A SOIL MOISTURE LOSS METHOD FOR CHARACTERIZING SIMULATED TILLAGE TREATMENTS

Thesis for the Degree of Ph. D.

MICHIGAN STATE UNIVERSITY

William H. Johnson

1960

This is to certify that the

thesis entitled

The Basic Soil Moisture Loss
Method of Characterizing Simulated
Tillage Treatments.

presented by

William H. Johnson

has been accepted towards fulfillment
of the requirements for

Ph.D. degree in Agricultural Engineering

Wesley F. Buchele
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Date Aug 12, 1960

A SOIL MOISTURE LOSS METHOD FOR CHARACTERIZING

SIMULATED TILLAGE TREATMENTS

By

William H. Johnson

AN ABSTRACT

Submitted to the School for Advanced Graduate Studies of

Michigan State University of Agriculture and

Applied Science in partial fulfillment of

the requirements for the degree of

DOCTOR OF PHILOSOPHY

Department of Agricultural Engineering

Year 1960

Approved Wesley F Buchele

WILLIAM H. JOHNSON

AN ABSTRACT

An analysis made of past work indicated that the emergence of corn was often slow and erratic in "minimum" seedbeds. The high rate of soil moisture loss from large-clod-size seedbeds, and therefore rapid drying of the soil at seedlevel, was postulated as being the major contributing factor to poor emergence.

The purpose of this study was to devise methods of characterizing soil moisture loss from a disturbed soil layer and evaluating the effect of varying clod sizes in the tilled profile, upon soil moisture loss.

Four size ranges of clods were used, varying from 0.046 to 0.335 inches in diameter. The control of temperature, humidity, wind flow, and radiant energy provided a basis by which multiple samples and soil treatments could be compared under common climatic conditions.

Newton's equation, $\frac{M - M_e}{M_o - M_e} = e^{-K\theta}$, plotted in the form of the moisture content ratio - time curve with slope K, provided an adequate means for characterizing the rate of soil drying after a stable diffusion system was established. A parameter, P, percentage of water lost during the first 24 hour period, was used to characterize the the initial drying period. In addition to characterizing the drying rate, this method provided a basis for comparing the various soil treatments.

WILLIAM H. JOHNSON AN ABSTRACT

The experimental results indicated that as clod size increased and compactive effort decreased, the rate of soil drying increased and the total emergence of corn was reduced.

No compacted and/or stratified treatment, in which the primary soil consisted of large clods, was as effective in reducing the drying rate of soil as a reduction in clod size to 0.046 inches. The lowest drying rate, however, occurred when the 0.046 inch clods were subjected to a compactive pressure treatment.

The application of 5 psi compactive pressure at seedlevel and again on the surface retarded, or at times inhibited, emergence to an undesirable extent. The stratified treatment was more satisfactory in that emergence was not inhibited and the fine, compacted clod layer at seedlevel provided a highly resistant layer to the diffusion of water vapor, yet capillary movement was broken.

A seedbed profile built up by separating and placing clods by size rather than subjecting a soil to a continual size reduction process has practical potential.

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ACKNOWLEDGMENTS

In a study such as this many individuals contribute to make progress possible. Specifically those on the Michigan State University staff:

Dr. Wesley F. Buchele, Agricultural Engineering Department, major professor, continously provided guidance, counsel and encouragement.

Drs. Carl W. Hall, E. A. Erickson, L. E. Malvern, and W. D. Baten respectively of the Agricultural Engineering, Soils, Applied Mechanics, and Statistics Departments served as guidance committee members.

Drs. B. A. Stout and F. W. Buelow for making experimental equipment available.

Dr. A. W. Farrall, Chairman of the Agricultural Engineering Department, made the research assistantship and project financial support available.

Mr. James Cawood and the service staff of the Agricultural Engineering Department for helpful assistance in the construction of apparatus.

Several members on the Ohio Agricultural Experiment Station staff have also contributed:

Director L. L. Rummell, W. E. Krauss, Associate Director and R. D. Barden, Chairman of the Agr'l Engineering Department, for providing the opportunity, and incentive to pursue additional formal study.

Drs. D. M. Van Doren and C. R. Weaver respectively, in the Department of Agronomy and Statistics, for their assistance in conducting tests and interpreting results.

The author wishes also to express sincere gratitude to his family:

Mrs. Wyoma Swift Johnson, wife, for her patience, endurance, encouragement and assistance.

Larry, Cheri and Dana Johnson, children, for their patience and confidence.

INTRODUCTION

Considerable research has been conducted since the early 1940's to minimize the number of tillage operations required to develop a suitable seedbed. This interest originates from concern for soil structural deterioration, high tillage costs, and yield reductions due to excessive tillage operations.

Cook, McColly, Robertson and Hansen (1958) define minimum tillage as being the least amount of tillage needed for quick germination and a good stand. Willard, Taylor and Johnson (1956) summarized the results of a corn tillage experiment by stating there was no advantage in working plowed land beyond that necessary to insure a good stand and that the equivalent of once-over techniques led to maximum corn yields <u>when a satisfactory stand was obtained</u>. Johnson and Taylor (1958) observed the stands of corn established in minimum seedbed treatments for six years and found stands from 72 to 100 percent. The deduction from this information was that the establishment of stands was erratic and a problem when minimum seedbed preparations were used. The definition of minimum tillage in terms of stand is inadequate. In order to <u>insure</u> the emergence of an adequate and consistant stand more precise specifications must be given. Research workers can use stand to evaluate a tillage operation; the farmer, however, can not. He must establish an adequate number of growing plants before a satisfactory yield can be expected.

Other workers have reported a slowness of a crop to emerge following the use of minimum seedbed treatments. Richey (1959) summarized a group of technical papers on tillage by indicating that one of the problems of minimum tillage mentioned in all papers was low emergence and early growth of the crop. He further suggested that this characteristic of minimum tillage must be overcome before full benefits can be obtained. In this regard, Buchele (1954) found that the retarded growth of young seedlings not only reduced yield and caused the crop to mature later but also affected adversely the quality of the crop produced.

Taylor and Johnson (1956) suggested one fundamental characteristic of seedbeds which contributed to both stand and rate of emergence. They found significant correlations between early stands of corn and the percentage of clods (by weight) smaller than 2 mm. in diameter. No correlation was found between early stands and soil moisture contents at the time of planting. Final stand was influenced by size of clods but not as much as early stands. These results are far reaching in that soil moisture transfer must have been more rapid and more complete as the quantity of small clods increased. A slower moisture loss from the seed zone in finer seedbeds would account for the above tendency.

Farmers know from experience that soils plowed after the first of May, must be "worked" quite soon after plowing to prevent rapid drying of the plow layer. This rapid drying makes successive tillage operations more difficult and contributes to lower soil moisture contents at planting time.

The hypothesis advanced in this thesis is that the coarser and less compact a seedbed is left after a tillage operation the more rapid the soil moisture loss from the seed zone and the slower the rate of emergence of the crop planted in the seedbed.

Research workers in soils have found it difficult to adequately describe the size distribution of clods for optimum crop emergence and growth. Because of this difficulty, engineers must assume sound axioms as a means of evaluating tillage treatments until more fundamental information becomes available. One such axiom is that it is desirable to retain (or conserve) a high soil moisture content at seedlevel after a tillage and/or planting operation. Many such axioms may be stated; however, this one will receive major emphasis.

Basically a tillage tool performs four functions: (a) alters clod size distribution, (b) changes location of the clods in the soil profile, (c) modifies the bulk density of the soil, and (d) changes location of any surface residues. Based on the hypothesis and axiom stated above, tillage treatments can be evaluated by characterizing the moisture loss rate as the above four functions are altered.

STATEMENT OF THE PROBLEM

The purpose of this study was to devise methods of characterizing moisture loss from a disturbed soil layer and evaluating the effect of varying clod size, degree of compaction, and location of various clod sizes in the tilled profile, upon moisture loss.

REVIEW OF LITERATURE

Influences of Clod Size.

Esser in 1884, as reported by Baver (1956), studied the evaporation from a sieved soil with clod sizes ranging from 0.071 mm. to 2 mm. He found, in 2 mm. particles, the evaporation was about 1/4 as much as from the smaller particles.

Yoder (1937) in a series of sieved soils found a clod mixture ranging from 1/8 to 1 inch to be optimum as evaluated by cotton response. He also found non-capillary pore space reduced as the clod sizes increased from 1/8 to 4 inches. Emergence rate was fastest on soil ranging from 1/16 to 1/2 inch. Early emergence reflected high yield.

Johnson and Taylor (1958) reported highest corn stands resulted from seedbeds in which 30 percent of the soil aggregates were smaller than 2 mm. in diameter.

Stout (1959) found no significant differences in sugar beet emergence as clod size varied from 0.59 to 6.35 mm. in 5 ranges. The soil moisture was, however, kept high through the use of covered sample boxes.

Greacen (1959) reported, in wind tunnel tests, that a coarse clod system with pore sizes greater than 2 mm. lost water at a much faster rate than soils in finer tilth, for example, 3 days as compared to 30 days for a loss of 1 inch of water. He further states there must be some air convection effect but to date they had not been able to set up an effective model.

Miller and Mazurak (1958) studied different growth rates of sunflowers in sand as soil particle size varied. At field capacity the maximum growth rate was obtained from separates ranging from 9 - 13 microns. Bulk density was highest for larger particles.

Sokolovsky (1933) emphasized the importance of granulation and porosity as measures of tilth. The results indicated clods 2 - 3 mm. in diameter were best for plant growth. Pore space should be equally divided between capillary and non-capillary pores. When the non-capillary porosity was lower than 10 percent by volume the tilth was poor.

Influences of Soil Compaction.

Stout (1959) found that the application of pressures above 5 psi to the soil surface decreased the emergence of sugar beet seedlings. In fact there was some evidence that the optimum pressure was below 5 psi.

Hanks and Thorp (1956) found excessive compaction pressures were detrimental to wheat seedling emergence on three soil types.

Hudapeth and Jones (1954) found a hollow rubber-tired 1 x 10 inch seed press wheel, spring loaded, running over the seed before they were covered, was beneficial in obtaining good cotton stands. A small harrow like device followed the press wheel.

Bowen (1959) reported stands in cotton of 10, 9, 8, 7 plants out of 10 for 0, 1, 3, 5 psi compaction pressure, respectively. He further noticed, however, that the moisture drying front had moved closer to the seed in uncompacted soil.

Fisher (1952), French (1952), Barmington (1950), all indicated beneficial effects in sugar beet emergence from press wheels packing the soil immediately around and below the seed zone. Correlation was found between firmness of the soil, the soil moisture content in the seed zone, and emergence of the seedlings.

Environmental Factors Influencing Germination and Emergence.

Hunter and Dexter (1951) found only slightly better emergence was obtained by pre-soaking sugar beet seeds in water prior to planting.

Dungan (1924) determined that the rapidity of water absorption was associated with the rate of germination in corn. Seed corn harvested before complete maturity and stored at 19.2 percent moisture emerged quicker but with less vigor than corn allowed to mature on the stalk or corn stored at 12.6 percent moisture. Corn dried to 6.1 percent germinated slower and with less vigor.

Hanks and Thorp (1957) reported that the ultimate seedling emergence of wheat, grain sorghum, and soybeans was approximately the same when the soil moisture content was maintained between field capacity and wilting percentage; however, the rate of emergence was related directly to moisture content. Oxygen supply limited wheat emergence when pore space was below 16 percent in a silty clay loam and 25 percent in a fine sandy loam.

Hunter and Erickson (1952) found corn required a kernel moisture of 30.5 percent for germination. Soil moistures which would just permit germination was 10.2 and 12.0 percent in Brookston soil.

Andrew (1953) found deep planting of sweet corn followed by temperatures of 50 degrees F. caused poor stands because of the following:

1. Delayed formation of permanent roots near the coleoptilar node.
2. Required longer first internodes and more time for emergence; thus, increasing the exposure to disease.
3. Modified the balance between the time of permanent root formation and time of decay of the first internode which resulted in earlier loss of the adsorptive capacity of temporary roots.

Stiles (1948) indicated there was a different uptake of water by seeds of corn, cotton and beans (both the total amount of water absorbed and rate of absorption) for different species and varities.

Movement of Water In or Through a Soil.

Bouyoucos (1915) studied small cylinders of soil subjected at one end to 0° C. and the other end to 20 - 40° C. The percentage of water transferred from warm to cold increased in all different soil types with a rise in moisture content until a certain water content was reached, then it began to decrease with a further increase in moisture content. This break occurred where inter-particle voids began to fill with water.

Jones and Kohnke (1952) evaluated the vapor movement in soils subjected to a temperature gradient of 2° and 32° C. For the three size ranges of sand tested (0.5 to .02 mm.), the rate of water transfer was approximately the same. The volume of unsaturated pore space, not the pore size, appeared to determine where vapor diffusion began.

Buckingham (1904) was one of the first investigators to apply the kinetic theory of the diffusion of gases to soils. He expressed the relation of the diffusion rate to the free pore space by the following equation: $D = kS^2$ where D is the diffusion constant, S is the free pore space, and k a proportionality factor or diffusion coefficient. This expression points out that the rate of diffusion is reduced 75 percent as the free pore space is reduced 50 percent.

Penman (1940) suggested a modification to Buckingham's equation. Instead of using $\frac{D}{Do} = S^2$ Penman suggests $\frac{D}{Do} = .66S$ where Do is the coefficient of diffusion in air. Several other workers, as summarized by Baver (1956), have found similar values for $\frac{D}{Do}$; however, the equation has been applied more often to soil aeration rather than vapor flow.

Rollens, Spangler and Kirkham (1954) checked the applicability of Hank's diffusion equation for the movement of soil moisture under a thermal gradient. They measured diffusion values six times greater than the calculated values.

Gurr (1952), also using a diffusion equation similar to Hank's equation, measured vapor flow 3.6 times the calculated values.

Taylor, Cavazza and Luigi (1954) developed an equation which would characterize the movement of soil moisture in response to temperature gradients. This equation was based on a moisture potential gradient. Measured water vapor flow was 11 times the calculated value.

Hanks (1958) characterized water vapor transfer in dry soil through an equation based on vapor pressure differences. Calculated values were low with the ratio of $\frac{\text{measured values}}{\text{calculated values}}$ being about 1.3.

Penman (1941) characterized evaporation from fallow soil by using cylinders of soil with some radiant energy applied. Air velocity, temperature, and humidity were varied; however, nothing was recorded about clod size though the soils were specified. No attempt was made to apply a diffusion equation but an emperical equation was evolved, $E = at^{1/n}$ where: E is total evaporation in inches of water, $n = 3$, t is time in days, and a is a proportionality factor.

Hide (1954) made observations on factors influencing the evaporation of soil moisture. Three ways were suggested to reduce water loss due to evaporation.

1. Decrease the amount of water which can be transported to the surface before drying occurs.
2. Decrease the temperature of the upper fringe of moist soil.
3. Increase the thickness of the static layer of air and thus increase the resistance to vapor diffusion.

Evaporation accounted for 70 - 75 percent of the moisture loss (of total precipitation) in dry land areas. Layered trays were periodically weighed; however, only drying curves were plotted. Clod size was not indicated.

Kolasew (1941) suggested ways of suppressing evaporation of soil moisture. Wind tunnel tests were used to compare the loss of soil moisture from a soil of uniform density to one with stratified layers of compact and loose soil. Soil was wetted to field capacity and the weight loss was observed with time. Layering reduced moisture loss because (1) compact layers were isolated so capillary movement was held to a minimum, (2) compact layers did not conduct vapor because of reduced porosity. The data in Table 1 were presented.

Table 1. Comparisons of Soil Moisture Contents From Normal Fallow and Stratified Tillage Treatments. Clod Size Varied From 0 to 50 cm. Kolasew (1941).

Treatment	Date of Sampling Soil Moisture Content	
	July 15	July 31
	%	%
Normal fallow	14.2	14.6
Stratified (alternate loose and compacted layers)	17.4	15.5

Lemon (1956) was interested in reducing soil moisture loss by evaporation. The following three methods were proposed:

1. Increase the surface barrier to water vapor diffusion by increasing surface roughness (stubble, mulch, etc.).
2. Decrease capillary continuity by tillage or chemical additives.

3. Decrease capillary flow and moisture holding capacity of the surface layers by chemical additives of the surfactant type.

In these tests, the soil moisture loss was characterized by plotting grams per hour lost vs. percentage moisture.

<u>Methods of Characterizing the Drying of Soils.</u>

Lewis (1921) was the first to indicate some drying systems can be characterized by the difference between the moisture concentration in the drying body and the equilibrium moisture concentration. In plotting this difference vs. time on semi-logarithmic paper, a straight line resulted.

