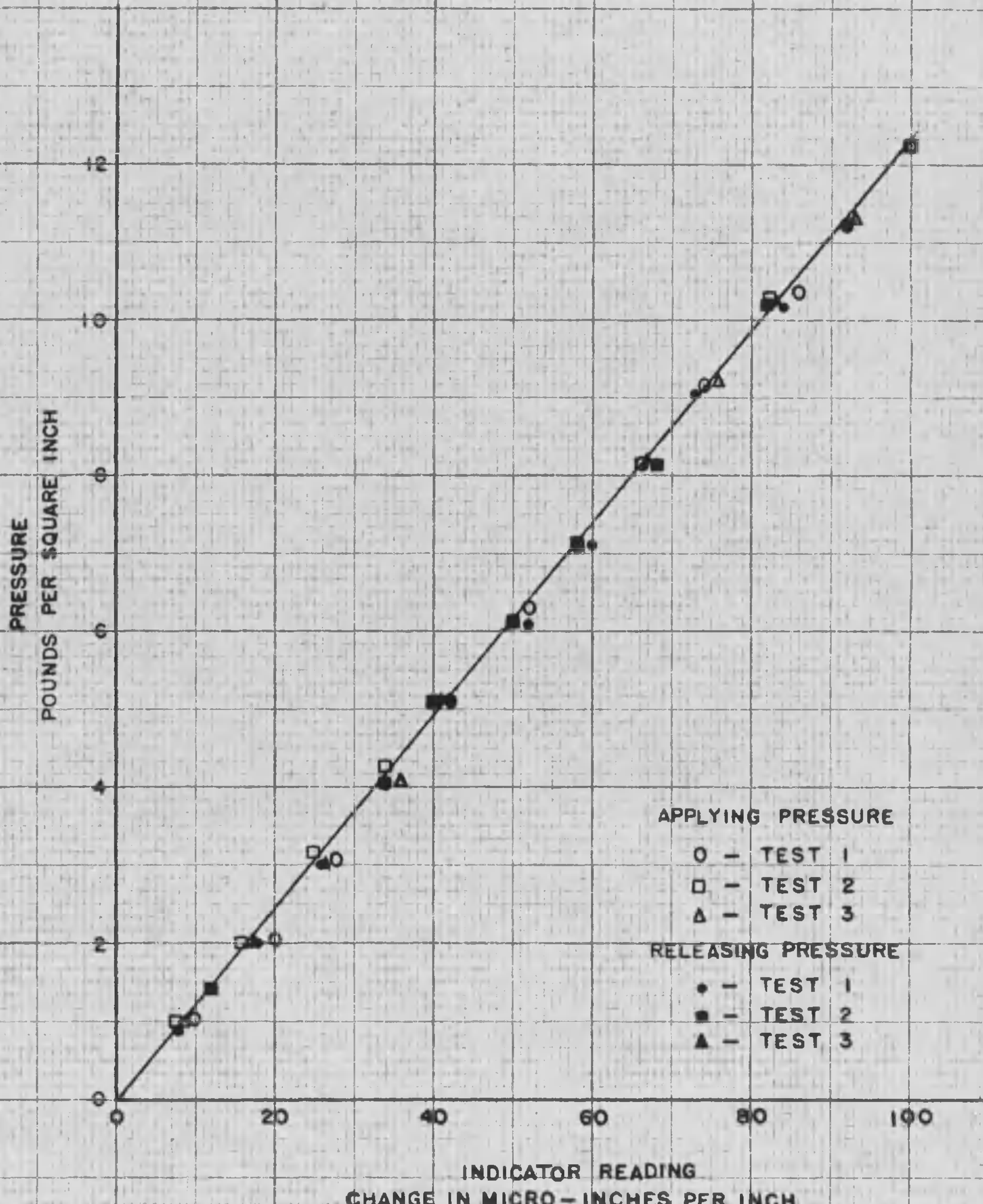


FIGURE 8. CALIBRATION CURVE

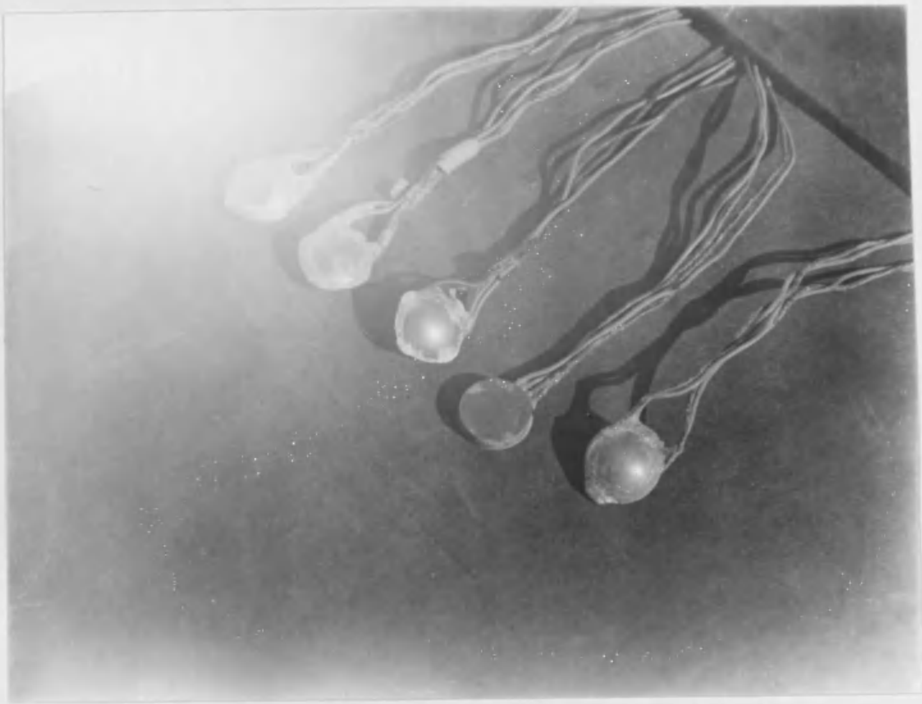


FIGURE 9. Pressure Cells Used in Emergence Study.

DEMONSTRATION OF USE OF CELL

To illustrate the use of the cells and to reveal practical problems in their application, it was desired to test them while conducting a laboratory cotton seed emergence study.

Design of Experiment

It was decided that four levels of pressure measurement would be desirable in illustrating the use of the pressure cell. Three soil moisture percentages were selected. Since the primary purpose was to test the pressure cell, only one soil type was selected. A design with treatments being divided into subtreatments is needed to compare the effects and interaction.

The split-plot design offers opportunity to obtain precise information on one factor and on the interaction of this factor with a second factor. This design was selected to accurately compare the effect of pressure levels and the effect of interaction between pressure levels and soil moisture content on emergence. Low--13.5 per cent, medium--17 per cent, and high--22 per cent moisture levels were chosen as the main treatments. Loads were selected to give four levels of surface pressure, 0, 5, 10, and 15 pounds per square inch. The layout of the experiment is shown in Figure 10. Two replications were watered during the emergence study, and two other replications were covered with an impermeable plastic film to prevent moisture loss.

FIGURE 10. Arrangement of Plot Boxes. Two replications were left uncovered and watered to maintain the desired moisture level. The other two replications were covered with plastic film.

The uncovered boxes were weighed periodically, and water was added to again obtain the initial soil moisture percentage. To distinguish between the two tests, the uncovered boxes are called replications I and II, and the covered boxes are called replications IC and IIC. The boxes were numbered and the treatments within the boxes were represented by a letter and number. The letter represented the moisture content and the number represented surface pressure in pounds per square inch caused by the applied surface load. L-5, for example, means that the soil contains low moisture content and had a load applied to the surface to give a surface pressure of 5 pounds per square inch. The moisture treatments were randomized in rows and the applied surface pressure was randomized within the rows.

Experimental Procedure

Soil was secured from the University of Arizona, Marana Farm. This soil had previously been cropped in cotton and was from a cotton producing area. A mechanical analysis of this soil is given in Appendix B. The soil was screened using one-half inch mesh hardware cloth set at an angle.

Soil samples were taken and the amount of water needed to achieve the desiredmoisture level was determined. After thoroughly mixing the water with the soil, the soil was wrapped in plastic to prevent moisture escape and remained undisturbed for 48 hours to permit an equilibrium state of moisture distribution to be reached.

To fill the plot boxes uniformly, the method, as illustrated in Figure 11, was used. Soil was first placed in the metal container shown in Figure 11, and then raked into the 14" x 14" x 5 7/8" wooden plot boxes. The soil was leveled in the plot boxes at a distance of two inches from the top of the boxes by using a notched board shown in Figure 11. Cotton seeds were than placed at this level using the template shown in Figure 12. Points where the cells were placed were also marked by the template. After placing the cells in the box, the remaining volume was filled with soil and leveled at the top edges of the box. Figure 13 shows the placement of the pressure cells and cotton seed within the plot box. The dashed lines in the figure indicate the one square foot of area that the steel plate covered when the surface load was applied.

A hydraulic press with the steel plate centered over the box was used to apply the load as shown in Figure 14. Readings of the pressure cells were taken before pressure was applied, while the pressure was held constant for one minute, and after pressure was released. The switching unit and indicator are also shown in Figure 14. The cells were removed after readings were taken and used in the next box.

This procedure was used on replications I and II. Pressure cells were not placed in replications IC and IIC. Acala 44 cotton seed of 1960 foundation stock was planted. A germination test using the blotter method yielded 97 per cent germination. Replications I and II were planted August 20, 1961, and replications IC and IIC were planted August 21, 1961.

Daily counts of emerging plants were made for 21 days, and then the number of nonemerging seedlings was determined. The number

FIGURE 11. Method of Filling Plot Boxes.