Hall and Rodriguez (1958) derived an equation similar to the one by Lewis; however, it was called an equation for the movement of moisture during the falling rate period of drying as based on Newton's equation of heating or cooling. This equation takes the form of $\frac{M - M_e}{M_o - M_e} = e^{-K\theta}$, where M is moisture content (dry basis), M_e is the equilibrium moisture, M_o is the initial moisture content, θ is time, K is a drying constant. This equation was used to characterize grain drying systems.

Sherwood (1929) (1932) characterized the rate of drying during the constant rate phase of drying. Three phases of drying were listed and were shown as grams of water lost per hour vs. percent water (dry basis):

1. Constant rate period - Evaporation takes place at the

surface of the wet solid. The rate of drying is limited by the rate of diffusion of water vapor through the surface air film.

2. Falling rate period I - Generally a linear relation exists between rate of drying and water content. It is characterized by a zone of decreasing wetted surface. The rate does vary with humidity and air velocity.
3. Falling rate period II - Generally the curve is concave upward. Internal diffusion of liquid controls during this period. Variations in humidity or air velocity do not affect drying rate.

The method of Lewis, discussed above, was found to represent some systems for the second falling rate period.

Geaglske and Hougen (1937) reported on the drying of different sized sands. In the second falling rate period, drying proceeded by diffusion of vapor through a dried portion of solid. The drying rate was not affected by the velocity of the air moving across the top of a drying layer. Drying rate increased with increased coarseness of sand and was linear according to the equation $\frac{dW}{Ad\theta} = aw$ where: w is moisture concentration in grams per gram of dry sand, W is weight of water in grams, θ is time in hours, A represents area in sq. cm., and $a = \frac{1}{10^{.216 L + .67}}$. L is thickness of layer in cm.

Bateman (1939) characterized the drying of wood. Moisture loss was by diffusion and was characterized by a plot of water loss in grams vs. square root of time in minutes. A straight line resulted from this plot.

Fisher (1923) characterized the drying of soil by the methods of Sherwood for all three phases of drying. The slopes of the curves which resulted from plotting water loss vs. percent water content were empirically determined.

ANALYSIS OF POSSIBLE MEANS OF CHARACTERIZING EVAPORATIVE WATER LOSS FROM SOIL.

A number of diffusion equations were found in the literature. Many of them were quite scholarly and eventually will provide strong mathematical tools to adequately characterize the diffusion processes. To date, the application of such equations to a soil system has a low accuracy which undoubtedly means all significant variables are not being considered. For example, none of the equations take into direct account the influence of clod size or the influence of eddy diffusion which results from simulated wind flow. For these reasons the common diffusion equations for soil were not used in this study.

Chemical engineers have done much to characterize drying systems; however, they have concentrated on the constant rate period of drying. It was reasoned that the moisture lost after a tillage operation would be associated with the second falling rate period. Therefore methods characterizing the falling rate periods would have the most applicability.

Based on what had been found in the literature, the application of Newton's equation to diffusion problems as used by Hall and Rodriguez (1958) had the greatest potential for development.

THEORETICAL CONSIDERATIONS OF NEWTON'S EQUATION USED AS A DIFFUSION EQUATION.

The drying of a layer of soil will continue until it is in equilibrium with the air above the surface of the soil. In attempting to characterize the rate of drying, the major driving force must be determined. In the application of Newton's equation the driving force is assumed to be moisture concentration. The rate of moisture loss then is proportional to the moisture concentration potential of the soil volume. The fundamental differential equation becomes:

$$\frac{dM}{d\theta} = -K\,(M - M_e) \qquad \text{equation 1}$$

where K is a proportionality constant, θ is time, M is the moisture content of soil (dry basis) at any time, M_e is the soil equilibrium moisture content. By separating variables and calling the initial moisture content M_o, equation 1 becomes:

$$\int_{M_o}^{M} \frac{dM}{M - M_e} = \int_{\theta_o}^{\theta} -K\,d\theta \qquad \text{equation 2}$$

Then by integrating:

$$\frac{M - M_e}{M_o - M_e} = e^{-K\theta} \qquad \text{equation 3}$$

Equation 3 takes the fundamental form of $y = Ae^{-BX}$ which will plot as a straight line on semi-logarithmic paper. The value K is the slope of this curve. Different K values will be obtained for various rates of drying. The steeper the slope of the curve the faster is the rate of drying.

Hall (1957) made a similar analysis in relation to grain drying. He called the term $\frac{M - M_e}{M_o - M_e}$ the moisture content ratio.

Wang and Hall (1958) raise some question as to what extent the vapor diffusivity is actually dependent upon moisture content. Conflicting evidence is cited for hydrophilic substances. An alternate equation is suggested assuming vapor pressure as the main driving force; however, the conclusion is drawn that the two equations are identical when the moisture concentration is directly proportional to the vapor pressure. In order for this to be exactly true the temperature must be uniform throughout the medium.

EXPERIMENTAL PROCEDURE

The general procedure will be discussed first, followed by a more detailed procedure where necessary.

A Brookston sandy loam soil was sieved into four clod size ranges from 0.046 inches to 0.335 inches. The soil was rewet to about 17.5 percent moisture (dry basis) and then placed in plastic sample boxes. The samples were placed in an environmental-control chamber and subjected to a constant air flow parallel to the surface of the soil. Some samples received radiant energy simulating sunlight. The atmosphere around the samples was conditioned to a standard climatic cycle (24 hour cycle) somewhat typical of the emergence season for corn at the middle of May. Corn was planted at the 1 1/2 - inch level and the time of emergence was noted. Periodic weights were made of the soil samples until emergence had occurred or until about 250 hours had transpired. Moisture loss in the upper three inches of soil only was used in the analysis even though the soil sample was 5 1/2 inches deep. Initial and final soil moistures were determined as well as the equlibrium moistures of the soil for the established air conditions.

The moisture contents, M, at each time of weighting were calculated as follows:

$$\frac{(W - w)\ 100}{D} = M \qquad \text{equation 4}$$

where W = total grams of water in upper 3 inches of soil, w = grams of water lost at any time in the upper 3 inches of soil, and D = grams dry weight in the upper 3 inches of soil. The calculation of the moisture content ratios followed according to the equation $\frac{M - M_e}{M_o - M_e}$. Table 2 is a compilation of this series of calculations for each sample. These data were then plotted as a moisture content ratio - time curve, Figures 13 and 14.

The slope, K, of the resulting curve was determined as follows:

$$\frac{Y}{X} = (.4343)\ (K)\ f \qquad \text{equation 5}$$

where Y is the vertical distance and X is horizontal distance (as in normal slope determination procedures) measured in inches; and f is a scale factor or number which is represented from the origin on the X axis equal to the height of one logarithmic cycle on the Y axis, 5.0 in this case.

The resulting slope, K, provided one means of comparing treatments. Percentage of the total water lost, P, in the first 24 hours from the upper three inches of soil provided a second means of comparing treatments.

Clod size, compaction 0 to 5 psi, and stratification of soil (fine clods placed and compacted in a 1-inch layer at seed level) were the major variables in samples which were subjected to cross-air-flow drying with and without radiant energy. In addition, two treatments were protected from the cross-air-flow by thin filter paper covers in an effort to provide additional thickness to the surface diffusion barrier and yet provide the standard air conditions around the sample. Radiant and no radiant energy were also applied to these samples.

The statistical design provided for a two-way classification of clod size and soil treatment. A regression of treatments on clod size was calculated. The mean values of the treatment regression lines also provided a basis for comparing treatments.

Three sub-samples were observed for each cell of the analysis. The use and no use of radiant energy was treated as two separate analyses. In all, 144 samples were required, 153 were observed.

In addition to the statistical summary, average values for K and P were calculated based on the three sub-samples. These average values are graphically presented as a single moisture content ratio - time curve representing each treatment. The calculations required to accomplish this are as follows:

$$\frac{W\ av. - (P\ av.)\ (W\ av.)}{D\ av.} = M\ av.\ \text{at 24 hours} \qquad \text{equation 6}$$

then by substituting M av. at 24 hours into $\frac{M - M_e}{17.5 - M_e}$ the resulting average moisture content ratio at 24 hours was obtained. The slope of the average curve was found by using K av. and Y = 1.5 inches in equation 5.

Screening the Soil. Air dried soil was separated into the following size ranges by the use of American Standard Sieves:

Sieve Opening Range inches	Sieves used	
0.335 to 0.263	through 3/8	on #3
0.263 to 0.185	through #3	on #4
0.185 to 0.093	through #4	on #8
0.093 to 0.046	through #8	on #16

Figure 1 illustrates the various clod sizes. Clod size will be referred to according to the opening size of the sieve upon which they were retained, that is, 0.263, 0.185, 0.093, 0.046 inches.

The sieves were shaken by hand with a gentle rotary motion to minimize additional clod size reduction. See Figure 2.

Wetting the Soil. The air dry soil was wetted in lots of about 4 pounds. Layers about 1/4 inch thick were sprayed with a small hand sprayer. See Figure 3. An exact, pre-determined amount of water was added to each lot to bring the soil bulk up to 17.5 percent moisture. The wetted soil was sealed and allowed to stand for 24 hours. After this time the container was rotated to induce mixing. The soil was then transferred to and sealed in a wide-mouth glass container. No soil was used within 48 hours after wetting.

Placing the Soil in Test Containers. The plastic test containers are shown in Figure 4 a, b, c. The lower portion of the container was filled with unsieved, wetted soil. The container was tapped in a more or less standard manner to induce some settling of the soil. This part of the sample was always left uncompacted.

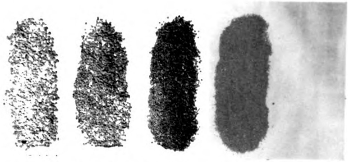
The upper three inches of the container was filled with soil of the various clod sizes. Where no compactive effort was used, the sample was tapped as described before to induce settling. Two fillings were used since 3 corn seeds were placed at the 1 1/2-inch level.

Where the sample was subjected to compactive effort, the container was over-filled at the 1 1/2-inch level, the compactive load was applied (reducing the level to 1 1/2 inches), 3 seeds were pressed into the soil at this level, the container was re-filled (over-filled again), and the compactive load was again applied. The final level of soil was at the container top or slightly above.

In the stratified samples, the sieved clods were placed un-compacted in the 2 - 3 and 0 - 1 inch level. A compacted layer of 0.046 inch clods was separately formed into a "plug" and placed at the 1 - 2 inch level. The "plug" was contained by a light waxed cardboard ring, Figure 4d, and pressed twice, once at seedlevel and once on the surface. Seeds were placed in the "plug" between the two applications of pressure. The "plug" was placed in the test container and surrounded with 0.046 inch clods.

Where the test container was divided, as shown in Figures 4b and c, a screen was first used as the bottom. This was later replaced with cotton gauze. A wide rubber band was used to seal the joint between sections of the test container.

Determining the Equilibrium Moisture Contents. Soil moisture contents were determined on samples of soil which had come into equilibrium with the particular air condition. Equilibrium was determined by observing static weight conditions for the sample over several weighings. Equilibrium moistures were determined both for the radiant energy and no radiant energy condition.



0.263 0.185 0.093 0.046

Figure 1. Visual comparison of the clod sizes used.

Figure 2. Sieves used in the separation of clod sizes.

Figure 3. A hand sprayer was used to wet thin layers of soil.

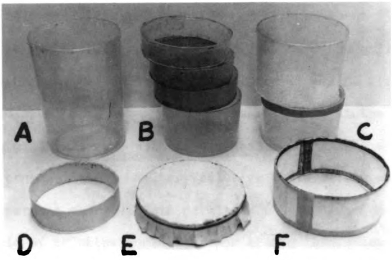


Figure 4. (a) The original plastic sample container. (b) Upper 3 in. layer of soil partitioned in 1 in. layers. (c) Container used to individually weight the upper 3 ins. and lower depth of sample. (d) Cardboard ring used to contain the 1-2 in. layer of .046 in. clods in the stratified samples. (e) Filter paper cover used to cover some samples not receiving radiant energy. A 1 in. high metal ring forms the paper structure. (f) Filter paper cover used to cover some samples receiving radiant energy.

SPECIAL EQUIPMENT AND TEST CONDITIONS

Climate Control Equipment. With the objective of characterizing rates of soil drying as influenced by soil treatment, by necessity, environmental conditions around the sample must be controlled. The fact that many samples were involved and the test work extended over a long period of time demanded that environmental conditions must also be duplicable. Also it was desirable to use temperatures and humidities which were reasonable for the field emergence season of corn.

Two environmental control chambers were used. The first chamber used a room air conditioner for temperature control and a saturated salt bath for humidity stablization. See Figures 5 and 6. $NaCl$ was used as the salt which according to Hall (1957) theoretically stablizes the relative humidity at about 75.5 percent over a temperature range of 50 to 104° F. A 30 gallon plastic container was filled with the saturated brine and air was circulated from the chamber through the salt bath at the approximate rate of 10 cfm. As long as the heat input into the chamber was held constant and laboratory relative humidity did not drop below 40 percent the salt bath permitted the duplication of a daily cycle of relative humidity. For heated laboratory conditions much more capacity in the salt bath would be required to maintain 75.5 percent relative humidity.

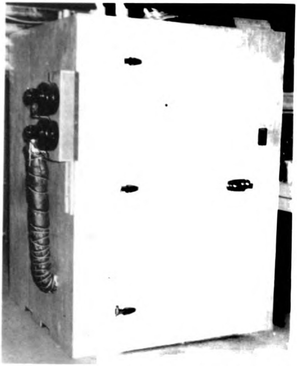


Figure 5. Exterior view of the MSU environmental control chamber.

Figure 6. Interior view of the MSU environmental control chamber. Saturated salt bath is below the arrow.

The second climate control box was a commercially available chamber on which the desired daily climatic cycle could be programmed. A cam type programmer provided a means of controlling the wet- and dry-bulb temperature.

Steam was automatically injected into the chamber when the control system called for humidification. Separate refrigerant coils were activated for temperature reduction and dehumidification. The refrigerant coil for dehumidification was designed and placed so that the surface of the coil was well below the dew point; whereas the temperature of the surface of the coil for temperature reduction of the chamber was generally not sufficiently low to cause condensation. Rapid air movement was provided over this latter coil. Heating was provided for by electric resistance coils also in the circulating air flow. Figure 7 shows this chamber. This chamber provided an adequate means of control regardless of laboratory air conditions.

Examples of the performance charts of both of the environmental-control chambers are presented in Figure 9 of the Appendix.

The Soil Sample Test Stand. Two test stands were used; each however provided the same function. See Figures 8, 9, and 10. Air was first drawn over the top of the samples which did not receive radiant energy. Then it proceeded across the samples receiving radiant energy after which it was discharged back into the environmental chamber. In this manner no samples were placed in the down stream air after it was slightly heated by the radiant lights. A glass top contained the air flow across the samples. A 75 watt radiant light source was placed outside the air stream, and so that the radiant beam was concentrated on one sample. The light source was 4 inches from the surface of soil which resulted in 170 Btu per hour sq. ft. being received by the soil surface. Radiant energy at the soil surface was measured with a General Electric Radiation meter.

The designed air flow across the surface of the sample was to be 6 miles per hour. The air flow was measured in a zone 1/4 to 1 3/4 inches above the soil surface with an Alnor Thermo-Anemometer and adjusted by dampering the fan outlet. Multiple measurements at various points across the air stream showed an actual range of air flows from 475 to 550 feet per minute with an overall average of 534 feet per minute or 6.06 miles per hour.

One treatment protected the sample surface from air movement. This treatment was used both in the samples not receiving and receiving radiant energy; however, there was a distinct change in method between these two conditions. Those samples receiving no radiant energy were covered with a filter-paper-surfaced ring as shown in Figures 4e and 8. The samples receiving radiant energy were protected from air flow with an open top filter paper ring as shown in Figure 4f. In this case, the space between the sample

Figure 7. The Ohio environmental control chamber.

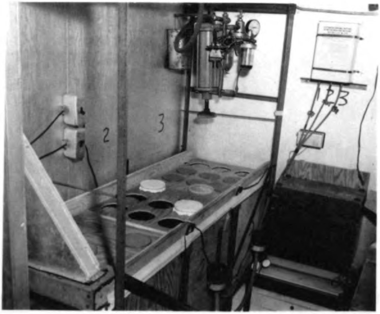


Figure 8. The MSU soil test stand with samples in position. A glass plate top and radiant lights have been removed. Air is exhausted from the near end of the stand.