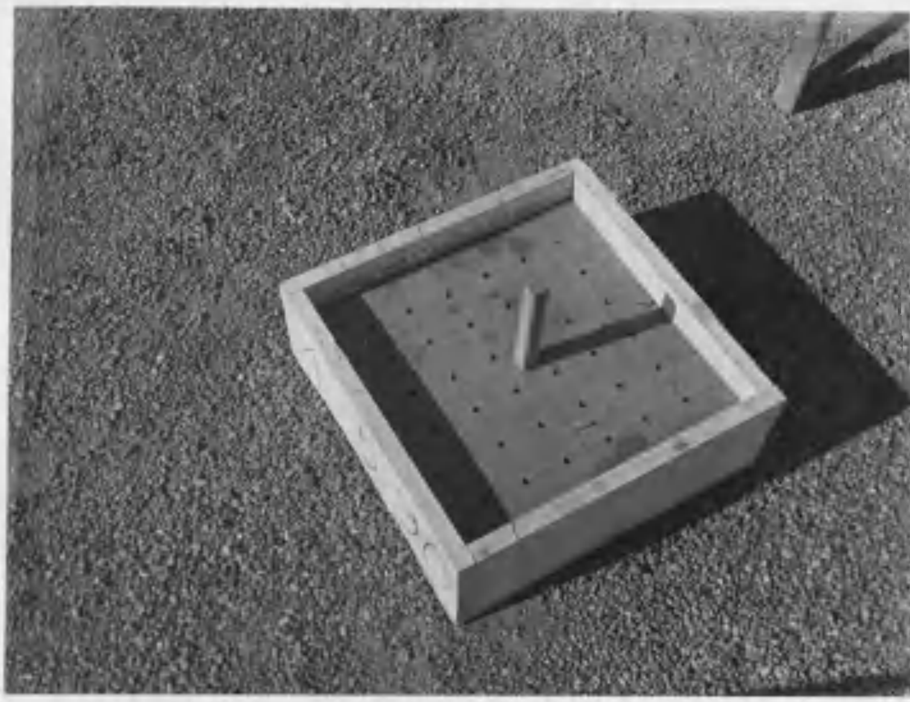


FIGURE 12. Template for Placement of Seed.

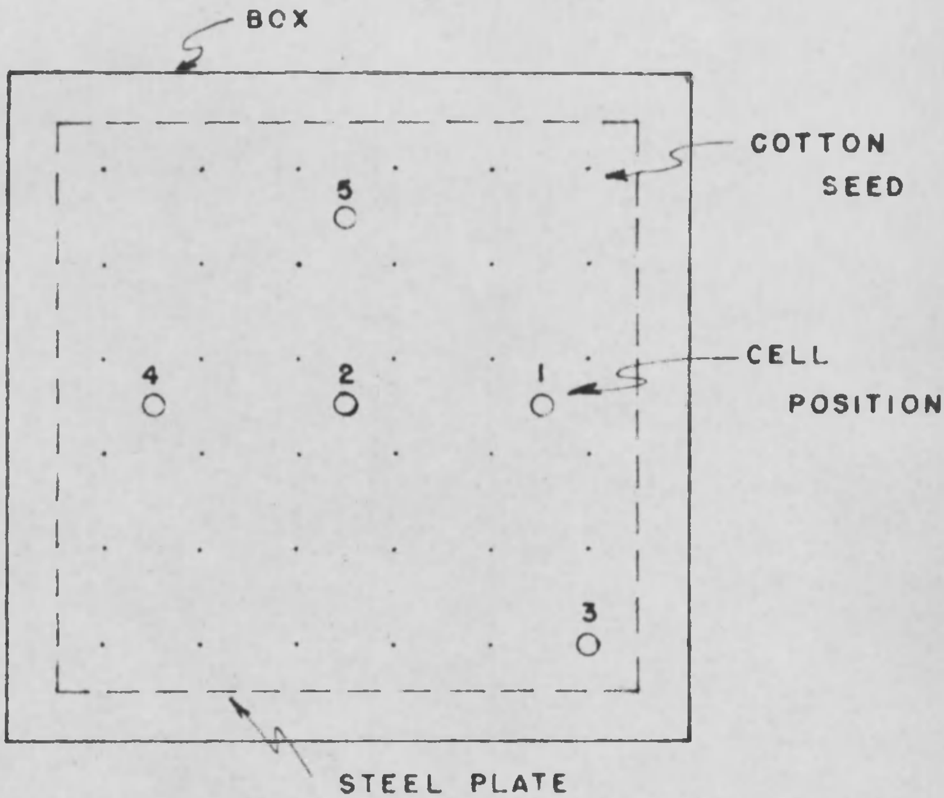


FIGURE 13. Pressure Cell Position and Cotton Seed Placement

FIGURE 14. Hydraulic Press, Switching Unit, and Indicator. Pressure is being applied to the soil in the box.

of nonemerging seedlings plus the number of emerging seedlings was considered to be the number of seeds that germinated.

Experimental Results

Pressure Cell Tests. The tests revealed that there is need for additional insulation between the SR-4 gage lead wires and the thin shell. Two of the cells were shorted out due to contact of these wires with the shell. One of the shorts resulted from accidentally pulling on the pressure cell lead wires while the cell was being removed from the soil.

Pressure cell number 4, the flat type cell, exhibited interesting characteristics in that compression readings were obtained at times, and tension readings were registered at other times. Sometimes one type of reading was indicated while loading and the other type registered upon release of the load. While checking the cell after the emergence test, it was found that the application of point loads to different regions of the diaphragm resulted in the different types of pressure indications. This may be explained by the arrangement of the gages on the diaphragm as shown in Figure 5. Point loads applied in the regions of the gages can affect one gage more than the other gage.

Obtaining these different types of readings from the cell when placed in the soil reveals that pressure is not acting uniform and normal to the diaphragm. This indicates that for the type of measurements desired in a seed's environment, this type of cell is unsatisfactory. The measurements from pressure cell number 4 were not used in the statistical analysis which follows. However, the measurements of this cell were recorded in Tables 1 and 2 with negative signs preceding the measurements which caused the null indicator to give readings in the opposite direction to that recorded when the pressure cell was calibrated. In Figure 15, measured internal pressures are shown at the various applied surface pressures.

Confidence intervals at the 5 percent level of significance were calculated for the mean measured pressures within the boxes and are listed in Table 3. They reveal that the variability of the internal pressure measurements prevents the establishment of a definite relationship between applied surface pressure and actual environmental pressures.

The different pressures measured in the same box reveal the nonhomogeneity of the soil. The readings of the flat cell indicate that pressure is not exerted uniformly over an area even as small as 0.196 square inch. Since the soil was confined and of shallow depth, it was thought that the pressures would be reasonably uniform. However, the arrangement of the particles around the cells would not be expected to be the same for each cell. This chance arrangement of the soil particles will undoubtedly cause different pressure action upon the cells. This same chance arrangement would also be expected to form around cotton seeds, so each seed would probably be in a different environment due to different pressure actions. It is conceivable that the seed may be exposed to a pressure completely different than that of the region immediately above it.

This would indicate that the measuredpressure at seed level would have more effect on germination than on seedling emergence. To

TABLE 1

Pressure Cell Readings During Load Application, Pounds Per Square Inch

Surface Pressure (psi)	5						10						15					
Moisture Level	Low		Med.		High		Low		Med.		High		Low		Med.		High	
Replication	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II
Position 1	7.4	-	7.7	-	-	-	17.6	-	12.4	-	-	-	21.0*	-	16.8	-	-	-
2	-	10.7	5.4	9.6	6.0	7.4	-	14.0	20.4	15.1	15.4	14.0	26.6*	23.4*	27.4*	21.5*	28.0*	14.6
3	5.2	8.9	6.2	5.4	6.0	4.0	15.6	10.9	8.4	42.4*	13.4	13.7	16.5	10.2	40.4*	22.8*	18.0	13.0
4	1.7	18.3	0	6.6	-2.8	8.6	8.6	10.0	31.0*	9.4	9.0	-4.7	11.4	14.8	14.5	-8.7	10.2	41.8*
5	11.6	9.3	10.0	6.5	14.7	5.1	15.2	10.7	17.7	14.0	16.2*	40.8*	13.8	20.4	14.8	48.8	16.3	40.6*

*Pressures indicated were higher than the cells had been calibrated.

-No reading taken.

TABLE 2

Pressure Cell Readings After Release of Load, Pounds Per Square Inch

After Surface Pressure (psi)	5						10						15					
Moisture Level	Low		Med.		High		Low		Med.		High		Low		Med.		High	
Replication	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II
Position 1	2.2	-	-	-	-	-	2.4	-	-	-	-	-	1.2	-	-	-	-	-
2	-	-	-	1.2	0.2	.0	-	1.0	-	1.2	1.8	1.0	-	2.0	-	1.6	1.8	1.0
3	0.7	2.5	-	1.8	1.4	1.2	3.0	2.0	-	0.2	3.4	2.8	3.0	1.4	-	4.3	3.0	1.2
4	-10.4	13.2	-	29.2*	-7.0	-9.4	-2.0	-21.4*	-	2.4	-4.2	-12.2	0.6	3.2	-	-31.2*	-6.2	41.6*
5	15.4	27.0*	-	26.8*	11.0	13.3	7.0	29.0*	-	1.8	12.1	20.0	0.9	1.5	-	34.2*	17.0	54.0*

*Pressures indicated were higher than the cells had been calibrated.

-No readings taken.