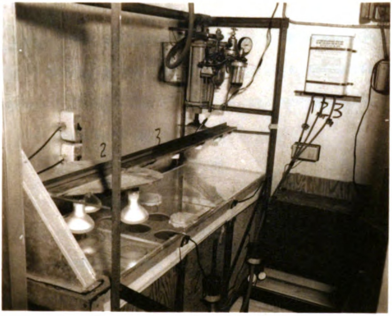


Figure 9. The MSU soil sample test stand with glass plate and radiant lights in the functioning position.

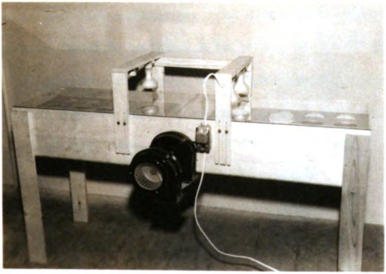


Figure 10. The Ohio soil sample test stand. Air is exhausted from the center and samples could be placed on both sides of the fan.

surface and the glass surface of the test stand was shielded from air flow; radiant energy, however, was received by the sample soil surface.

<u>The Soil</u>. The soil was classed as a Brookston Sandy loam. A mechanical analysis was run according to a procedure developed by Bouyoucous (1937). The following data are summarized:

Sand $> 50\ \mu$	64.6%
Silt $< 50 > 2\ \mu$	17.7%
Clay $< 2\ \mu$	17.8%

Detailed data on this analysis can be found in Table 1 of the Appendix. No difference in mechanical analysis for the various clod sizes could be observed from these data.

The aeration porosity and field capacity for each clod size was determined for the uncompacted condition using the standard core system. Clods were placed into the core rings in a similar manner as in the test container. The cores were allowed to stabilize at zero tension, weighed after being at 60 cm tension for 48 hours, weighed as saturated, and weighed as dried at 105° C. for 48 hours. The data in Table 2, Appendix, are summarized as follows:

Clod size ins.	Aeration porosity %
0.263	44.2
0.185	46.0
0.093	46.1
0.046	48.3

These data indicate the aeration porosities of the uncompacted samples were quite high and to some extent a function of clod size (1.5% is the approximate difference required for significance at the 95% level). Yoder (1937) also found that the aeration porosity decreased as clod size increased. An estimate of the aeration porosity at the 5 psi level of compaction was determined to be in the order of 37 percent.

Pressure-Application Equipment. French and Snyder (1958) devised a pneumatic ram mechanism as the means of compacting laboratory samples. This equipment was available and used as one means of compacting the soil after a calibration was made for the pressures desired and for the area of the pressure plate. This equipment can be seen in use in Figure 11. A flat pressure plate was used between the soil surface and point of force application from the ram. A similar method was used in Ohio except a dead weight was used as means of loading the soil.

The Standard Climatic Cycle. The following weather data were taken from a compilation made by Baten and Eichmeier (1951) characterizing the period May 20 to June 1 at East Lansing, Michigan.

Radiation	1385 Btu/day sq. ft.*
Av. soil temperature at 1"	58° F.
Av. air temperature above soil	62° F.
Av. relative humidity at 1:30 PM	55%
7:30 PM	65%
7:30 AM	78%
Av. wind velocity	6.5 mi/hr.

*Reference indicates East Lansing is low for this period. Interpolated value of 1700 Btu/day sq. ft. is based on a smooth curve by date and is expected to be more typical of Ohio-Michigan conditions.

It was not possible to duplicate these values exactly nor was it demanded since the meaning of average values is questionable. Instead, a reproducable cycle close to the above values was used as follows:

Radiation	2000 Btu/day sq. ft.
Av. air temperature above soil	66° F.
Av. relative humidity, lights on	68%
Av. relative humidity, lights off	82%

Av. wind velocity (1 in. above soil surface) 6 mi/hr.

The cycle of relative humidity is depicted in Figure 12 and represents an overall average humidity cycle for the entire test period of July through September 1959. An actual weekly chart of temperature and relative humidity is shown in Figure 9 of the Appendix.

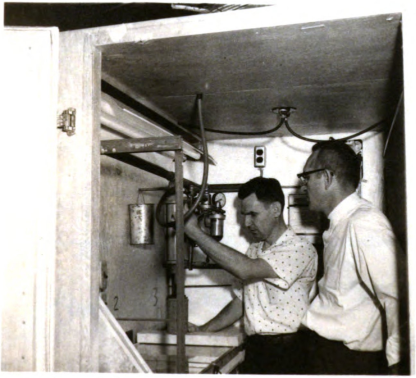


Figure 11. Equipment used to compact the soil.

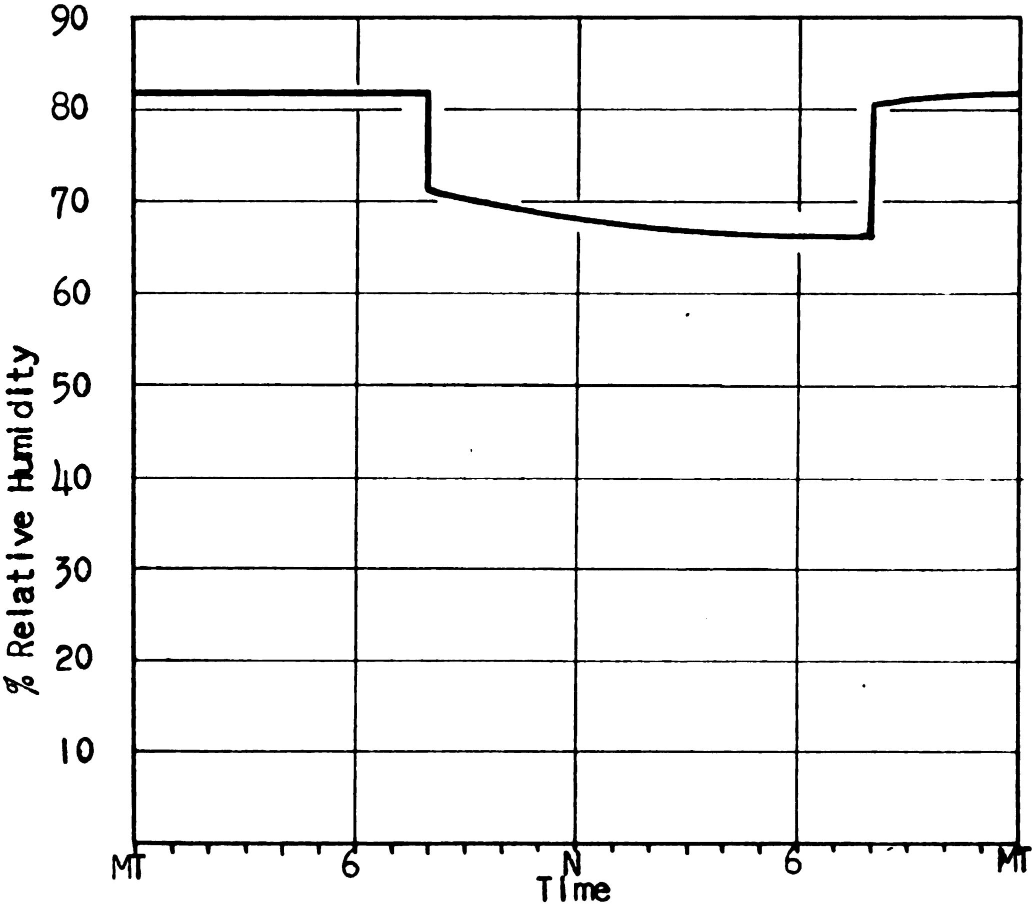


Fig. 12 - The Relative Humidity Portion of the Standard Climatic Cycle

This same standard climatic cycle was reproduced by environmental control equipment used in Ohio. A chart of this cycle is also shown in Figure 9 of the Appendix.

In an attempt to check the extent to which the standard climatic cycle was reproduced, a record was kept of the weight of water per 24 hour period which evaporated from a 4 inch diameter free water surface maintained in the air stream near the samples. The weights were quite reproducable. When a parameter, inches water lost from the free surface per day, was calculated for each sample period, the most extreme range between two samples was from 0.169 to 0.197.

The Constant Climatic Condition. With the Ohio environmental control equipment it was possible to hold relatively constant climatic conditions within the cabinet. The conditions selected for this series of tests were those equivalent to the daytime conditions of the standard cycle. These were:

Dry bulb temperature	66° F.
Relative humidity	68%
Wind velocity (1 in. above soil surface)	6 mi/hr.
Radiant energy (where used)	4000 Btu/24 hrs. sq. ft.

APPLICATION OF NEWTON'S EQUATION TO SOIL DRYING

The possible application of Newton's equation to soil drying has previously been pointed out. Several examples will be shown to indicate the extent to which the actual data conforms to the theoretical equation.

Table 2 setsforth the observed and calculated data for one soil sample. A similar data sheet was compiled for each soil sample. Figures 13 and 14 illustrate the moisture content ratio-time curves plotted from data in or similar to that found in Table 2. After about 24 hours, a drying rate was established which conforms to the straight line relationship expressed by equation 3. Other data and curves showing the same characteristic are presented in the Appendix as further evidence that the actual drying data conforms well to the relationship after 24 hours of drying. Based on the fact that the actual drying data conforms to the expected relationship after 24 hours of drying, the use of Newton's equation is justifiable for this period.

The fact that the data from the first 24 hours of drying did not conform to the equation caused concern. As previously indicated, the first climatic condition used was the daily standard climatic cycle. The samples were always started in the early daytime portion of the cycle. Thus, the first environmental condition experienced by the soil sample was the more severe portion of the daily cycle. This being true, a region of increased slope in the moisture content ratio-time curve could be accounted for in the first ten hours of drying. It was reasoned that if the increase slope of the curve was due to an abnormal environmental

Table 2 - Observed and Calculated Data for Upper 3 inches of Soil, Sample Number 23.

Clod size - 0.093 inches
Uncompacted
No radiant energy applied

Equilibrium moisture content 2.7%
Dry weight - 438.8 grams

Hours	Total water lost grams	Total water lost %	Water remaining grams	Soil moist. %	Moist. content ratio
0	0	0	77.1	17.6	1.0
10.5	8.7	11.3	68.4	15.6	0.865
22.3	12.2	15.9	64.9	14.8	0.812
34.5	15.8	20.5	61.3	14.0	0.759
46.8	17.8	23.1	59.3	13.5	0.725
58.0	20.5	26.7	56.6	12.9	0.685
70.5	21.3	27.7	55.8	12.7	0.671
82.3	23.9	31.1	53.2	12.1	0.631
94.3	24.9	32.4	52.2	11.9	0.617
106.5	27.1	35.2	50.0	11.4	0.584
118.3	28.7	37.3	48.4	11.0	0.557
130.5	31.2	40.6	45.9	10.5	0.524
142.3	32.3	42.0	44.8	10.2	0.504
154.5	34.1	44.3	43.0	10.0	0.490
166.0	34.4	44.7	42.7	9.7	0.470
178.0	36.5	47.5	40.6	9.3	0.443
190.0	37.7	49.0	39.4	9.0	0.423
202.0	39.5	51.4	37.6	8.6	0.396
214.0	40.4	52.5	36.7	8.4	0.382
226.0	42.3	55.0	34.8	7.9	0.349
250.0	44.6	58.0	32.5	7.4	0.315

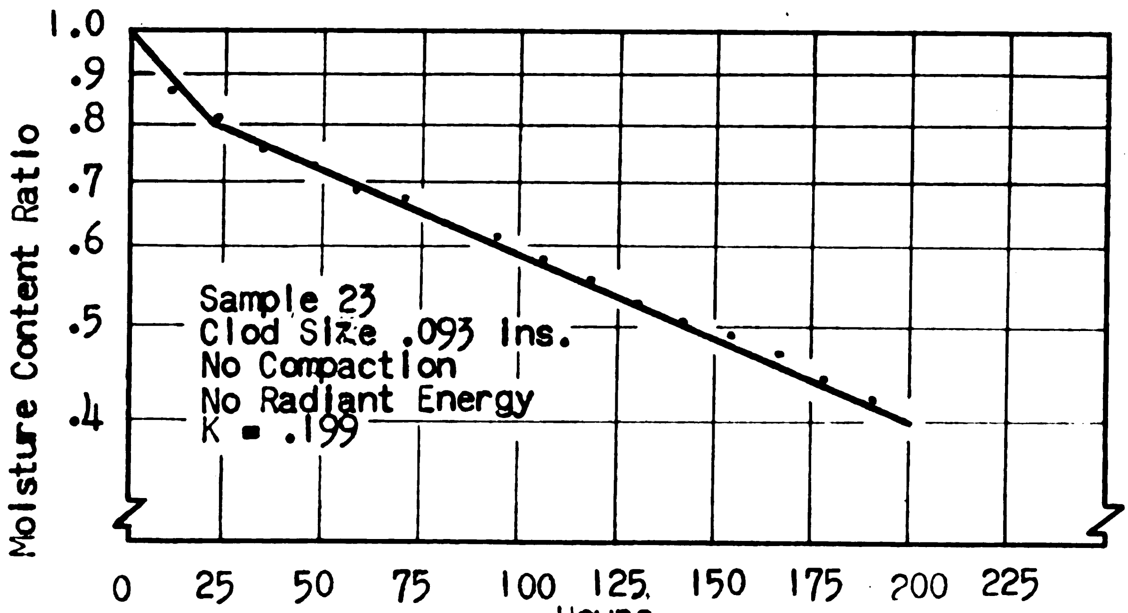


Fig. 13 - Sample Drying Curve
Standard Climatic Cycle

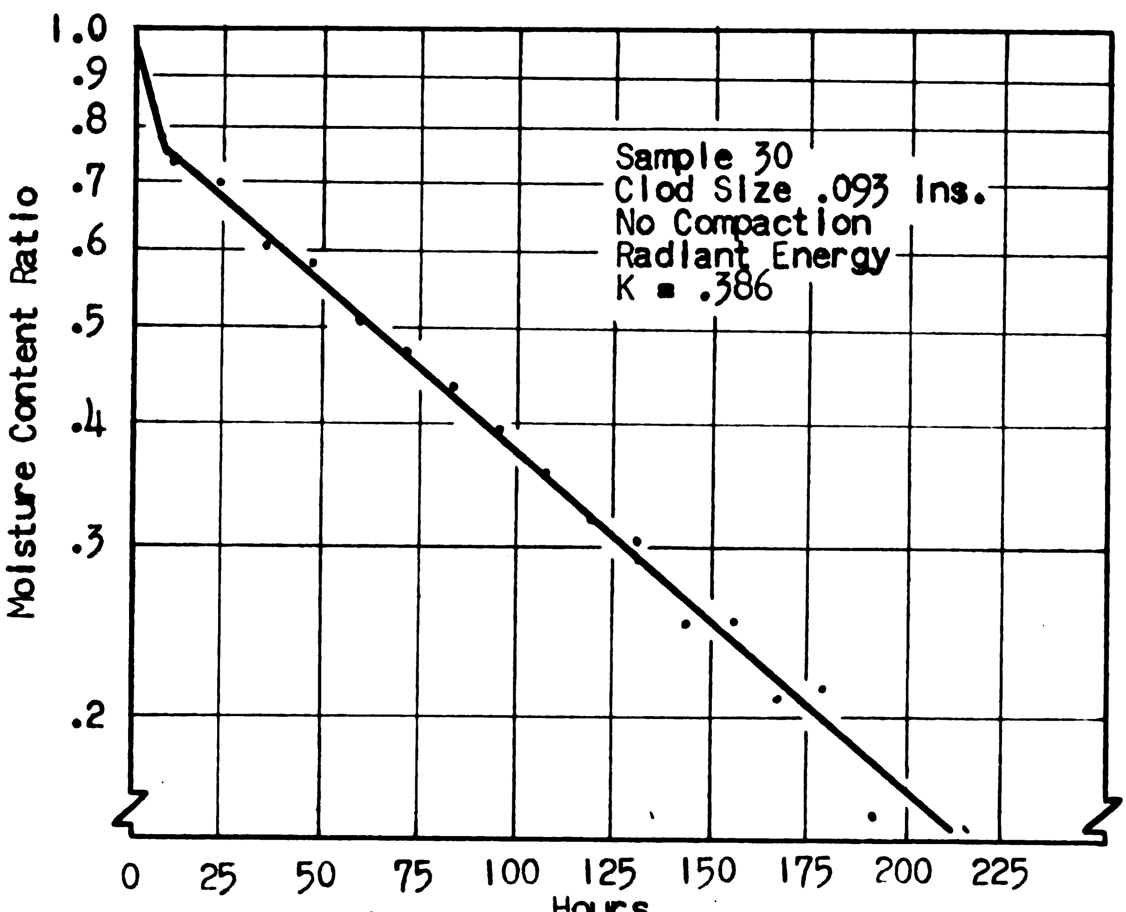


Fig. 14 - Sample Drying Curve
Standard Climatic Cycle

condition, a constant climatic condition should make the early hours of drying conform to the equation. A series of samples were run under the constant climatic conditions, previously described as being equivalent to the daytime portion of the daily cycle, to check their conformity to the equation. Figures 15 and 16 represent samples dried under the constant climatic conditions. It can be seen that the curve during the first 24 hours of drying still does not conform to the theoretical equation.

The work of Sherwood (1929) (1932) is again referred to here. The constant rate period was associated with the early drying of a saturated material. This phase did not apply to this study since the soil was not wetted to saturation. The first falling rate period was characterized by a zone of decreasing wetted surface and the second falling rate period by diffusion of water from within the body (or clod). In effect, the drying rate changed between these three phases. This information was applied in establishing the reason for the change of slope in the moisture content ratio-time curve.

In the early hours of the soil drying, water evaporated from the periphery of the clods on or near the surface of the sample. As drying continued, diffusive potentials were established from the clod center to outside and from within the soil body to the surface. Once a stable diffusion system was established Newton's equation characterized the rate of drying. It took from 12 to

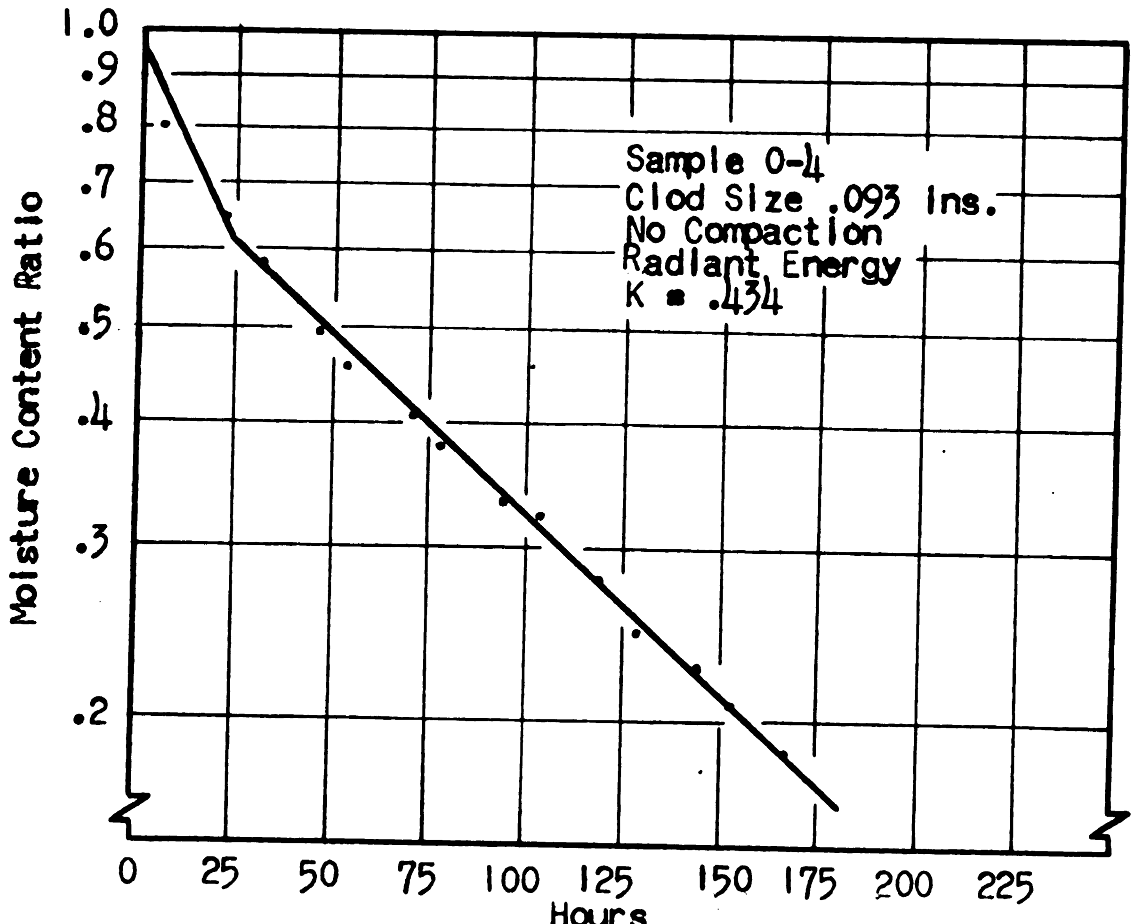


Fig. 15 - Sample Drying Curve
Constant Environmental Conditions

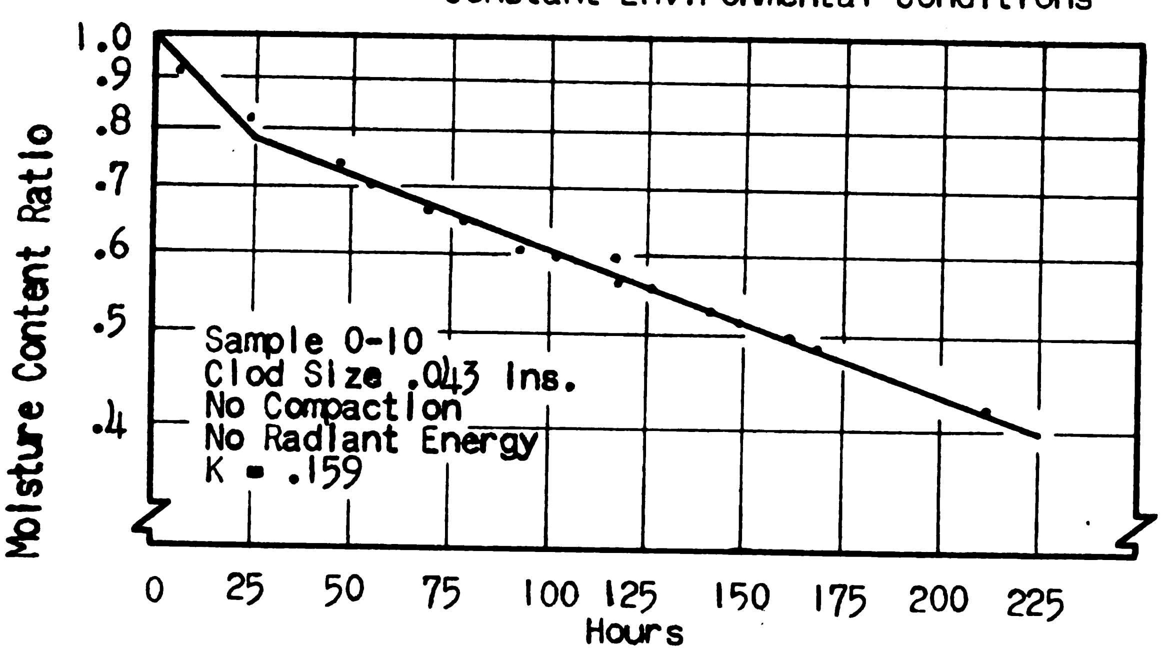


Fig. 16 - Sample Drying Curve
Constant Environmental Conditions

24 hours to establish a stabilized system. The ratio curves of the samples receiving radiant energy stabilized more rapidly than the non-radiant energy samples.

It was apparent that the first 24 hour period of drying would have to be regarded differently than the later period. Based on the work of Sherwood (1929) (1932), Newton's equation will not characterize the first falling rate period. This must be regarded as an unstable period since temperature changes occurred when the samples were placed in the air stream or under the radiant energy source. Also the sample condition was somewhat artificial in nature because the whole depth of soil was of constant moisture content which is not typical of secondary field tillage conditions. It is believed that, for a typical soil moisture condition in the field, Newton's equation, resulting in a single slope, will characterize the drying rate. Because of the doubtful application of Newton's equation in, the instability of, and the few points upon which to base a fitted curve in, the first 24 hour period, it was decided to characterize it through the use of a single parameter rather than to completely characterize the drying rate. On this basis, percentage of water lost during the first 24 hours of drying in the upper three inches of soil was used as this parameter.

Two parameters, then, were used to characterize the drying rate: (1) Percentage of water lost during the first 24 hours of drying, P; and (2) The slope of Newton's drying curve, K. A definite correlation for any one treatment between P and K will be illustrated later. Once this is done the entire drying period can be estimated by determining the simple parameter P.

CHARACTERIZATION OF CERTAIN TILLAGE RELATED SOIL TREATMENTS BY THE SOIL DRYING RATE

The foregoing methods were used to characterize various soil treatments. For convenience the treatments are presented in Table 3.

Table 3 - Description of the Soil Treatments

Constant climatic conditions.
1. No compaction, sample vibrated, radiant or no radiant energy applied.
Standard climatic cycle.
2. No compaction, radiant or no radiant energy applied.
3. Soil pressed at seedlevel and at the surface with 1.2 psi, no radiant energy applied.
4. Soil pressed at seedlevel and at the surface with 5 psi, radiant or no radiant energy applied.
5. Soil stratified, with 0.046 inch clods pressed at 1.2 psi in 1 - 2 inch level; no radiant energy applied.
6. Same as 5 except 5 psi applied, both radiant and no radiant energy applied.
7. No compaction, sample covered, radiant or no radiant energy applied.

In each of the seven treatments all four clod sizes were used. Triplicate sub-samples were observed for each treatment condition.

See Figures 5 and 6 of the Appendix.

There was question as to when and how the three sub-samples should be combined. An attempt was made to statistically fit a second degree polynomial to the points of the three sub-sample drying curves, percentage soil moisture by time, according to a multiple regression method given by Baten (1945). A trial curve was fit; the degree of fit, however, was not sufficient to retain the straight line relationship in the moisture content ratio - time curve. See Figures 7 and 8 of the Appendix. Because of this, the method was abandoned.

Instead, the data on each sub-sample were carried through individually to yield a value P, percentage of water lost the first 24 hours, and K, the slope of the moisture content ratio - time curve. This method has already been illustrated.

Three corn seeds were planted in the sub-sample. The time of emergence of each of the seeds or the condition of the seed at the completion of the test was observed. A summary of these data are presented as Tables 21 and 22 of the Appendix. The time of emergence of the sprout was noted on each of the moisture content ratio - time curves. The points of emergence (or condition of the sprout or seed at the end of the test) for all sub-samples was transfered to one chart. These points were bounded with lines which identified three zones: (1) Full emergence, (2) Partial emergence, and (3) No emergence. These zones are represented in Figures 17 and 18. For the environmental conditions studied in this experiment, these charts provide a basis for evaluating the moisture content ratio - time curves.

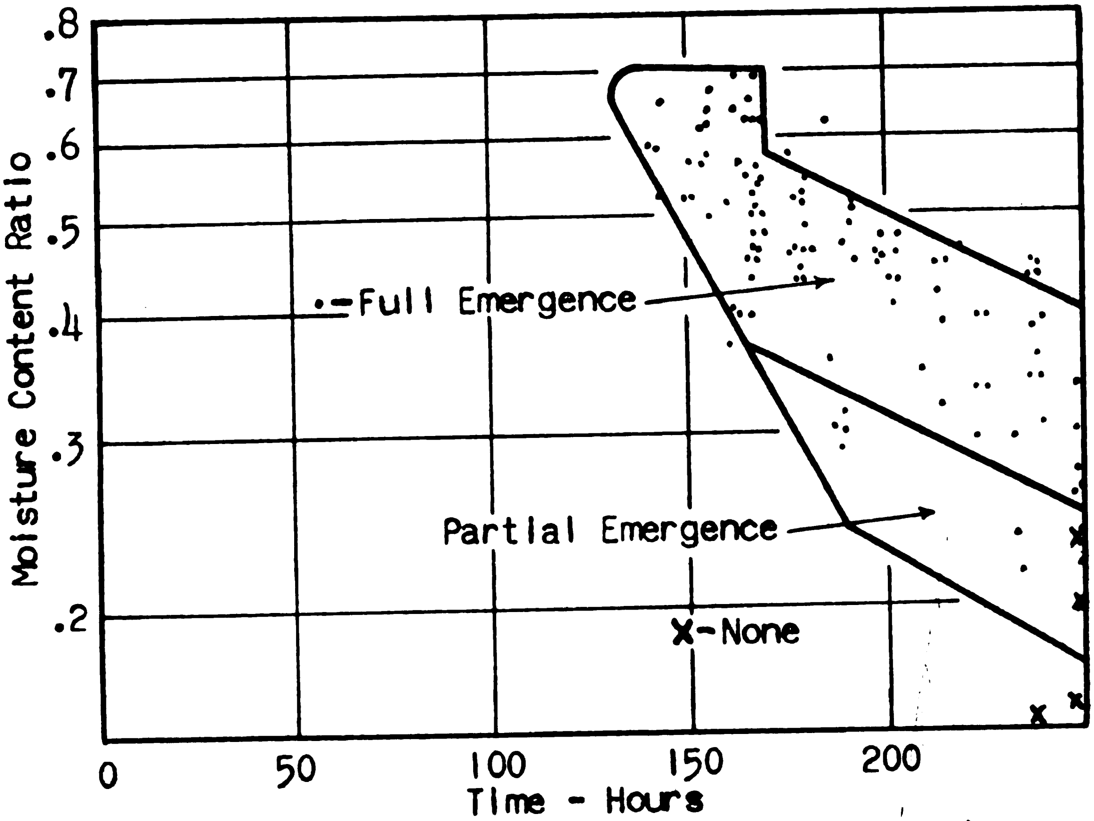


Fig. 17 - Zones of Emergence for Corn Sprouts
No Radiant Energy Applied

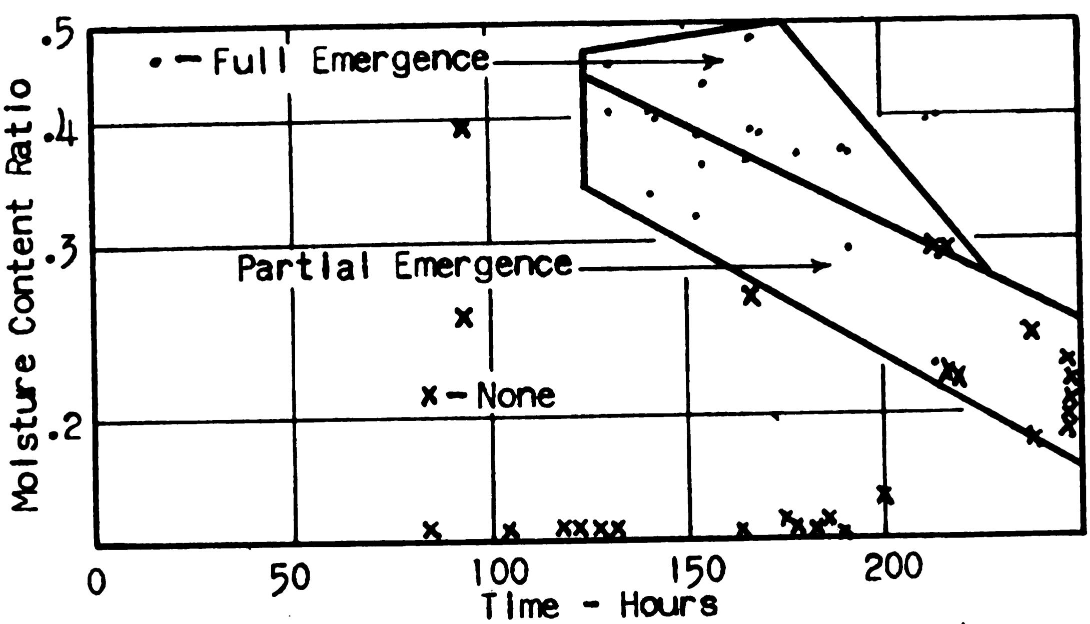


Fig. 18 - Zones of Emergence for Corn Sprouts
Radiant Energy

If the curve falls outside the zone where emergence occurred it can be concluded that the soil environmental conditions were not conducive for the proper germination of the seed.

Accumulated values of P and K are presented in tabular form for all sub-samples. See Tables 12 to 15 of the Appendix. As a means of visually checking these data, the mean value of the three sub-samples for P and K was plotted in a moisture content ratio - time curve. This gave a single curve for each treatment. These curves are shown in Figures 19 through 26 with the zones of emergence sketched in.