TABLE 3

Confidence Intervals of the Means of the Measured Pressures at the 5 per cent Level of Significance

Replication	Moisture Level	Applied Surface Pressure (psi)	Mean Measured Pressure (psi)	Confidence Interval
I	L	5	8.07	-0.01 to 16.15
II	L	5	9.63	7.28 to 11.98
I	M	5	7.20	1.09 to 13.31
II	M	5	7.17	1.76 to 12.58
I	H	5	8.90	3.58 to 21.38
II	H	5	5.50	1.18 to 9.82
I	L	10	16.13	12.93 to 19.33
II	L	10	11.87	7.27 to 16.47
I	M	10	15.50	-0.12 to 31.12
II	M	10	23.83	16.15 to 63.81
I	H	10	15.00	11.69 to 18.31
II	H	10	22.83	-15.81 to 61.47
I	L	15	18.63	3.26 to 34.00
II	L	15	16.13	-0.52 to 32.78
I	M	15	27.53	-4.27 to 59.33
II	M	15	31.03	-7.22 to 69.28
I	H	15	20.77	5.07 to 36.47
II	H	15	22.73	-15.77 to 61.23

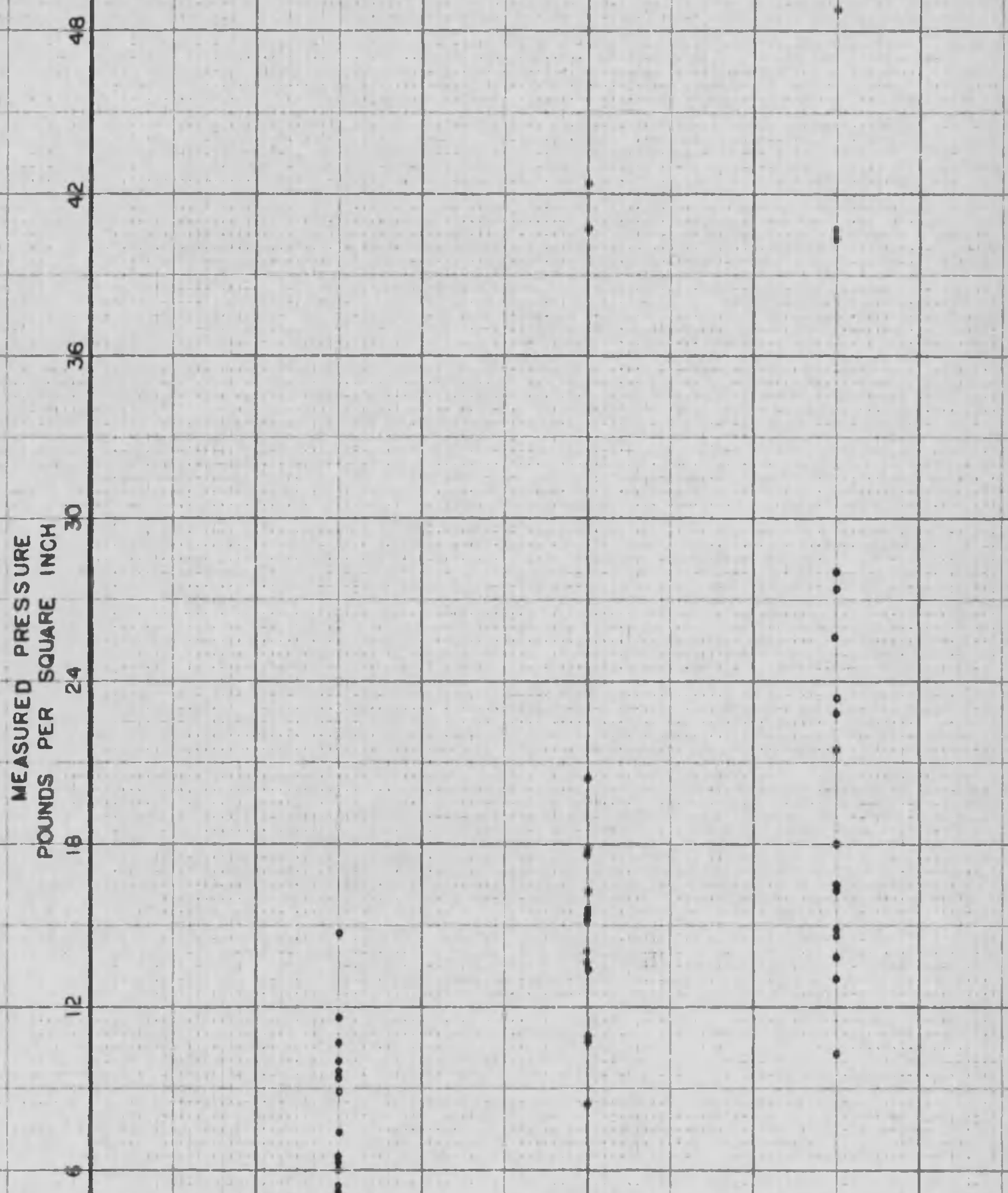


FIGURE 15. INTERNAL SOIL PRESSURES MEASURED AT DIFFERENT APPLIED SURFACE PRESSURES

evaluate seedling emergence, measurements would have to be taken in a series of layers above the seed.

In field studies, more variables are present than in laboratory studies; therefore, the environmental pressures will probably vary more also. If this is true, numerous internal pressure measurements would be required to evaluate emergence in field studies.

Recalibration Tests. The recalibration tests shown in Appendix A, reveal that the calibration curves of cell number 3 changed appreciably during the emergence study. There are two possible causes of this change. One possibility is that the cement applied to the edges of the cell had not hardened thoroughly before the first calibration test, since it was the last cell completed before making the emergence study. The other possibility is that the soil pressure has changed the characteristics of the cell. The recalibration curve of cell number 5, composed of a two active arm bridge, also shows slight change.

These deviations indicate that the cells should be further tested using a method of calibration to permit direct contact of the cell with soil. This could be done using a soil tri-axial shear testing device and would reveal any malfunction of the cell due to soil particle contact.

Germination and Emergence Results. By placing confidence limits about the mean measured pressure within the boxes, it was shown that there was no definite relationship between the internal pressure and the applied surface pressure. By superimposing these confidence limits about the points obtained by plotting the number of seedlings that emerged against the average measured pressure, it is seen that again the variability of the internal pressure measurements prevents making conclusions about the effect of measured pressures on seedling emergence. The number of plants that emerged at different moisture levels and various measured pressures are shown in Figure 16.

Since the variability of internal measurements is so large, germination and seedling emergence results are evaluated according to applied surface pressure. The number of plants that emerged at different moisture levels and applied surface pressures are shown in Figure 17. The number of seeds that germinated during the 21 day test period is presented in Tables 4 through 7. Analyses of variance for testing the differences in germination due to the various treatments are given in Appendix B. At the 5 per cent level of significance, there was no difference in germination due to the various treatments.

The number of seedlings that emerged during the 21 day test period are shown in Tables 8, 9, 12 and 13. Analyses of variance for testing the difference in seedling emergence due to various treatments are also given in Appendix B. In replications I and II, there was difference in seedling emergence caused by loading the soil surface at the different moisture levels. In replications IC and IIC, there were differences at the 5 per cent level of significance in emergence due to soil moisture content and surface loading at the different moisture levels.

The effects of surface loads applied at different levels of moisture were compared at the 5 per cent significance level by using