Further, a method of analysis of the accumulated data was used which would characterize the influence of clod size for each treatment as well as permit a comparison between treatments. This method basically required the calculation of the regression line for each treatment; that is, the regression of the slope, K, and the percentage of water lost the first 24 hours, P, on clod size.

Not all the variances of the samples were equal because P has percentage units and a check of K values indicated this also. In such a case a transformation is normally required; however, in this case the meaning of the transformed regression values was unclear. It was most desirable to compare treatments in the actual units of K and P. Based on this fact, the fact that not all K variances were found different; and since the percentage values fall in a narrow range below 30 with a relatively large base number, it was decided not to transform the values of P and K. Box and Anderson (1954) cited examples where rather wide differences in the variance did not greatly affect the final confidence level of the test.

A trial plot of K and P values vs. clod size showed that in most cases a straight line regression characterized the data in the range studied. Undoubtedly, however, over a wider range of clod size the relationship would not be maintained. Overall there was no reason to believe a quadratic regression line would contribute enough higher accuracy to warrant its use. A high residual was noted only in a few of the 24 regression calculations.

Table 16 of the Appendix represents the mean, $\bar{x}$; regression slope, b; and the standard error of each. These data along with the arrayed confidence limits at the 95 percent level are shown in Figures 27 to 30.

INTERPRETATION OF RESULTS

<u>The Influence of Two Climatic Cycles</u>. These comparisons were drawn from columns 1 and 2 in Tables 12, 13, 14, and 15 of the Appendix and Figures 27 to 30.

The two climatic cycles, the standard cycle and the constant climatic condition, were compared primarily to check the drying characteristics of the first 24 hours. In this regard the two climatic cycles gave essentially the same general shape of drying

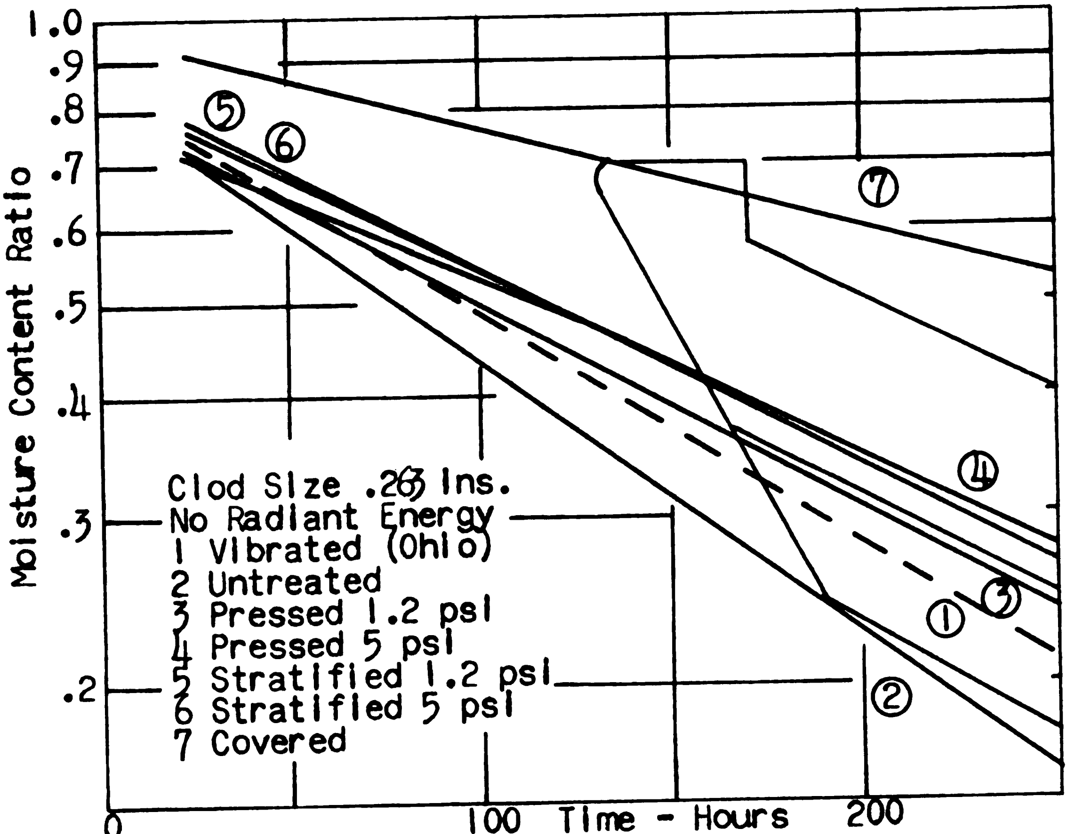


Fig. 19 - Consolidated Drying Curves

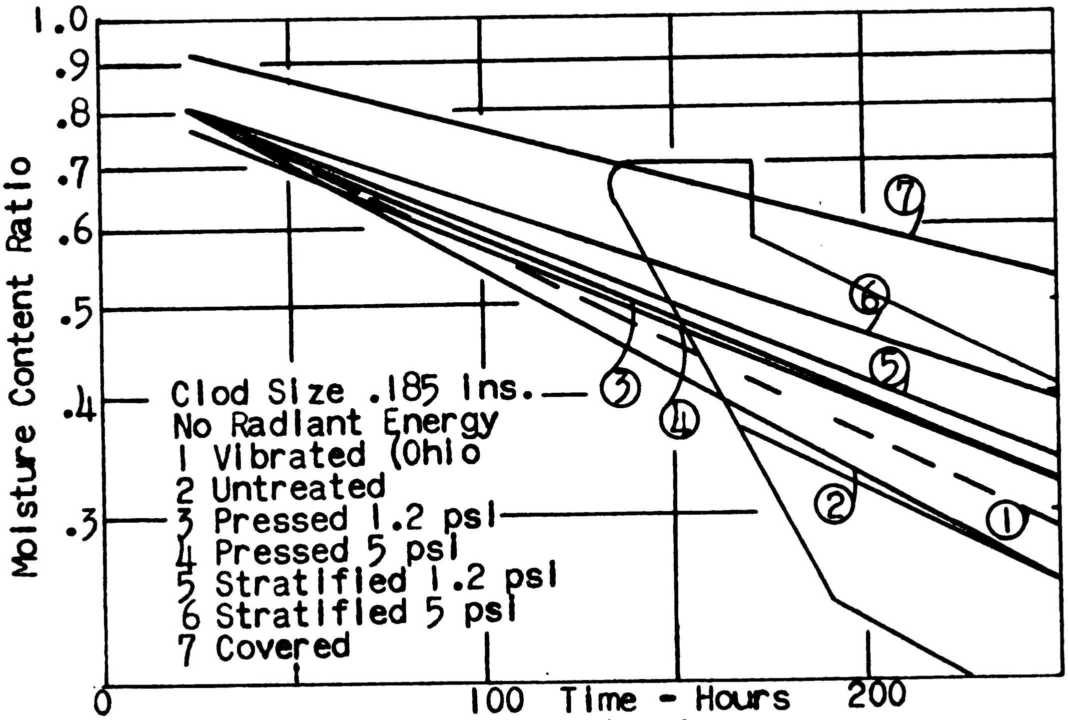


Fig. 20 - Consolidated Drying Curve

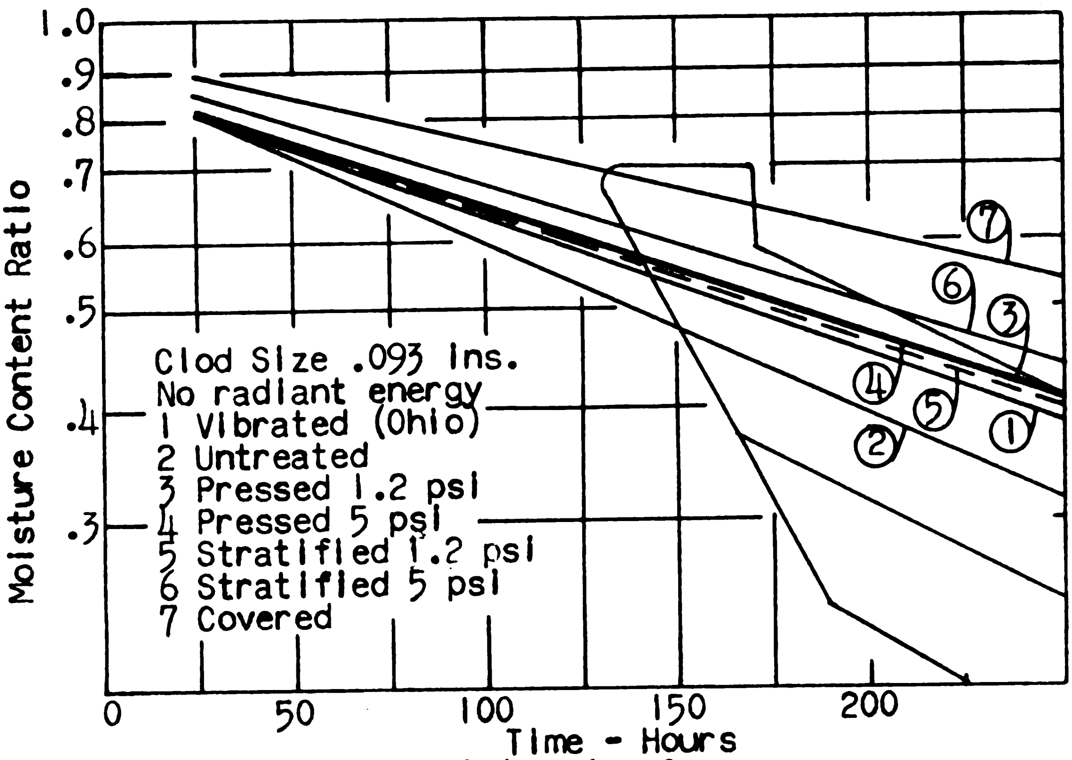


Fig. 21 - Consolidated Drying Curves

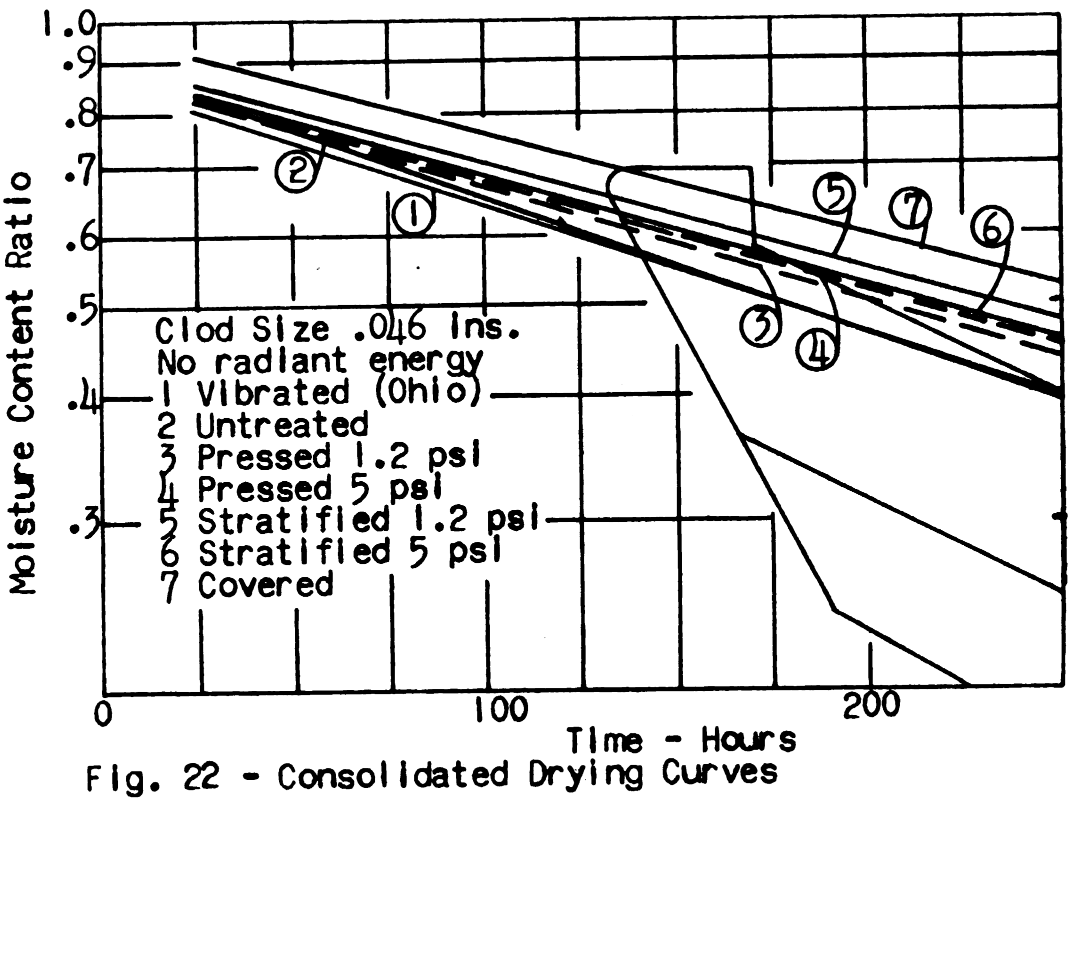


Fig. 22 - Consolidated Drying Curves

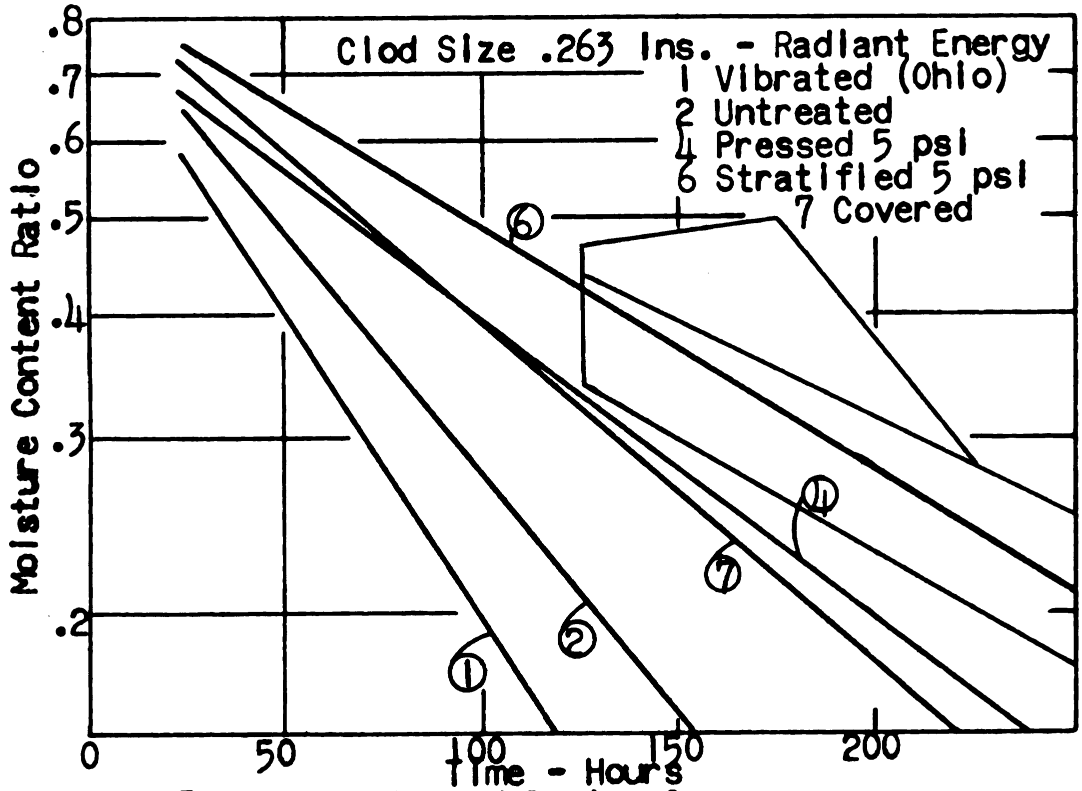


Fig. 23 - Consolidated Drying Curve
Radiant Energy Applied

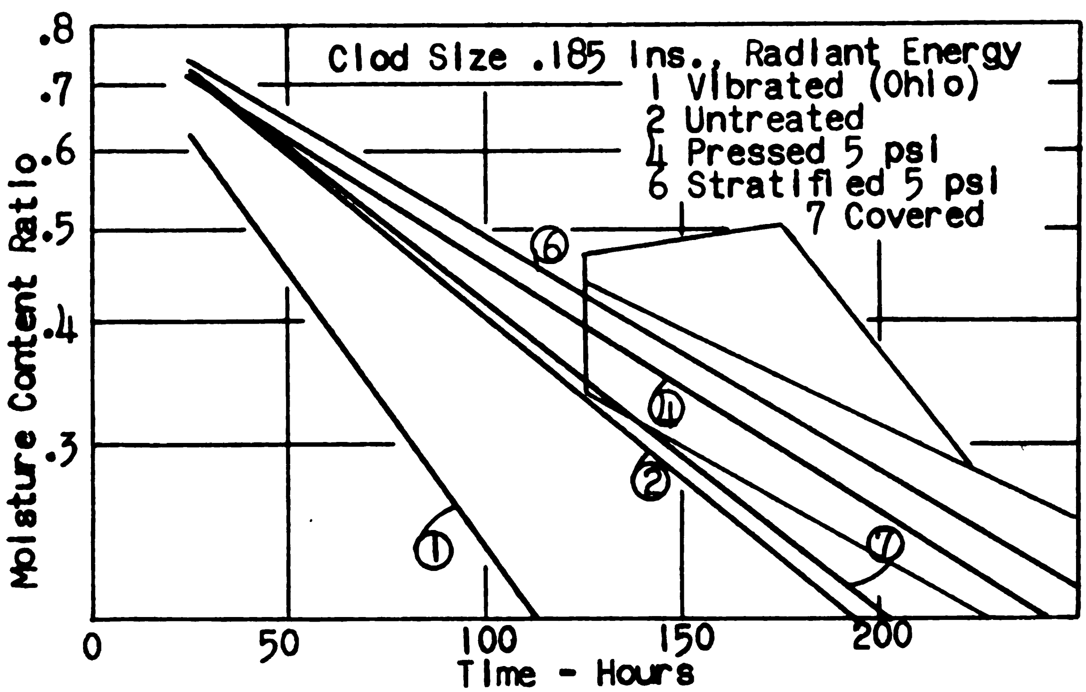


Fig. 24 - Consolidated Drying Curve
Radiant Energy Applied

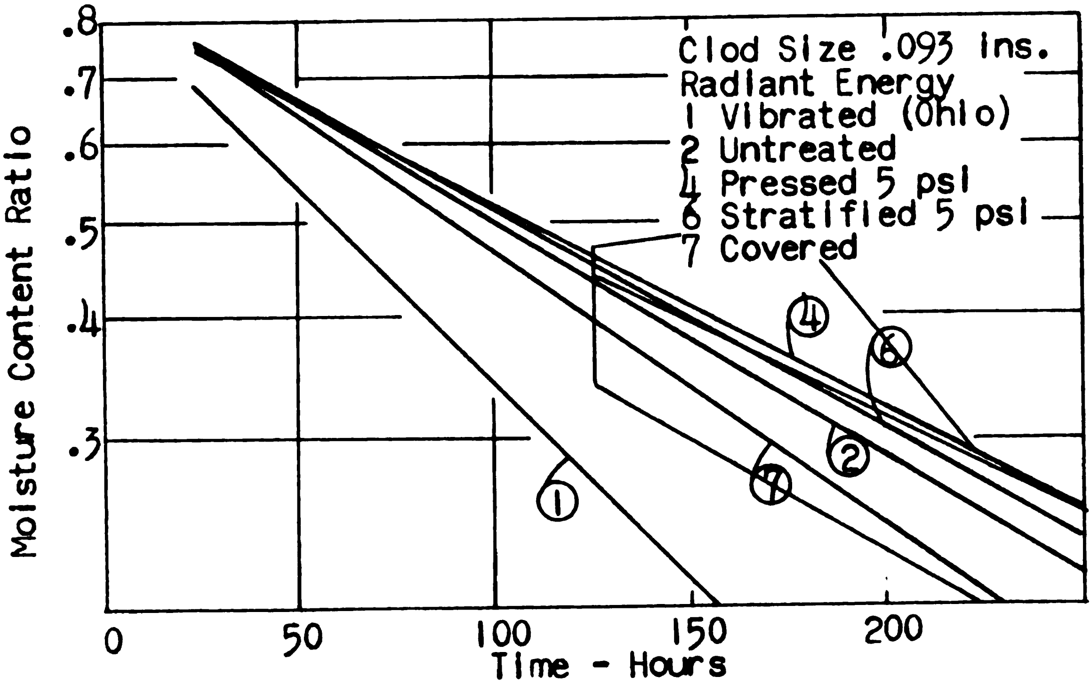


Fig. 25 - Consolidated Drying Curves
Radiant Energy Applied

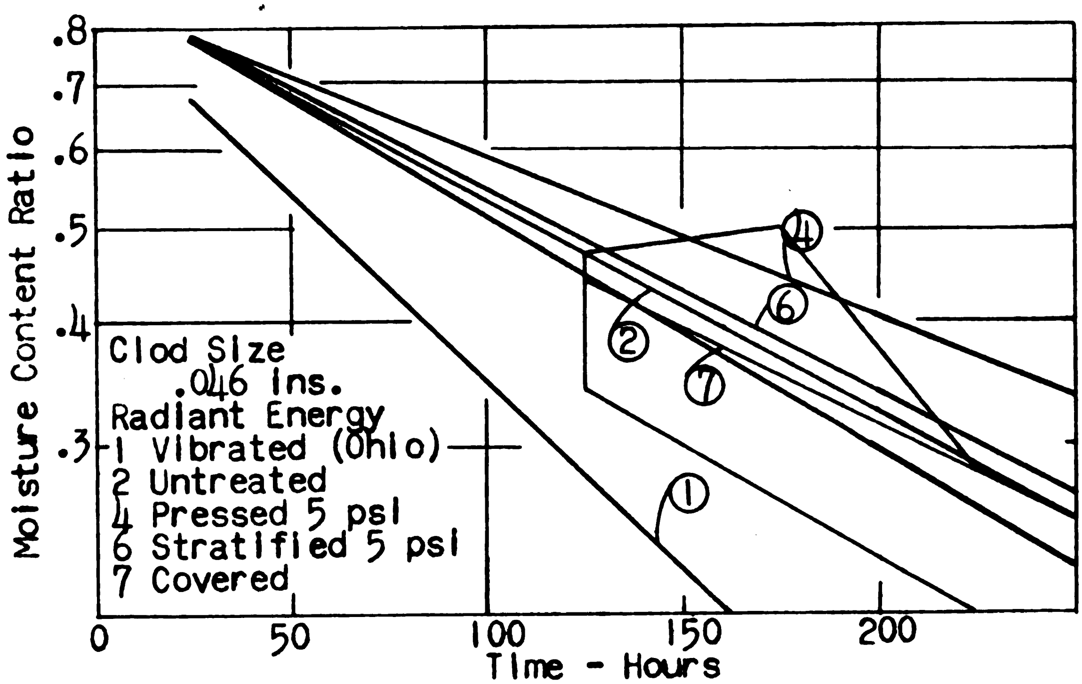


Fig. 26 - Consolidated Drying Curves
Radiant Energy Applied

curve; therefore, the constant climatic condition was of no assistance in providing a single slope drying curve. Compare Figures 13, 14 to 15, 16.

Where radiant energy was applied during the whole 24 hour period, in the constant climatic condition, a more rapid drying rate would be expected. The experimental evidence varified this.

For the two climatic cycles, where no radiant energy was applied, little difference in the overall drying curve was expected. Sherwood (1929) indicated that during the second falling rate period of drying, variations in humidity or air velocity do not affect the drying rate. Therefore, even though the constant climatic condition was more severe, little influence on the resulting K value was expected. Also little affect was expected in P even though the initial drying occurred in the first falling rate period of drying since the first 10 - 12 hours of drying was under similar climatic conditions for the two climatic cycles.

The data did not bear out the expected results. The values for P (no compaction treatment and no radiant energy applied) were similar for the two climatic cycles; although there was a tendency for P to be higher for the constant climatic condition.

The K values were higher for the standard climatic cycle condition (no compaction and no radiant energy applied). This was not expected and requires an explanation.

A change in location of work occurred between these two series of tests. The standard climatic cycle series was run at Michigan State University and the constant climatic series in Ohio. All obvious variables were controlled; however, a check of the dry weights for the samples for the two locations showed some difference. For all samples, the resulting dry sample weights were: (See Tables 17 and 19 of the Appendix).

Constant climatic condition,	no compactive treatment	470.7g
Standard climatic cycle,	no compactive treatment	442.3g
Standard climatic cycle,	1.2 psi (pressed)	493.8g

These data indicate, and a review of the procedures used varify, that a more severe vibration process was used in the sample preparation for the constant climatic condition.

Although these results indicate clod orientation was an effective means of reducing the drying rate it was not an intended variable of the study. For that reason no further conclusions will be drawn other than to point out the effect and to indicate that the experimental error of the uncompacted samples could undoubtedly be decreased by better controlling the dry weight of sub-samples.

<u>The Influence of Compaction, No Radiant Energy Applied</u>. The data for these comparisons are from the standard climatic cycle conditions as found in columns 2, 3 and 4 Tables 12 and 14 of the Appendix and Figures 27 and 29.