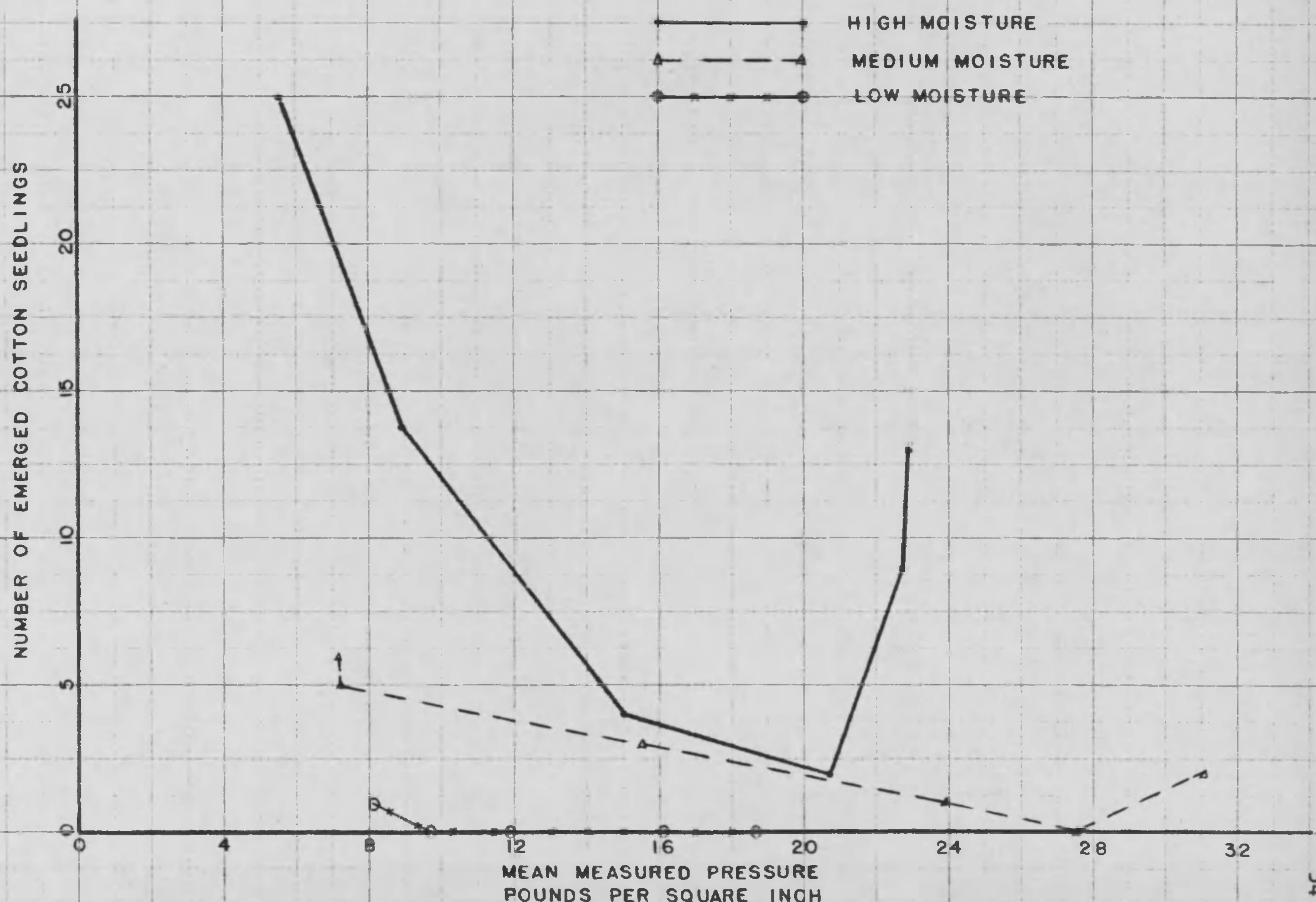


FIGURE 16. NUMBER OF COTTON SEEDLINGS THAT EMERGED AT VARIOUS MEAN MEASURED PRESSURES AND SOIL MOISTURE LEVELS

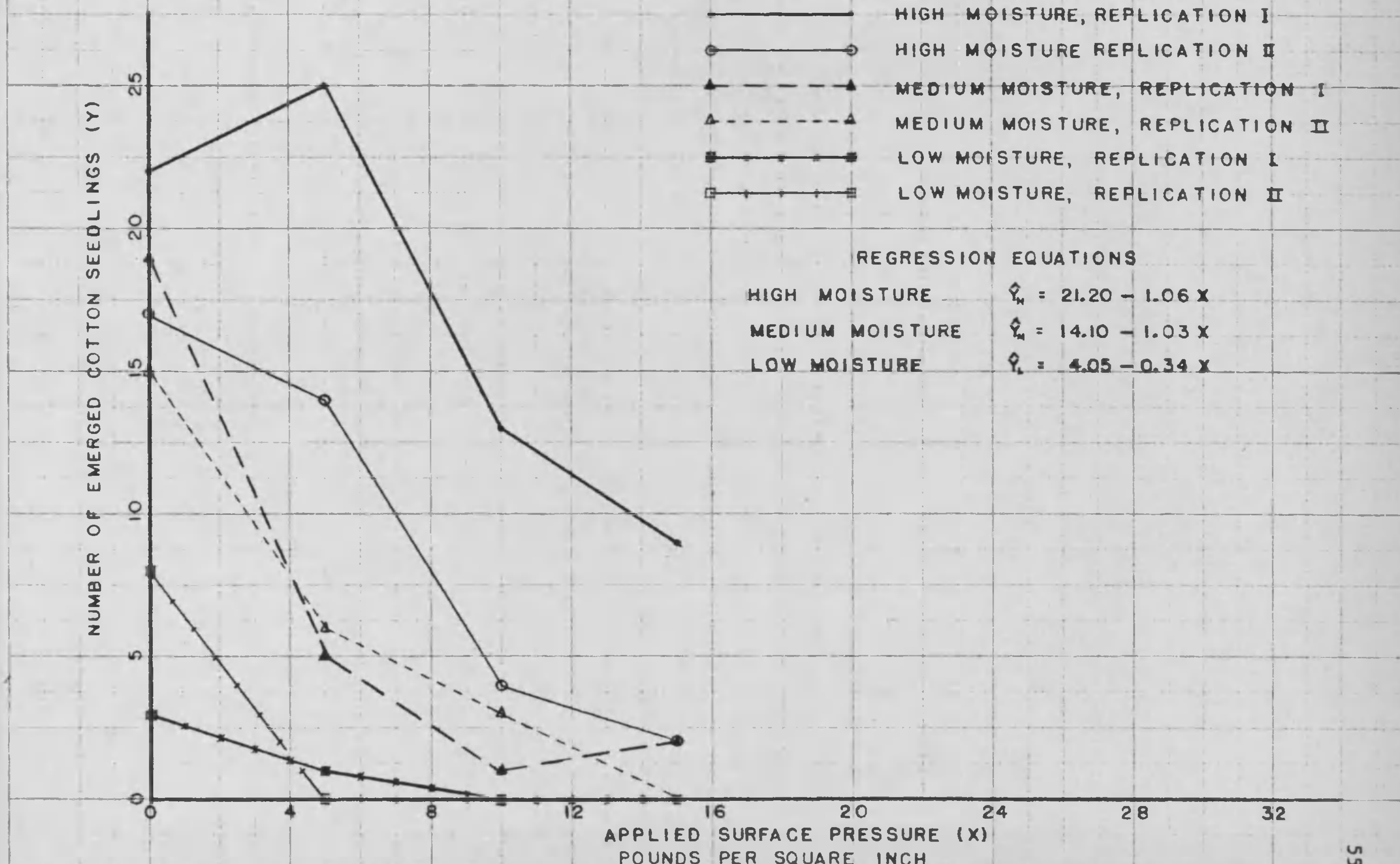


FIGURE 17. NUMBER OF COTTON SEEDLINGS THAT EMERGED AT VARIOUS APPLIED SURFACE PRESSURES AND SOIL MOISTURE LEVELS

Duncan's Multiple Range Test (24). The resistance caused by loading the soil surface reduced seedling emergence. High soil moisture content helped seedlings to overcome this increased resistance to seedling emergence.

Tables 10 and 11 show Duncan's Multiple Range Tests in replications I and II. Comparisons shown in Table 10 reveal that emergence was reduced each time surface loading was increased. Comparisons shown in Table 11 reveal that in soil of low moisture content, seedling emergence was best where there was zero pressure applied to the surface. At the low moisture level no significant difference in seedling emergence occurred between treatments of 5, 10, and 15 pounds per square inch loads. In soil of medium moisture content, seedling emergence was best where zero pressure was applied, least where 15 pounds per square inch was applied, and intermediate where loading was 5 and 10 pounds per square inch. In soil of high moisture content, loads of zero and 5 pounds per square inch resulted in seedlings emerging equally well and greater than where 10 and 15 pounds per square inch loads were applied.

Duncan's Multiple Range tests made in replications IC and IIC are shown in Tables 14, 15 and 16. Table 14 shows how seedling emergence was reduced by loading the soil surface. Surface loading of zero pounds per square inch resulted in best emergence, and 5 pounds per square inch resulted in a reduced emergence but not as great a reduction as where the equally damaging loads of 10 and 15 pounds per square inch were applied. In Table 15, comparisons reveal that a soil containing low moisture content had no difference in seedling emergence due to pressure treatment. Soil containing high and medium moisture content had the same seedling emergence pattern due to pressure treatment. Seedling emergence was best where no load was applied and least where loads of 10 or more pounds per square inch were applied. Five pounds per square inch loads reduced seedling emergence, but by an amount that was less than the reduction caused by loads of 10 and 15 pounds per square inch.

The results on replications I and II were slightly different from the results on replications IC and IIC. The watered boxes had no significant differences in emergence due to moisture level; but in the covered boxes, emergence significantly increased with increase in soil moisture content as shown in Table 16. These differences in results were caused by the variable moisture content in the watered boxes as compared to the constant moisture content maintained in covered boxes. Some crusting and cracking of the soil surface occurred after each watering in replications I and II. Soil crusts did not form in the covered boxes, and this could also contribute to the differences in results between the covered and uncovered replications.

Figures 18 through 28 show the significance of the seedbed compression problem. A visualization of how soil compression hinders seedling emergence may be obtained by comparing the emerged seedlings shown in Figure 18 to the bare soil shown in Figure 19. Figures 20, 21, and 22 show how seedlings grow in all directions seeking the path of least resistance. Figures 23 and 24 illustrate how seedlings emerge in soil that is not compressed. The effects of surface loading on seedling development are shown in Figures 25 through 28. Soil compression causes abnormal seedling development as illustrated by the curled and twisted seedlings in Figure 26.

TABLE 4

Number of Cotton Seeds that Germinated from Samples of 35 Seeds, Replications I and II

Moisture Level	Surface Pressure (psi)	Replication I	Replication II	Totals
Low	0	22	15	37
	5	21	16	37
	10	20	18	38
	15	20	24	44
		83	73	156
Medium	0	23	19	42
	5	15	26	41
	10	16	24	47
	15	23	24	47
		77	93	170
High	0	21	28	49
	5	26	27	53
	10	23	26	49
	15	24	32	56
		94	113	207
		254	279	533

TABLE 5

Total Cotton Seeds that Germinated, Replications I and II

Moisture Level	Pressure (psi) 0	5	10	15	Totals	Means
Low	37	37	38	44	156	19.50
Medium	42	41	40	47	170	21.25
High	49	53	49	46	207	25.13
Totals	128	131	127	147	533	
Means	21.33	21.83	21.17	24.50		

TABLE 6

Number of Cotton Seeds that Germinated from Samples of 35 Seeds, Replications IC and IIC

Moisture Level	Surface Pressure (psi)	Replication IC	Replication IIC	Totals
Low	0	20	29	49
	5	19	25	44
	10	23	24	47
	15	16	21	37
		78	99	177
Medium	0	26	19	45
	5	28	31	59
	10	31	30	61
	15	29	26	55
		114	106	220
High	0	29	30	59
	5	34	30	64
	10	31	28	59
	15	26	31	57
		120	119	239
		312	324	636

TABLE 7

Total Cotton Seeds that Germinated, Replications IC and IIC

Moisture Level	Pressure (psi) 0	5	10	15	Totals	Means
Low	49	44	47	37	177	22.13
Medium	45	59	61	55	220	27.50
High	59	64	59	57	239	29.88
Totals	153	167	167	149	636	
Means	25.50	27.83	27.83	24.83		

TABLE 8

Number of Cotton Seedlings that Emerged from Samples of 35 Seeds, Replications I and II

Moisture Level	Surface Pressure (psi)	Replication I	Replication II	Totals
Low	0	3	8	11
	5	1	0	1
	10	0	0	0
	15	0	0	0
		4	8	12
Medium	0	19	15	34
	5	5	6	11
	10	3	1	4
	15	0	2	2
		27	24	51
High	0	17	22	39
	5	14	25	39
	10	4	13	17
	15	2	99	11
		37	69	106
		68	101	169

TABLE 9

Total Number of Seedlings that Emerged, Replications I and II

Moisture Level	Pressure (psi) 0	5	10	15	Totals	Means
Low	11	1	0	0	12	1.50
Medium	34	11	4	2	51	6.38
High	39	39	17	11	106	13.25
Totals	84	51	21	13	169	
Means	14.00	8.50	3.50	2.17		

TABLE 10

Duncan's Multiple Range Test

Effect of Pressure Level on Seedling Emergence in Replications I and II

Surface Pressure (psi)	0	5	10	15
Means of Reps. I and II	14.00	8.50	3.50	2.17

Standard Error: 0.212

LSR for test between means in groups of:
2 - 0.68
3 - 0.71

TABLE 11

Duncan's Multiple Range Test

Effect of Pressure Level at a Given Soil Moisture on Seedling Emergence in Replications I and II

Means of Replications I and II

		Surface Pressure (psi)			
		0	5	10	15
Moisture Level	Low	5.5	0.5	0	0
	Medium	17.0	5.5	2.0	1.0
	High	19.5	19.5	8.5	5.5

Standard Error: 1.34

LSR for test between means in groups of:
2 - 4.30
3 - 4.48
4 - 4.58

TABLE 12

Number of Cotton Seedlings that Emerged from Samples of 35 Seeds, Replications IC and IIC

Moisture Level	Surface Pressure (psi)	Replication IC	Replication IIC	Totals
Low	0	2	9	11
	5	0	1	1
	10	0	0	0
	15	0	0	0
		2	10	12
Medium	0	24	19	43
	5	6	12	18
	10	0	3	3
	15	0	1	1
		30	35	65
High	0	29	28	57
	5	18	19	37
	10	1	3	4
	15	0	1	1
		48	51	99
		80	96	176

TABLE 13

Total Number of Seedlings that Emerged, Replications IC and IIC

Moisture Level	Pressure (psi) 0	5	10	15	Totals	Means
Low	11	1	0	0	12	1.50
Medium	43	18	3	1	65	8.25
High	57	37	4	1	99	12.38
Totals	111	56	7	2	176	
Means	18.50	9.33	1.17	0.33		

TABLE 14

Duncan's Multiple Range Test

Effect of Pressure Level on Seedling Emergence in Replications IC and IIC

Surface Pressure (psi)	0	5	10	15
Means of Reps. IC and IIC	18.50	9.33	1.17	0.33

Standard Error: 0.85

LSR for test between means in groups of:
2 - 2.72
3 - 2.84

TABLE 15

Duncan's Multiple Range Test

Effect of Pressure Level at a Given Soil Moisture on Seedling Emergence in Replications IC and IIC

Means of Replications IC and IIC

		Surface Pressure (psi)			
		0	5	10	15
Moisture Level	Low	5.5	0.5	0	0
	Medium	21.5	9.0	1.5	0.5
	High	28.5	18.5	2.0	0.5

Standard Error: 1.70

LSR for test between means in groups of:
2 - 5.42
3 - 5.66
4 - 5.78

TABLE 16

Duncan's Multiple Range Test

Effect of Moisture Level on Seedling Emergence
in Replications IC and IIC

Moisture Level	Low	Medium	High
Means of Reps. IC and IIC	1.50	8.25	12.38

Standard Error: 0.316

LSR for test between means in groups of:
2 - 1.92
3 - 1.92

FIGURE 18. Emerged Cotton Seedlings After 21 Days. (Replication IIC.) Cotton seedlings emerged from soil with high moisture content and 0 surface pressure applied when seeds were planted.

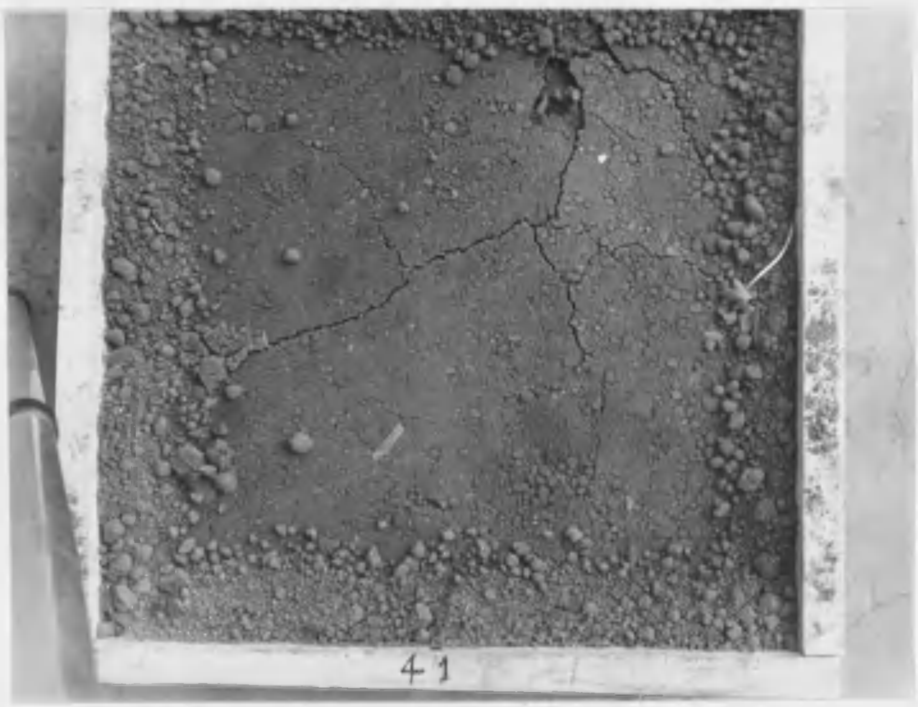


FIGURE 19. Cracking and Lifting of Compressed Soil by Cotton Seedlings. (Replication IIC.) This occurred in soil with medium moisture content and 10 psi surface pressure.

FIGURE 20. Profile Showing Nonemerged Seedlings. (Replication I.) Seedlings were in soil with medium moisture content and 5 psi surface pressure.

FIGURE 21. Profile Showing Nonemerged Seedlings. (Replication I.) Soil contained high moisture content and was compressed by 15 psi surface pressure.

FIGURE 22. Profile Showing Nonemerged Seedlings. (Replication IC.) Soil contained low moisture content and was compressed by 5 psi surface pressure.

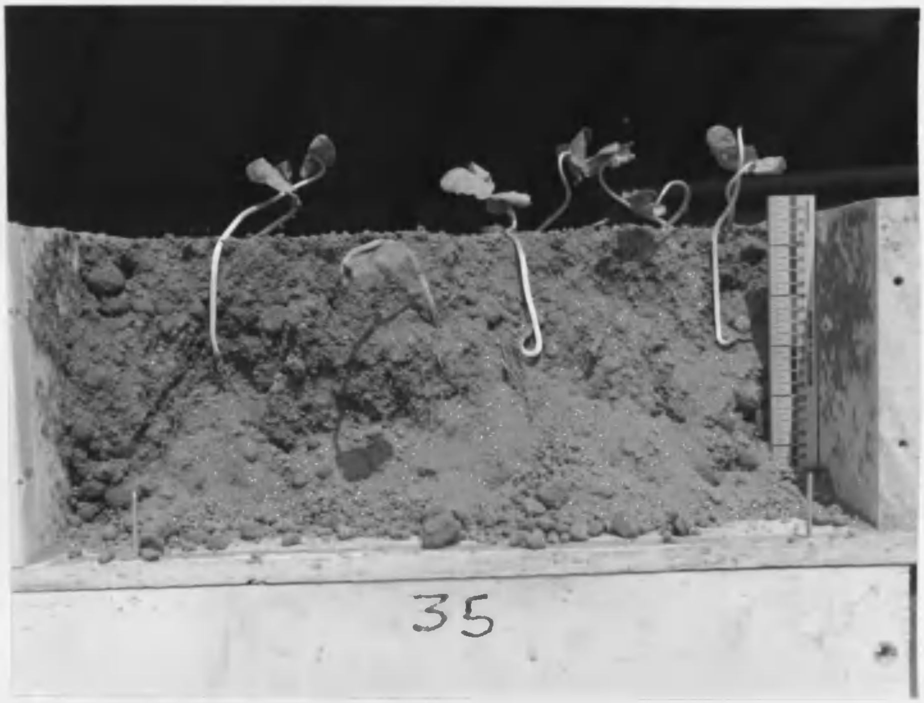


FIGURE 23. Profile Showing Emerged Seedlings. (Replication IC.) Seedlings were in soil with medium moisture content and no surface pressure.

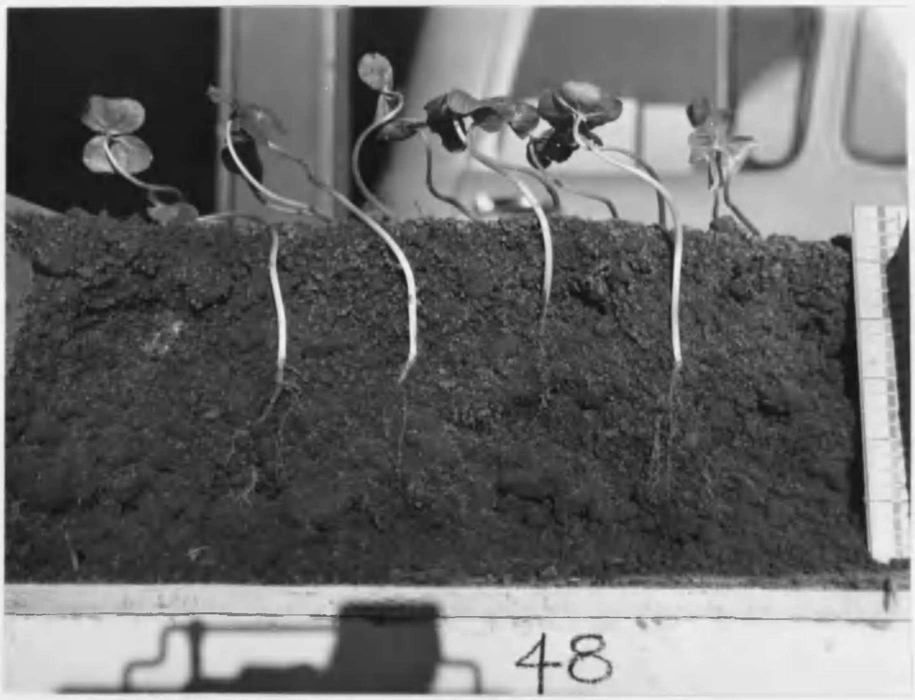


FIGURE 24. Profile Showing Emerged Seedlings. (Replication IIC.) Soil had high moisture content with 0 surface pressure.