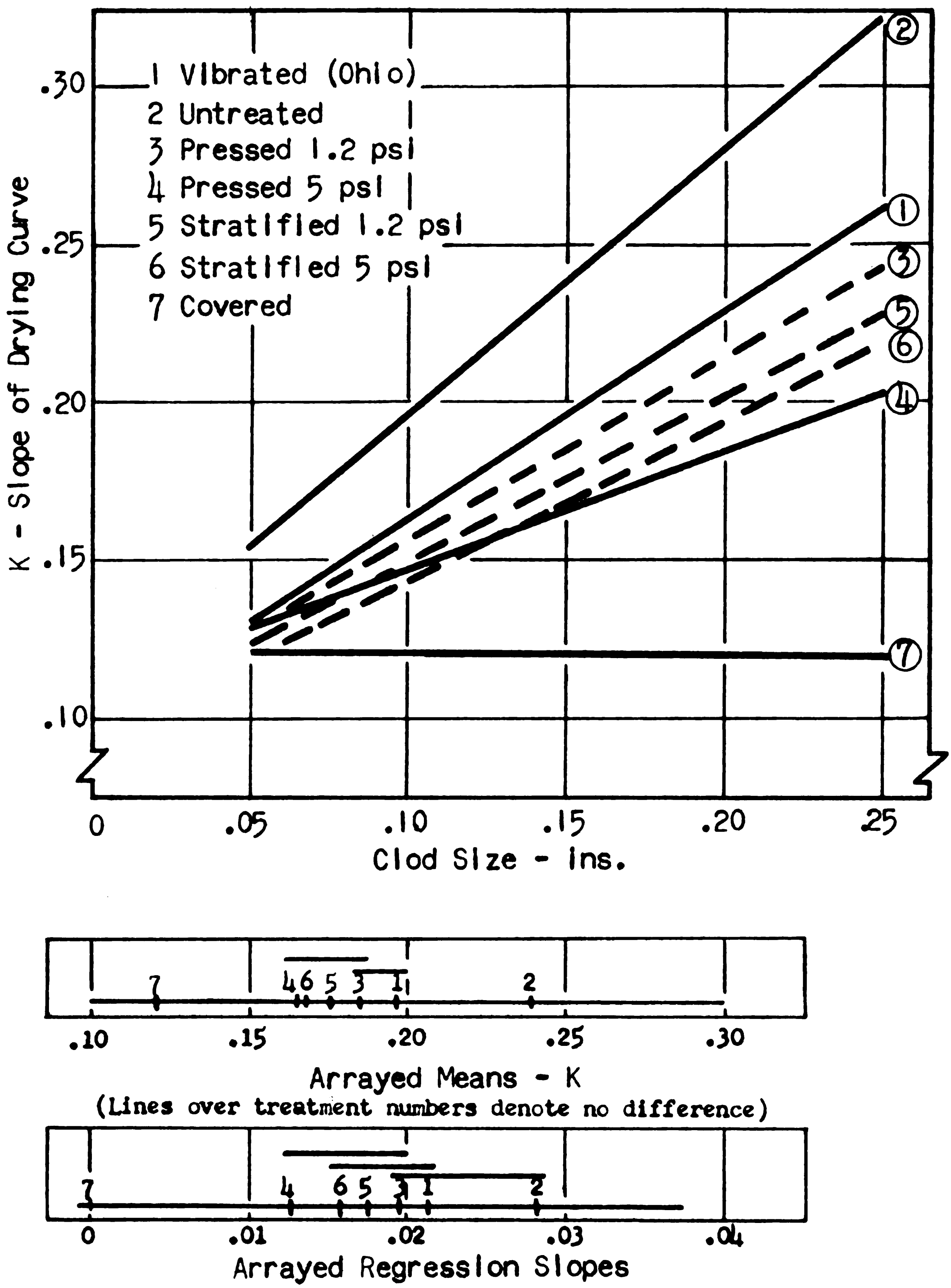


Fig. 27 - Regression of K on Clod Size
No Radiant Energy Applied

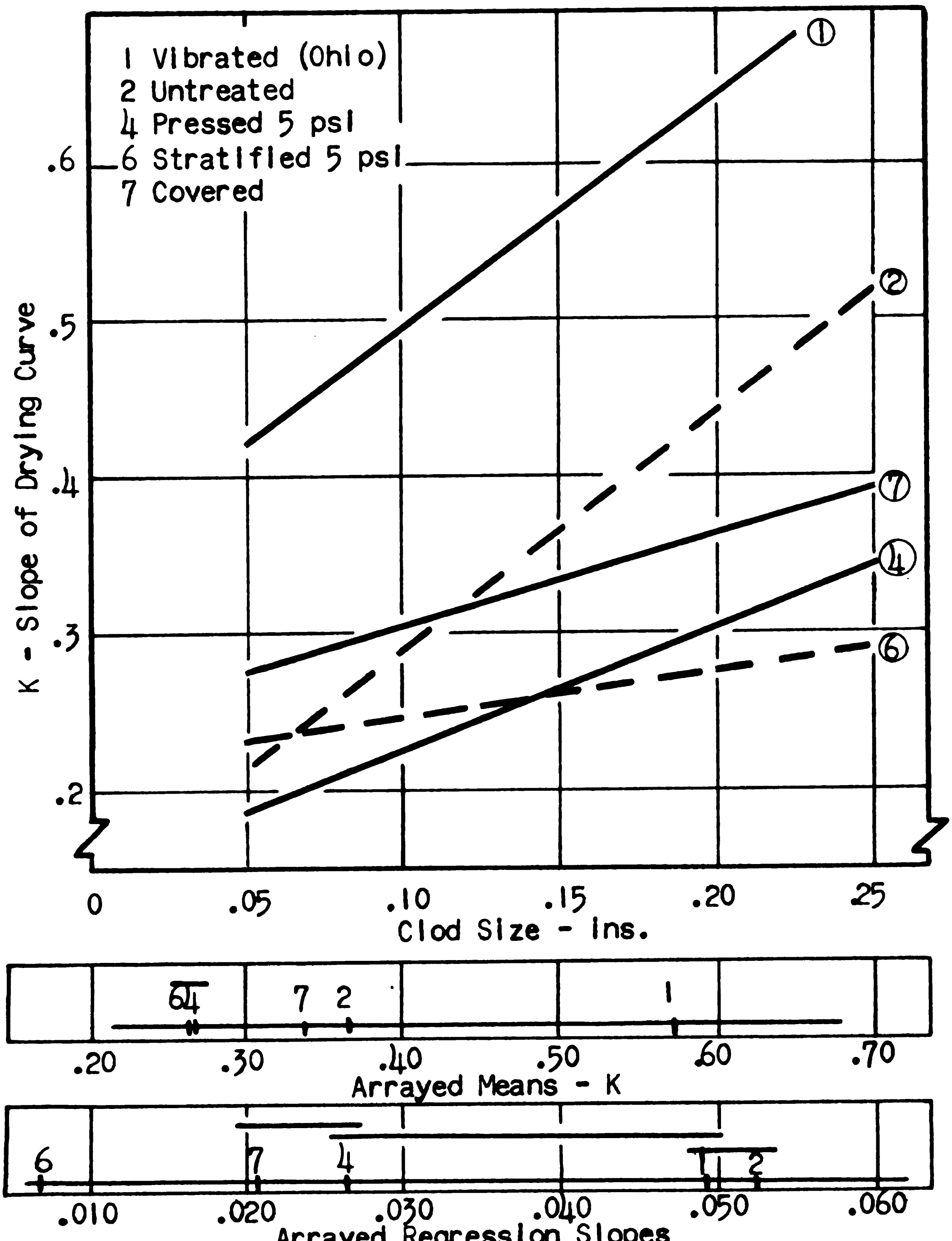


Fig. 28 - Regression of K on Clod Size Radiant Energy Applied

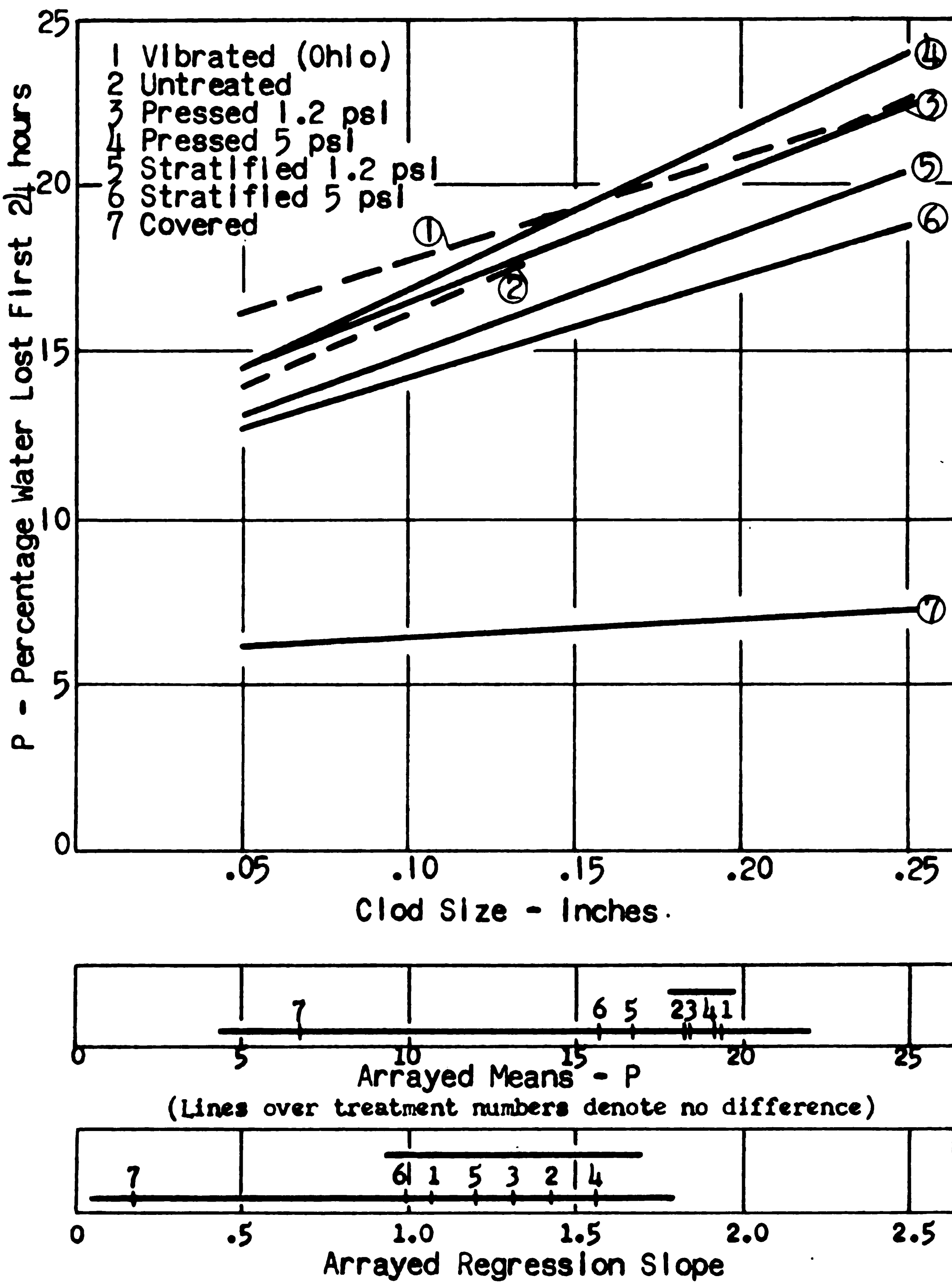


Fig. 29 - Regression of P on Clod Size.
No radiant energy applied.

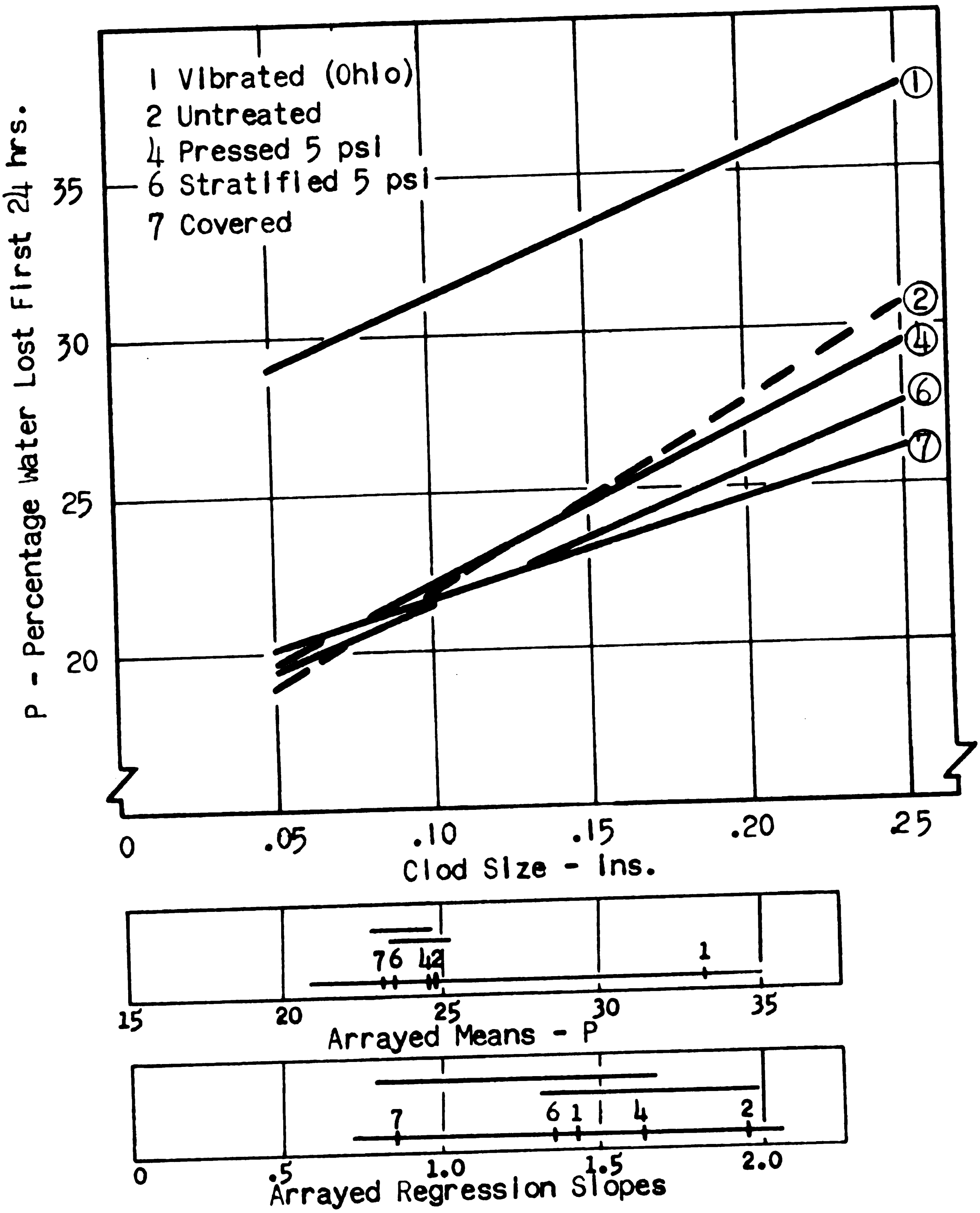


Fig. 30 - Regression of P on Clod Size
Radiant Energy Applied

The mean value (all clod sizes considered) for the percentage water lost, P, the first 24 hours was similar for all pressed treatments. There was no difference between the regression slopes for P. From the same data, the mean K values for the pressed and no treatment condition were different; however, no significant difference was apparent between 1.2 and 5 psi although a trend existed of a decreasing K with pressure. Only the regression slopes, of K on clod size, of 0 and 5 psi were different.

Several conclusions were drawn from these statements:

1. The application of pressure had little or no affect on reducing the percentage of water lost the first 24 hours. Also the influence of clod size was similar for all pressure treatcments. It was observed and these data varify that a more complete capillary system was set up as pressure was applied. The untreated samples dried in a pronounced change of color wave which was not true in the compacted samples. The moisture which was brought to the soil surface of the pressed samples permitted drying rates equal to the drying rate of the untreated samples which dried because of high vapor diffusion rates through the soil voids.

2. The application of pressure had an affect on K; although any difference between 1.2 and 5 psi was slight and uncertain. Also as pressure was applied, the effect of clod size on K tended to reduce even though only the two extreme conditions were signicantly different. These results represented those expected except

for the lack of effect between 1.2 and 5 psi. A smooth plate was used as a means of distributing force over the top of the soil in the pressed samples. The surface of the soil which was subjected to the plate was greatly deformed; thereby, the void opening was reduced at the surface. It was concluded that the major barrier for diffusion for the later period of drying was a relatively "closed" surface and it was not necessary to fully consolidate the volume of soil. Also, a more complete capillary system which transmitted water to the soil surface was established, and functioned over a longer period of time at higher pressures. This tended to compensate for a slightly lower vapor diffusion rate.

3. At no time did pressure on the 0.263 inch clod samples give an equal effect in reducing the drying rate, either K or P, that a decrease in clod size to 0.046 inches gave.

The data on emergence showed the fine clod samples did not require an application of pressure to bring the treatment into the emerging zone; whereas, the large clod samples, pressure did improve the slope, K, enough to bring the curve into or near to the emerging zone. At the 5 psi pressure level, evidence of delayed emergence was observed even though the slope, K, caused the moisture content ratio - time curve to fall into the emerging zone. As the soil dried, after being subjected to the 5 psi pressure treatment, it offered considerable resistance to the emerging sprout. Several of the sprouts were severely curled as a result of attempting to emerge through the compacted soil layer. Not only was emergence delayed but in extreme cases the resistance was great enough to entirely prevent emergence. A summary of those sprouts which were curled is presented in Tables 21 and 22 of the Appendix. The 5 psi pressure treatment was of doubtful overall benefit, under the conditions of this experiment, because of the additional resistance to sprout penetration.

Influence of Clod Size Stratification, No Radiant Energy Applied. The data of these comparisons, for the standard climate cycle, are found in columns 2, 5, 6 of Tables 12 and 14 of the Appendix and is represented in Figures 27 and 29.

The mean P value (all clod sizes considered) for the percentage of water lost during the first 24 hours for both stratified treatments was different from the no treatment condition. In fact the two stratified treatments were also different. Studying the regression slopes for P showed no difference. From the same data the mean K values for the stratified treatment and no treatment were significantly different; however, no significant difference was apparent between pressures in the compressed layer, although a trend existed of a decreasing K with additional pressure in the compressed layer. The regression slope, of K on clod size, of the no treatment condition was different from the two stratified treatments.

In comparison of the stratified treatments with the pressed treatments there was a significant difference between the mean P values.

The following conclusions were based on the above data:

1. Both stratified treatments were effective in reducing the percentage of water lost during the first 24 hours of drying over the pressed and the no treatment conditions. Since the small clods, as placed at the 1 - 2 inch level in the stratified treatments, were an additional barrier to diffusion some water must be lost from below the 1 - inch level the first 24 hours in order to make the above fact true. A check of this point revealed from 2 to 3 percent less of the total water in the sample was lost during the first 24 hours in the 1 - 3 inch level from the stratified samples as compared with the pressed or no treatment condition. The influence of clod size on P was similar for the two stratified treatments.

2. The stratified treatments had a similar effect on K as did the pressed treatments over the no treatment condition. In fact no difference was detected between the two pressed treatments and two stratified treatments. The effect of clod size on K tended to reduce even though only the extreme conditions were significantly different.

The fact that the stratified treatments were at least as desirable, and in some respects were more desirable from a rate of soil drying standpoint, has important ramifications. No detrimental effects were observed on emergence characteristics from the compressed layer. Also having an uncompacted surface exposed should provide more stability to rain drop impact and resistance to soil crusting conditions.

The fine clod size, compacted layer provided a barrier for vapor diffusion and intimate soil-to-seed contact without possible damaging effects of heavy applications of pressure to the entire soil volume.

Influence of Covering the Soil, No Radiant Energy Applied. The data for this comparison for the standard climatic cycle are found in columns 2 and 7 of Tables 12 and 14 of the Appendix and Figures 27 and 29.

As indicated before, this treatment had its value in showing the effect of increasing the thickness of the surface film barrier to diffusion and removing the possibility of eddy diffusion in the surface layer of soil. In this case, a filter paper cover was placed one inch above the soil surface. This treatment was quite unique when comparing it to others. The percentage of water, P, lost during the first 24 hours was significantly lower than all others and P was affected by clod size to a much lesser extent. The value of K also was quite low and independent of clod size since the filter paper apparently offered a greater surface barrier to diffusion than any of the clod size surfaces.

In a practical sense, this treatment offers some reason as to why mulches are effective and brings up the possibility of providing relatively stagnet layers of air on top of a soil which would not inhibit the emergence of a seedling. By placing a 1 inch layer of 0.263 inch or larger clods on the surface of the soil a thick, relatively stagnet air layer would be provided; yet the plant could develop as a seedling while emerging through this layer. Lower moisture losses would result; and the plant could be planted at a relatively shallow depth.

The Influence of Radiant Energy. The data for these comparisons are from Tables 13 and 15 of the Appendix and Figures 28 and 30.

The application of radiant energy to the soil surface was a more realistic environment in that sunlight intensity was simulated. Due to the limited capacity of the environmental equipment to remove heat supplied within the chamber, fewer sample conditions were run.

The constant climatic condition used in part of the work done in Ohio, required the use of radiant energy 24 hours per day rather than a cyclic application used in the remainder of the tests. This series of tests was run primarily to check the early portion of the moisture content ratio - time curve.

On many of the 0.263 inch clod treatments, where the light intensity was high, the plant no longer emerged as a sprout but as a leafed out seedling. Although this characteristic has questionable desirability it provided the basis for the preceding statement that plants may develcp as a seedling through a large clod soil layer.

When considering the pressure and stratified treatments receiving radiant energy, the effects were quite similar to those already discussed. The stratified treatment was low in water lost the first 24 hours, in the value of K, and was affected by clod size to a lesser extent. The minimum K value, which represents the slowest rate of drying, occurred with the 0.046 inch clods pressed at 5 psi. This was not apparent in the samples receiving no radiant energy but is reasonable since 0.046 stratified treatment had less compacted volume than the pressed samples.

In the covered treatment of this series, the radiant energy was applied directly to the surface of the soil; however, air flow was prevented from passing over the surface of the soil by the vertical ring of filter paper. This is a rather artificial condition; however, information was gained. The heat penetration into these samples was different than those receiving air movement across the surface. The effect of this can be seen in Figure 28 in that the K value for the covered treatment was higher in the small clod sample as compared with the same no treatment K. In both cases the influence of eddy currents in the surface layer of soil was minimized. In the 0.263 inch clod samples the effect of removing the eddy currents in the surface layer was greater than the effect of increased heat penetration; thus, the net effect was a reduction in the K value over the no treatment condition.

In all the samples which received radiant energy, the moisture in the three-inch layer moved in two directions; through the surface of the soil and to deeper depths of soil. The data taken in Ohio with constant radiation provided the most complete information regarding the two directions of water movement. See Table 4.

From this information, 1/3 to 1/4 of the total water lost after 170 hours had moved downward out of the 0 - 3 inch layer. Also as clod size decreased the percentage of water lost which moved downward increased. The quantity of water which moved downward was almost constant for all clod sizes. This suggests the downward movement was essentially independent of clod size whereas the movement out of the surface was not.

Table 4 - Direction of Water Movement in the Samples Which Received Radiant Energy. (After 170 Hours of Drying).