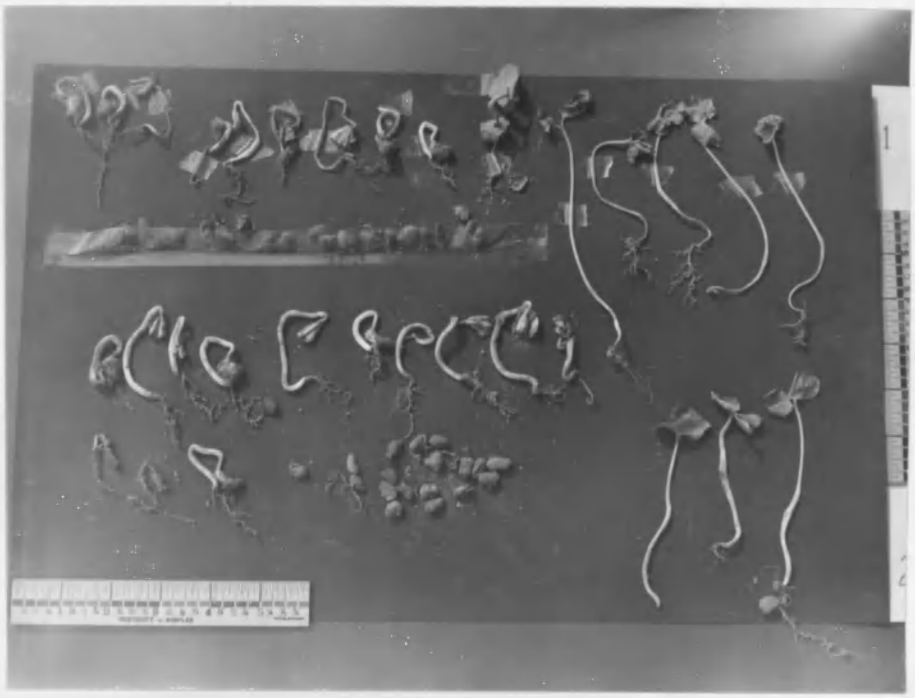


FIGURE 25. Comparison of Seedlings from Soil with Medium Moisture Content. (Replication I.) Upper half shows seeds and seedlings from soil with 5 psi surface pressure, and lower half shows ones with 10 psi surface pressure.

FIGURE 26. Comparison of Seedlings from Soil with Medium Moisture Content. (Replication I.) Upper seedlings were from soil with 0 surface pressure, and lower seedlings were from soil with 15 psi surface pressure.

FIGURE 27. Comparison of Seedlings from Soil with Low Moisture Content. (Replication I.) Upper seedlings were from soil with 0 surface pressure, and the lower seedlings were from soil with 15 psi surface pressure. Notice the difference in root development between the two groups of seedlings.

FIGURE 28. Comparison of Seedlings from Soil with High Moisture Content. (Replication IC.) Seedlings were from soils with the following surface pressures: Upper left - 15 psi, upper right - 5 psi, lower left - 0 psi, and lower right - 5 psi. Note the enlarged seedling diameter where 15 psi surface pressure was applied. The other seedlings were unable to emerge.

SUGGESTIONS FOR IMPROVEMENT AND FURTHER APPLICATION OF THE MINIATURE PRESSURE CELL

No claim is made that "seed-type" cells are perfect. It is believed that the design provides a means for adequately measuring low soil pressures, but methods of construction limit the conclusions that have been made.

Exact duplication has not been achieved by the present method of construction, but is needed for perfection of the pressure cell. A method which provides interlocking of the thin shells and arched strips would probably allow more exact duplication and easier construction. Foil gages would probably be easier to cement to the arched strips and also might increase sensitivity. The SR-4 strain gage lead wires should be insulated and carefully arranged within the cell to prevent contact with the shell.

Small pressure cells of this type provide a means to make measurements of seed environment resulting from planter press-wheel operation. The pressure cells could be used with recording instruments to record soil pressures and to study performance of planting equipment during field operations. The cells could be arranged at various depths to determine pressures created in various zones of the seedbed. They could be arranged across the row to determine the resultant pressure action of the entire planting unit and any adverse effect it may leave in the vicinity of the seed. Pressure cells placed in the seed furrow before the seed is covered, might enable determination of impact pressures caused by the falling soil particles as the seed is covered. Pressure cells could be arranged at various intervals along the row to determine the uniformity of the seedbed as left by the planting equipment. This would contribute to the development of planting units for improving seedbed uniformity. The measurements along a row could also be used to establish limits of seedbed pressures that do not hinder seedling development.

SUMMARY

Maximum profit in agricultural production requires the elimination of all unnecessary operations in crop production. The thinning of cotton plants costs farmers approximately $4.50 per acre. If the desired plant population could be obtained from the initial planting operation, thinning would be unnecessary.

To obtain the desired stand, planting equipment must leave a seedbed that is conducive to germination of seeds and emergence of seedlings. It is believed that some soil compression to firm soil around the seed is conducive to its germination and emergence. To establish limits that enhance seedling development of certain crops, studies have been made by applying loads to the soil surface. Interpretation of results from such studies assumes that a uniform seed zone has been established. It was believed that a knowledge of seedbed environmental pressures would be more useful in evaluating performance of planting equipment in field emergence tests since a uniform seed zone is almost impossible to achieve in field operations.

Many investigators have developed theoretical laws in an attempt to predict pressures beneath a surface load. These laws are helpful as estimates, but do not precisely predict pressures because soil only approximates the assumptions upon which the laws are based.

Other investigators have developed soil pressure measuring devices primarily for measuring high pressures such as those found beneath highways, foundations, or airfield runways. Numerous problems have been revealed about pressure measurement during the development of these devices.

A study of these problems in relation to the measurement of seedbed environmental pressures resulted in the design of a small "seed-type" soil pressure cell. The "seed-type" pressure cell measured micro-variations in soil pressure distribution which were previously unexpected. No definite relationship between surface loads and measured pressures could be established while demonstrating the cell.

A germination and seedling emergence study was made while demonstrating the use of the cell. The pressures acting directly on the seed may not be as important as previously thought because they cannot be used as an indication of the total emergence energy required. Surface pressure is more reliable in evaluating emergence than measured pressure because it is an index of the summation of the conditions through which the seedling emerges. Germination was not affected by the various treatments, but seedling emergence was reduced when loads were applied to the soil surface. High soil moisture content helped seedling emergence overcome the restrictions on growth caused by surface loads.

CONCLUSIONS

General

1. No definite relationship between surface pressures and actual soil pressures exerted on cotton seeds was found in this study.

2. The variability of the measured pressures in the laboratory test indicates that many measurements would be needed to establish a relationship between measured pressures and emergence.

3. The small "seed-type" pressure cell revealed heretofore unsuspected micro-variation in soil pressure distribution resulting from nominally uniform surface loading.

4. If the number of measurements necessary to establish a relationship between measured pressures and emergence becomes extremely large, the use of surface pressures to evaluate emergence may be an easier and more reliable method of evaluation.

Soil Pressure Measurement

1. The "seed-type" pressure cell provides measurement of low soil pressures such as those exerted on seeds during field and laboratory studies of planting equipment.

2. Construction methods should be modified to permit more precise duplication.

3. Calibration of the pressure cells in a soil tri-axial shear test device should be investigated further.

Seedling Emergence

1. Pressures acting directly on individual seeds may not be as important in explaining emergence as originally believed because they are not indicative of the total emergence energy required.

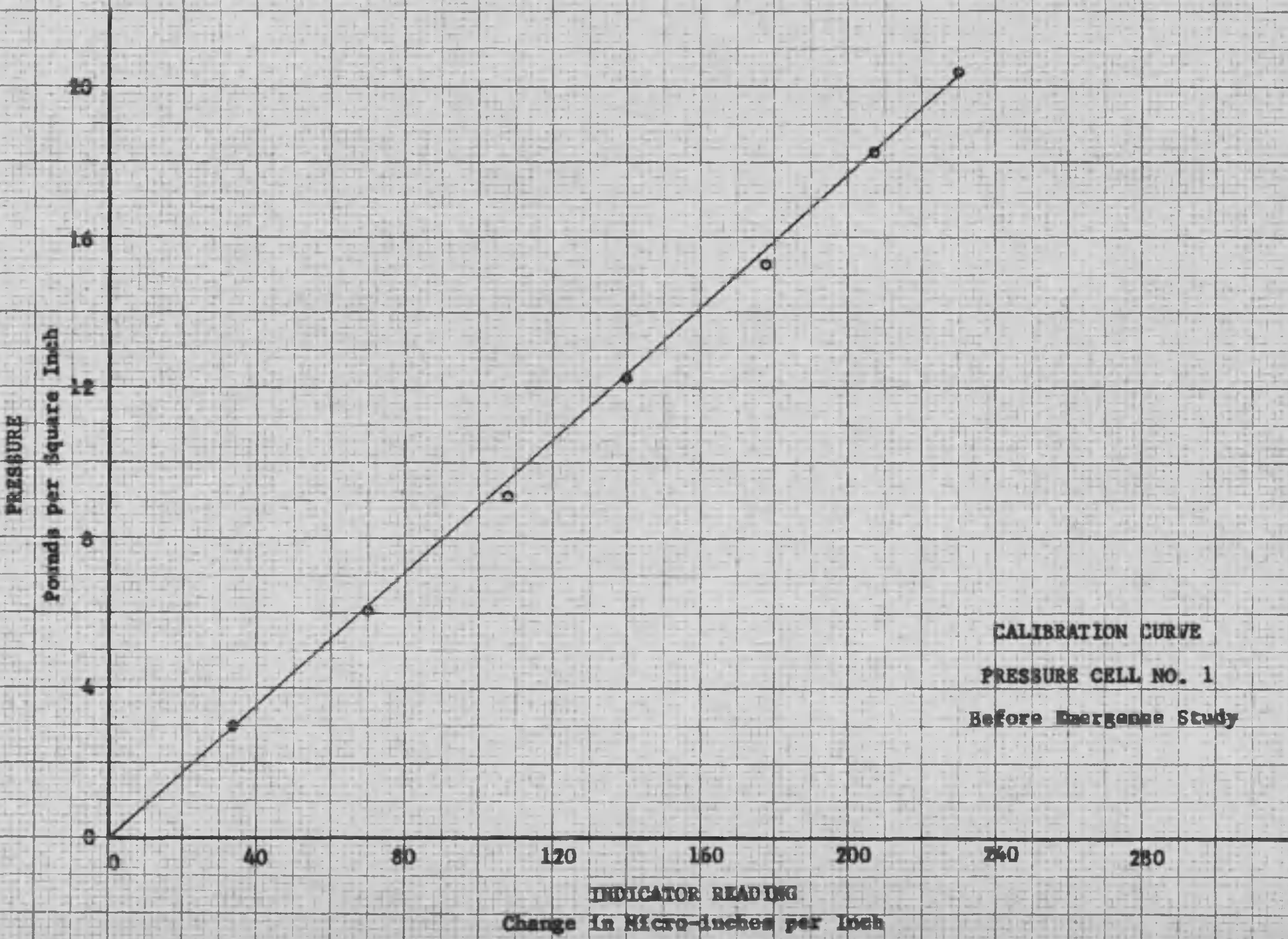
2. Applied average surface pressure is more reliable in predicting emergence than measured internal pressure because it is an index of the summation of soil conditions through which the seedlings must emerge.

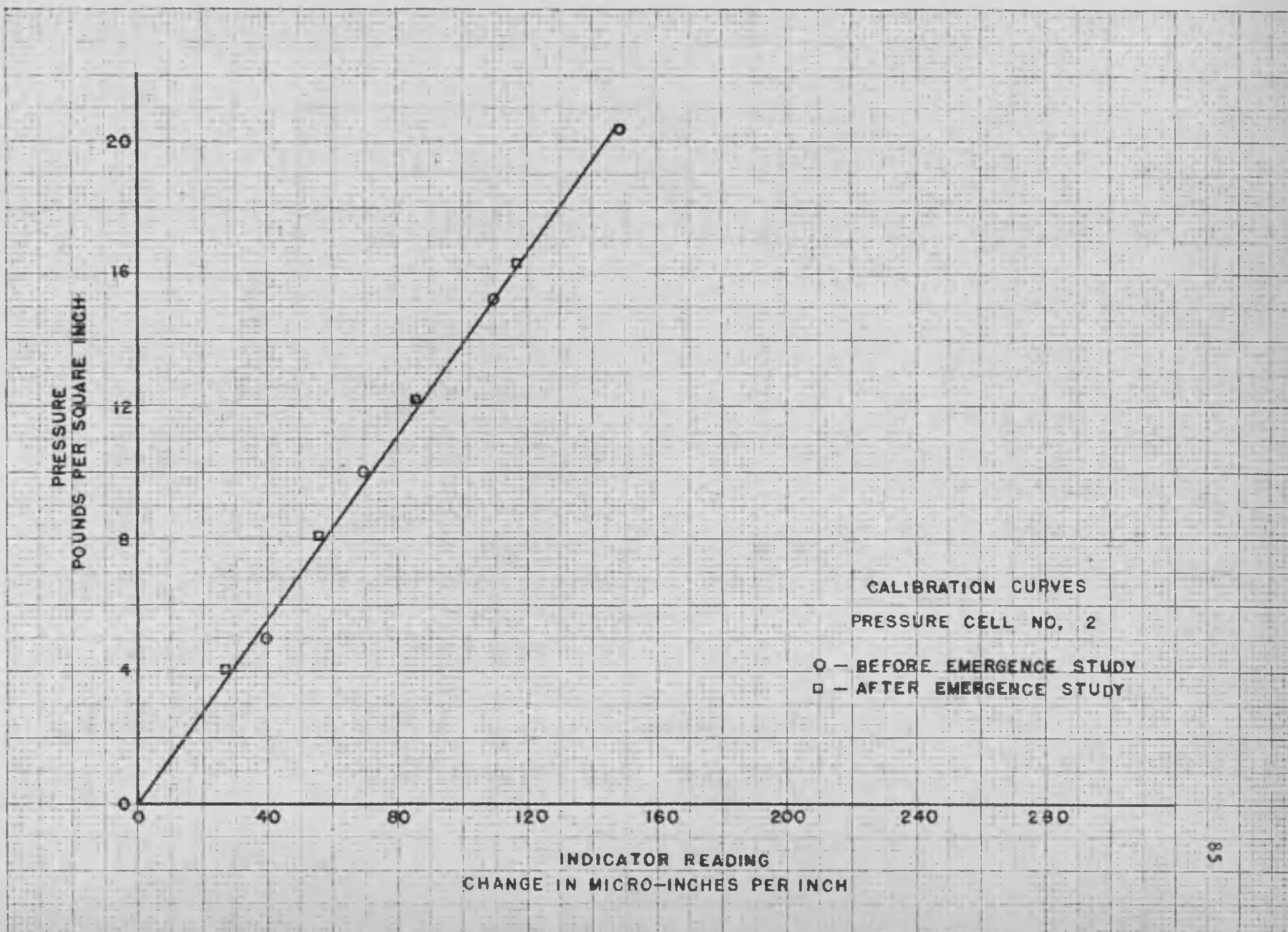
3. Crusting of the soil surface can prevent seedling emergence and should be avoided.

4. Surface pressures should not exceed 10 pounds per square inch when studying its effect on cotton seedling emergence.

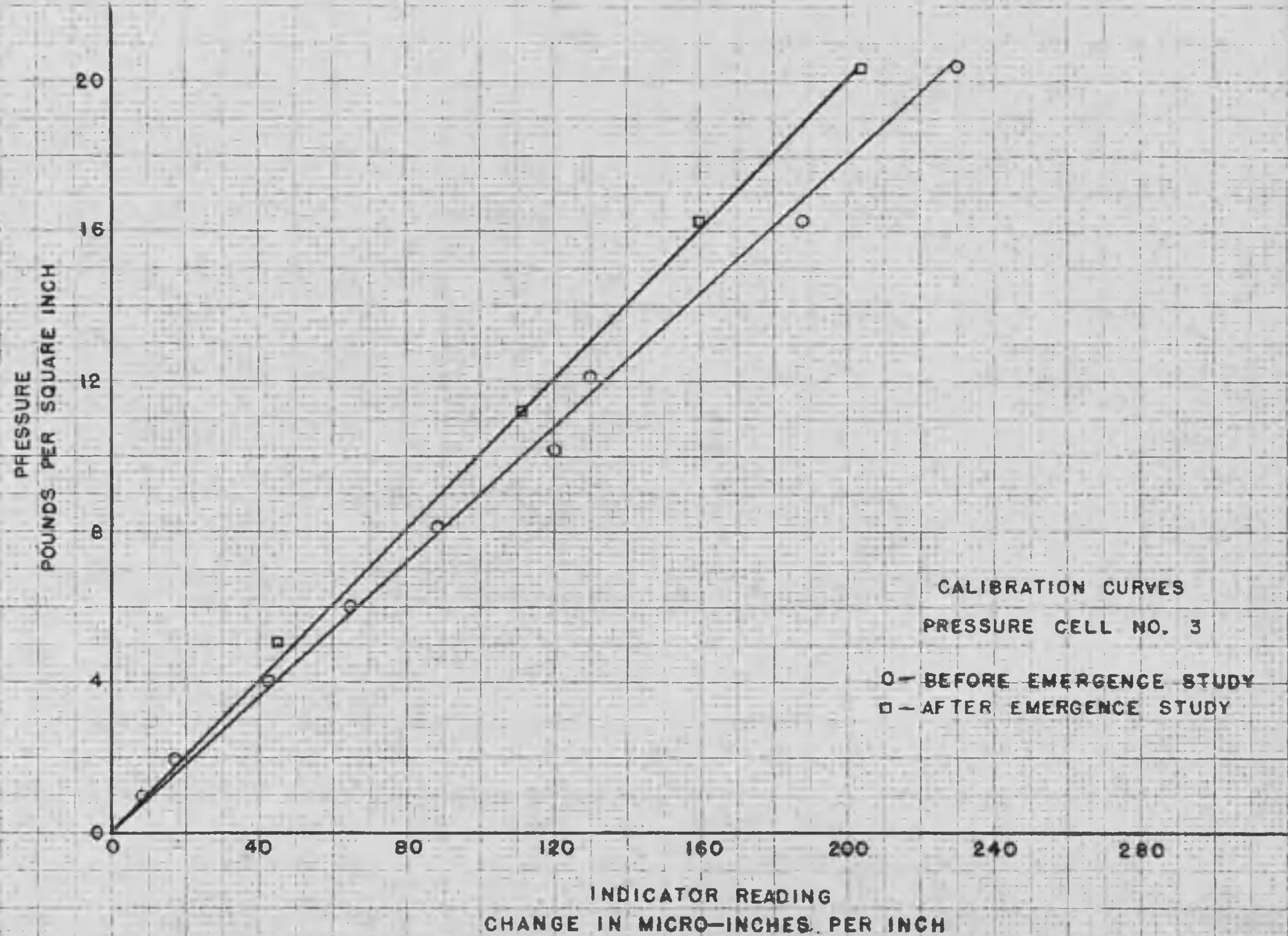
5. Surface pressures between zero and 5 pounds per square inch should be of primary interest for determining any beneficial aspect of rolling above cotton seed.

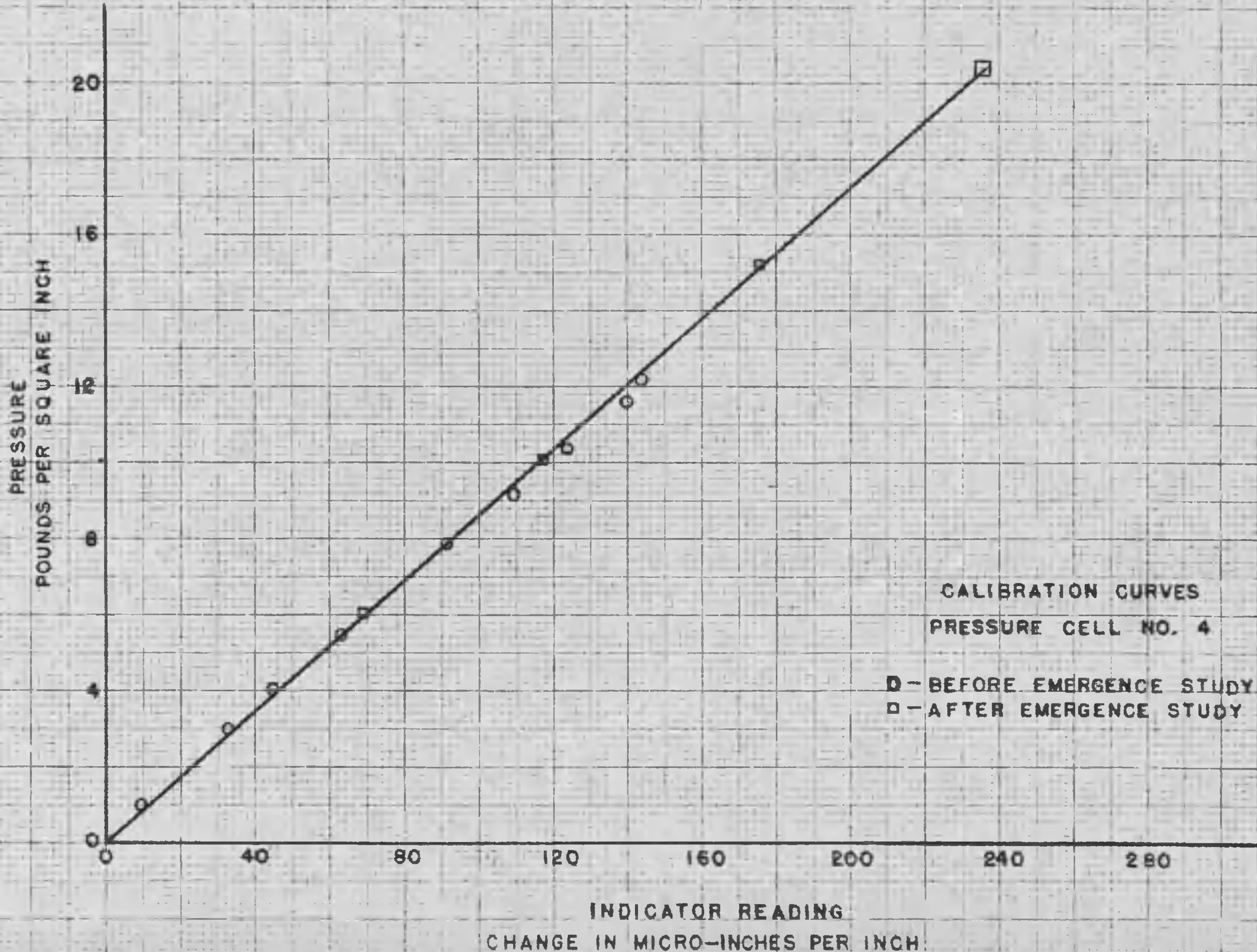
APPENDIX A


PRESSURE
Pounds per Square Inch
20
16
12
8
4
0
0
40
80
120
160
200
240
280
INDICATOR READING
Change in Micro-inches per Inch
CALIBRATION CURVE
PRESSURE CELL NO. 1
Before Emergence Study

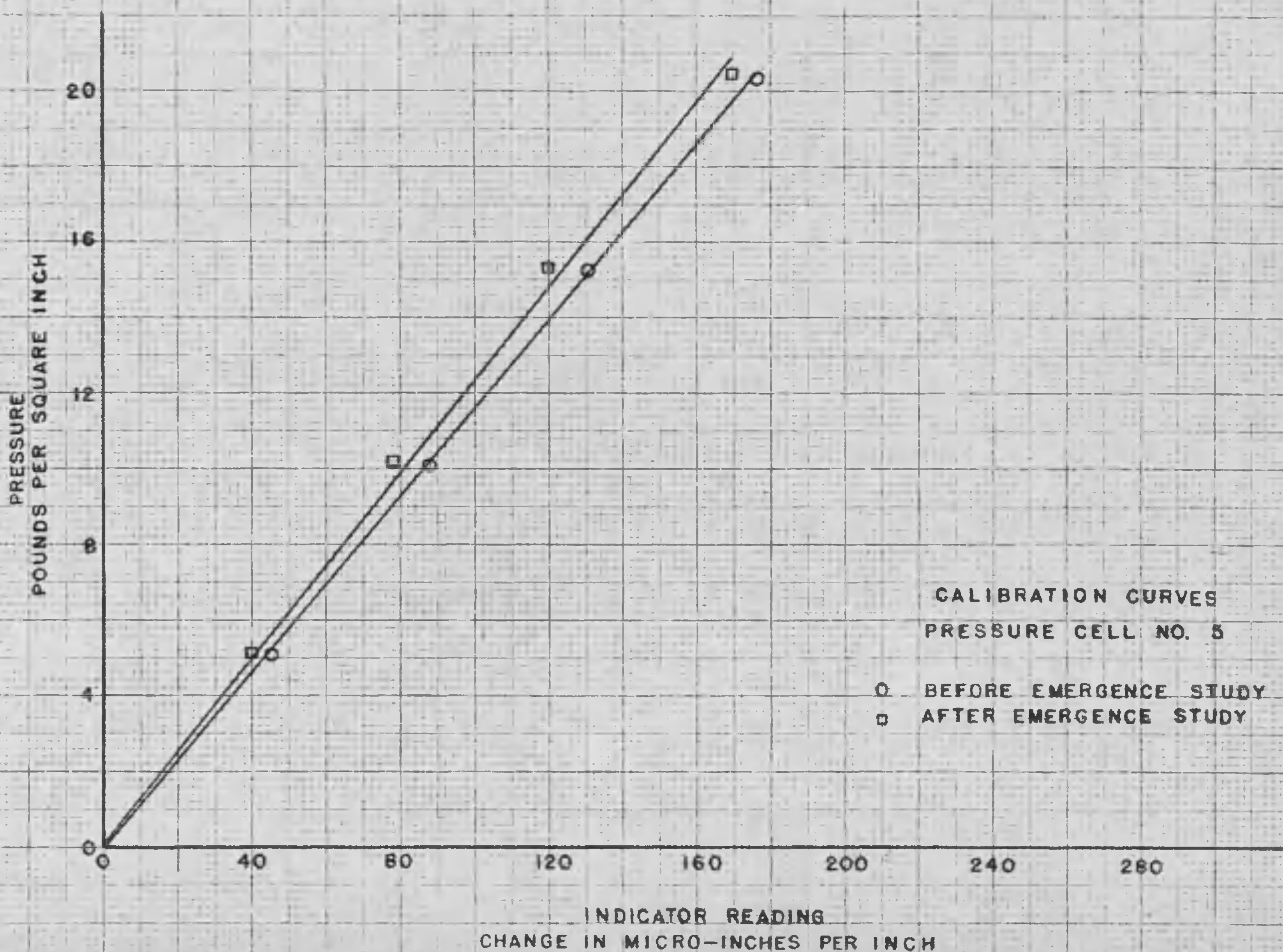


PRESSURE
POUNDS PER SQUARE INCH
0
4
8
12
16
20
0
40
80
120
160
200
240
280
INDICATOR READING
CHANGE IN MICRO-INCHES PER INCH
CALIBRATION CURVES
PRESSURE CELL NO. 2
O — BEFORE EMERGENCE STUDY
□ — AFTER EMERGENCE STUDY


PRESSURE
POUNDS PER SQUARE INCH
0
4
8
12
16
20
0
40
80
120
160
200
240
280
INDICATOR READING
CHANGE IN MICRO-INCHES PER INCH
CALIBRATION CURVES
PRESSURE CELL NO. 3
O — BEFORE EMERGENCE STUDY
□ — AFTER EMERGENCE STUDY



CALIBRATION CURVES
PRESSURE CELL NO. 4
▫ - BEFORE EMERGENCE STUDY
▫ - AFTER EMERGENCE STUDY
PRESSURE
POUNDS PER SQUARE INCH
0
4
8
12
16
20
0
40
80
120
160
200
240
280
INDICATOR READING
CHANGE IN MICRO-INCHES PER INCH



20
16
12
8
4
0
PRESSURE
POUNDS PER SQUARE INCH
0
40
80
120
160
200
240
280
INDICATOR READING
CHANGE IN MICRO-INCHES PER INCH
CALIBRATION CURVES
PRESSURE CELL NO. 5
O BEFORE EMERGENCE STUDY
□ AFTER EMERGENCE STUDY

APPENDIX B

SOIL SAMPLE ANALYSES

pH VALUES Paste	ml EDTA 1x5	Soluble Salts in Saturation Ext. $EC_e x 10^3$	ppm.	NO_3	PO_4	% Sand	% Silt	% Clay
7.6	1.86	2.4	1680	184	8	37	35	28

TABLE B.1

Analysis of Variance
Treatment Effects on Germination in Replications I and II

Source	Degrees Freedom	Sums of Squares	Mean Square	F	
Main Plots					
Moisture	2	173.59	86.80	2.70	NS
Replication	1	26.04	26.04	0.82	NS
Main Plot Error	2	63.58	31.79		
Sub Plots					
Pressures	3	43.46	14.49	1.09	NS
P X M	6	5.41	0.90		NS
Sub Plot Error	9	119.88	13.32		
Total	23	431.96			

TABLE B.2

Analysis of Variance
Treatment Effects on Germination in Replications IC and IIC

Source	Degrees Freedom	Sums of Squares	Mean Square	F	
Main Plots					
Moisture	2	225.25	126.13	4.40	NS
Replication	1	6.00	6.00		NS
Main Plot Error	2	57.25	28.63		
Sub Plots					
Pressure	3	44.00	14.67	1.95	NS
P X M	6	86.75	14.46	1.92	NS
Sub Plot Error	9	67.75	7.53		
Total	23	514.00			

TABLE B.3

Analysis of Variance
Treatment Effects on Seedling Emergence in Replications I and II

Source	Degrees Freedom	Sums of Squares	Mean Square	F	
Main Plots					
Moisture	2	557.59	278.80	6.50	NS
Replication	1	45.38	45.38	1.06	NS
Main Plot Error	2	85.74	42.87		
Sub Plots					
Pressure	3	521.13	173.71	48.25	**
P X M	6	166.74	27.79	7.72	**
Sub Plot Error	9	32.38	3.50		
Total	23	1408.96			

TABLE B.4

Analysis of Variance
Treatment Effects on Seedling Emergence in Replications IC and IIC

Source	Degrees Freedom	Sums of Squares	Mean Square	F	
Main Plots					
Moisture	2	480.58	240.29	300.36	**
Replication	1	10.66	10.66	13.33	NS
Main Plot Error	2	1.59	0.80		
Sub Plots					
Pressure	3	1294.33	431.44	75.03	**
P X M	6	404.40	67.40	11.72	**
Sub Plot Error	9	51.75	5.75		
Total	23	2243.33			

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