Clod Size inches	The part of the total water, originally in the upper 3 ins. of soil, lost --				The part of the water loss from the upper 3 ins. of soil, lost --
	Out surface		To deeper depths		To deeper depths
	grms.	%	grms.	%	%
0.263	53.8	62.4	19.1	22.1	26.0
0.187	47.5	57.4	20.8	25.2	30.6
0.093	42.1	51.8	19.9	24.5	32.1
0.046	38.9	50.4	19.5	25.2	33.4

The Relationship of P and K to Inches of Water Lost. A more common method of indicating evaporation rate in soil is inches of water lost per unit time. A general method to relate the two parameters, P and K, to inches of water lost, is presented in Figures 31, 32, and 33. Two rate periods are proposed in these charts, the first 24 hours and the period from 24 hours to 240 hours. Through the use of these charts any moisture content ratio - time curve can be transformed into inches of water lost per day.

The relationship of P to inches of water lost during the first 24 hours required the consideration of sample dry weight. The quantity of water present in the three-inch sample depth was a function of the quantity of soil. Compactive treatments resulted in a higher quantity of soil, and therefore water, being placed in the sample. Dry weights of all samples are recorded in Tables 17 and 19 of the Appendix.

The relationship of K to inches of water lost was a function of the moisture content ratio at 24 hours as well as the dry weight of the sample. As P increased, the amount of water which remained in the sample after 24 hours decreased, then for a common K the quantity of water lost after 240 hours was less. Separate curves were proposed for the radiant energy and no radiant energy environmental conditions since the equilibrium moisture contents were different.

In order to develop these generalized relationships a common original soil moisture, 17.5%, was assumed. Knowing the original

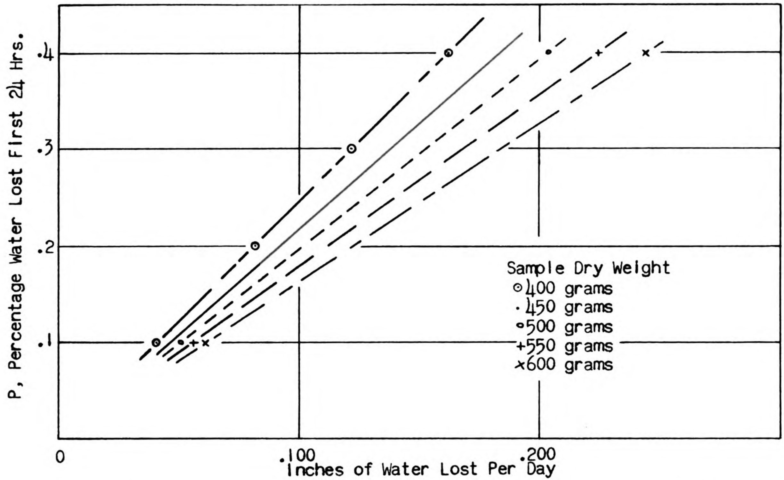


Fig.31 - Relationship By Which P Can Be Transformed Into Inches of Water Lost

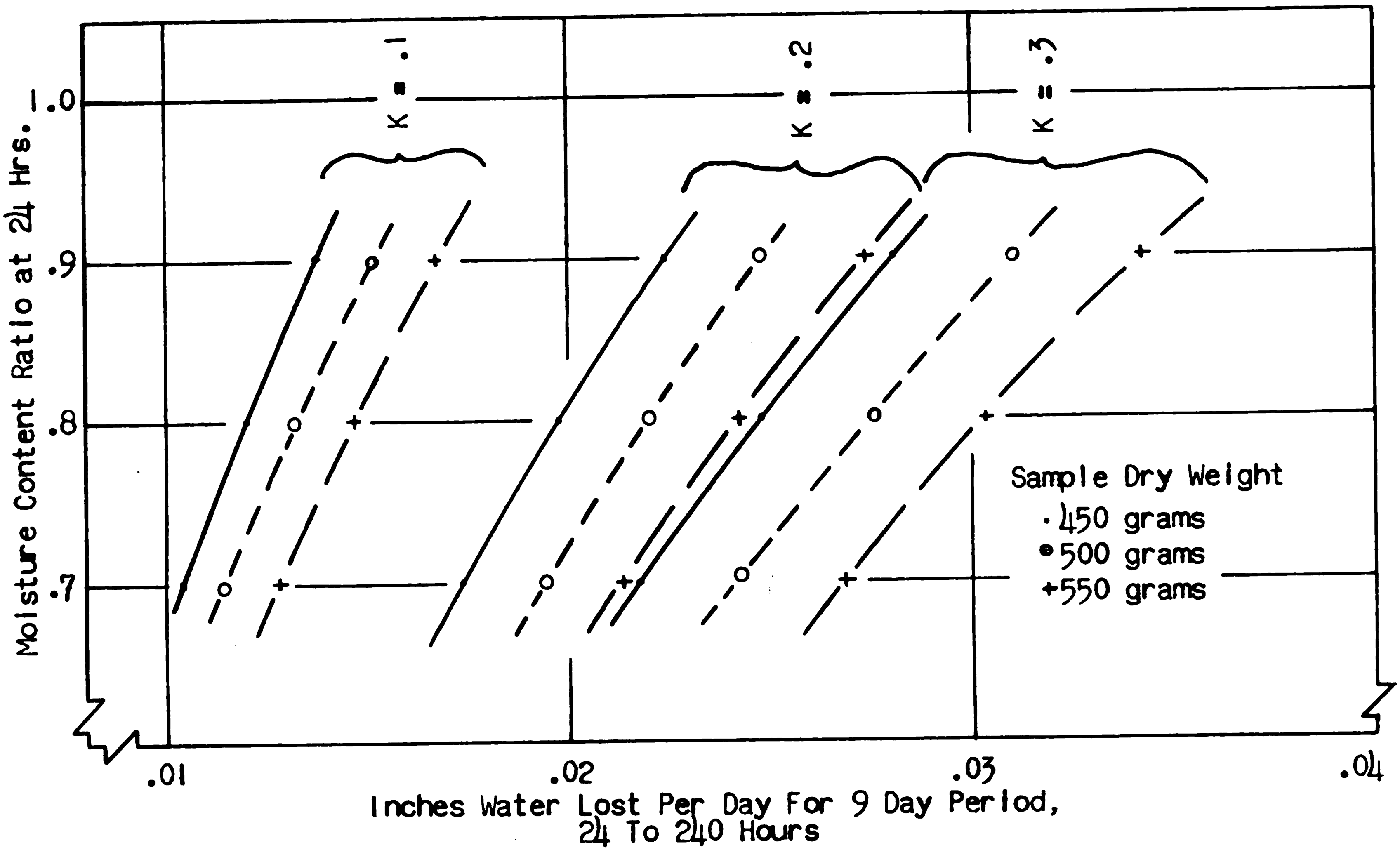


Fig. 32 - Relationship By Which K Can Be Transformed Into Inches of Water Lost
No Radiant Energy Applied

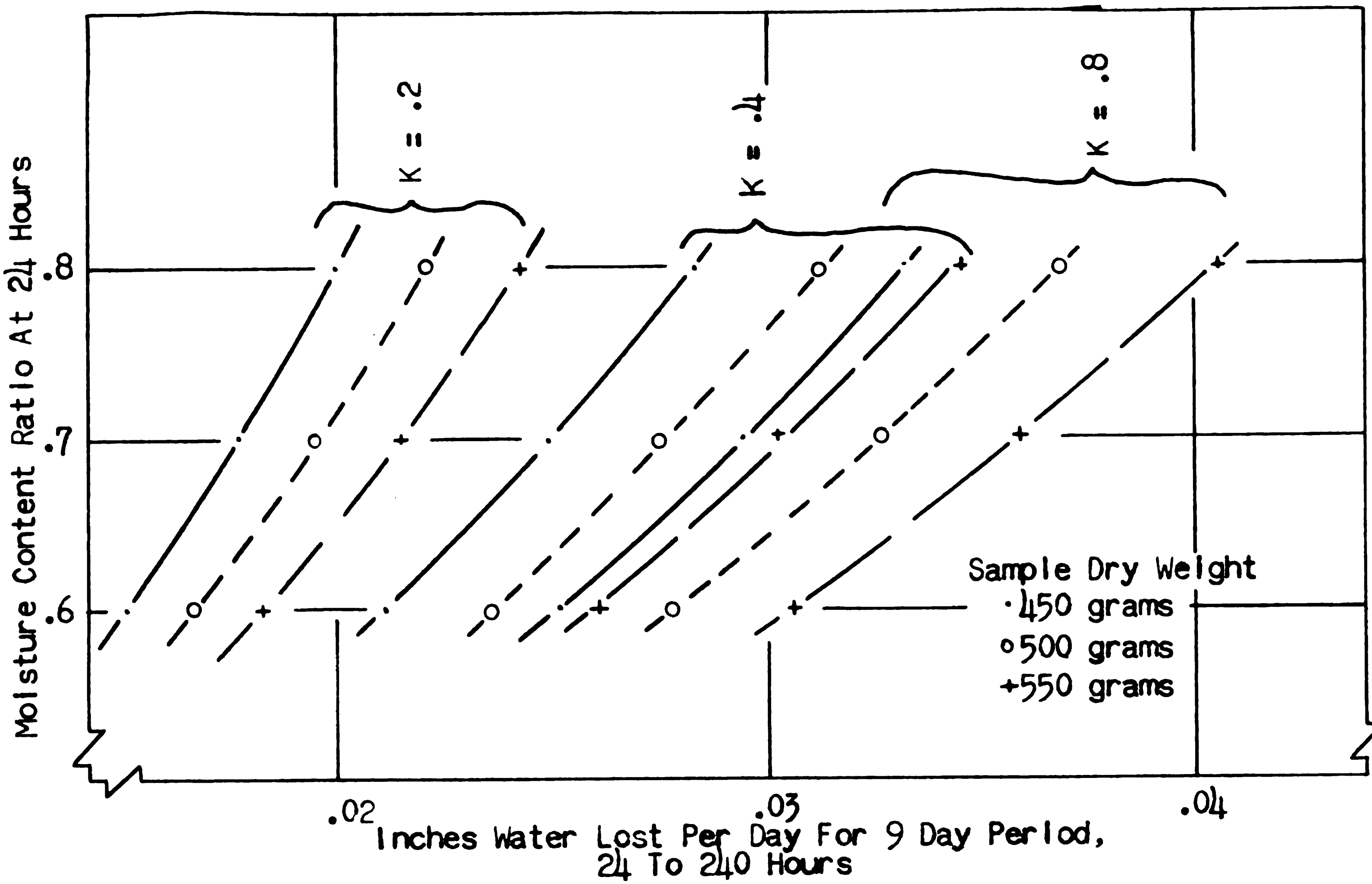


Fig. 33 - Relationship By Which K Can Be Transformed Into Inches Of Water Lost. Radiant Energy Applied.

weight of water in the sample the water remaining after 24 hours was directly calculated. The weight of water lost was related to inches of water. To relate K to inches of water lost, a moisture content ratio at 24 hours was assumed and transformed into soil moisture percentage by the equation $\frac{M - M_e}{M_o - M_e}$. The final moisture content was similarly calculated from a moisture content ratio at 240 hours found by plotting the curve for a given K according to equation 3. From the two moisture contents and the dry sample weight the quantity of moisture loss was calculated.

<u>The Influence of Soil Type</u>. The soil used in this experiment was a Brookston sandy loam. The extent to which Newton's equation will characterize soils high in clay content is not known.

<u>The Influence of Soil Treatment on Emergence</u>. Under the climatic conditions used in this experiment, when soil was placed in the sample container and left untreated, (uncompacted, not vibrated, stratified or covered) complete emergence occurred only for the 0.093 and 0.046 inch clod sizes when no radiant energy was applied. When the samples were subjected to radiant energy, only 70% emergence occurred for the smallest clod size. All others, larger clod sizes, were less complete in emergence or there was no emergence at all.

There was a trend toward a slower rate of emergence as the soil drying rate increased. This can be seen from the Ohio data:

Sprouts emerged from the 0.046 inch clod sample receiving no radiant energy in 193 hours; from the 0.093 samples in 204 hours; and sprouts were quite wilty and not through the soil in the 0.185 inch clod size at 240 hours when the sample was destroyed.

DISCUSSION OF RESULTS

Both the climatic conditions used in this experiment were severe; however, the standard climatic cycle was reasonable for emergence seasons with little or no rainfall. It is believed that the characterization of the rate of drying and the resulting emergence was a reasonable evaluation from a climatic standpoint as well as one controlled.

The clod sizes used in the test were not typical of those from normal tillage operations since rather narrow clod size ranges were used. These ranges not only were a simplifying measure used for experimental purposes, but also represented more nearly what was beleived to be those conditions resulting from minimum tillage operations. Overall, however, the narrow clod size ranges contributed to more severe test conditions in that small clods or particles which normally fill voids had been removed.

Even though the overall test conditions were to some extent extreme, comparative results were obtained. Results indicated that as clod size increased and compactive effort decreased in a seedbed the rate of soil drying increased and total emergence was less complete (unless water was resupplied by rainfall during the emergence season). There was some evidence that vibration of the seedbed would also reduce the rate of soil drying. As indicated before, however, no compactive or stratified treatment which used the 0.263 inch clods as the primary soil was as effective in reducing the drying rate as a reduction in clod size.

Even though the above statement is made, it is not reasonable to recommend finely prepared seedbeds based on the yield advantages of "minimum" seedbeds as reported by many workers and the increased danger of soil crusting as the soil treatment is subjected to rainfall. The results emphasize that a difference exists between "seedbed" and "rootbed" and give rise to increased enthusiasm for strip preparations which can give more optimum soil conditions for both. Such a treatment must provide fine clods in a layer around the seed.

Further investigation of soil stratification is justifiable. As previously indicated, very fine clods are not desirable on the surface of the soil from the standpoint of crusting; however, a fine compact layer at seed-level should contribute to a desirable soil-to-seed contact and also provide a diffusion barrier. The fine layer covered by large clods on the surface would reduce the risk of crusting. If it were found acceptable to permit the seedling to photosynthesize while proceeding through the large clod layer, the depth of planting can be increased at no expense to the crop and another effective diffusion barrier would be provided on the surface. The assumption is made here that the entire soil area would be subjected to the stratified treatment. From a physical viewpoint this seems justifiable; however, if the treatment could be restricted to a strip without horizontal diffusion movement of water being extremely significant, the treatment would have greater practical potentialities.

Stratification of the soil in the seedbed requires clod separation. Such a concept has several interesting ramifications. The aeration porosities resulting in these samples were quite high even in the compacted treatments. As the clod size range becomes narrow, material which normally fills the voids is removed. Removal of fine clods or particles provides an effective method of increasing aeration porosity and increasing its expected longevity because the material which contributes to crusting has been removed. (In concrete, a mixture of aggregate sizes is used to permit "keying" together thus forming a dense mixture). A layer of soil lifted and screened would permit placing the fine clods and individual particles of soil in a lower layer where their effects should be less damaging. Successive layers could be placed as is desirable. A seedbed profile can be built up from existing clod sizes rather than subjecting the soil to a continual mechanical clod size reduction process.

USE OF NEWTON'S EQUATION FOR THE PREDICTION OF DRYING RATES

Newton's equation as used in this work can be and was used to some extent as a predictive equation. For any one treatment, a correlation existed between P and K which meant that for any P a definite K was determined. Such a curve is presented in Figure 34. This correlative curve, as proposed, takes into account clod size, application or no application of radiant energy, and may be independent of soil type. In order to predict the entire drying curve and judge whether emergence would occur, only P need be determined once the correlative curve is known.

Only one correlative curve is proposed since the degree to which this generalization is valid is unknown at the present time.

POWER OF THE STATISTICAL TEST

Concern was expressed at the start of the experiment as to the number of sub-samples which would be required to measure physical differences between treatments. Considerable time and effort was required for each sample and to go beyond three sub-samples was impractical. The intent was not to show statistical significance of any difference but to have an adequate measure of physical difference which might be of practical importance. Any attempt to decide the difference which is of practical importance is largely a matter of judgment.

In this experiment since the emergence of corn was desired, the emergence consolidation shown in Figures 17 and 18 offered the best criterian. The difference required to show practical importance must be much narrower than the zone where emergence occurred.

Weaver (1960) stated that about four standard deviations will equal the difference that can be discovered 95 percent of the time with any test. Applying this information to data extracted from Table 16 of the Appendix, the following differences could be detected 95 percent of the time:

An overall estimate of $S\,\bar{x}$ (K) = 0.005 and $S\,\bar{x}$ (P) = 0.5

Variation in $\bar{x}$ (K) then = 0.02 and $\bar{x}$ (P) = 2.0%

Assuming an intermediate treatment condition similar to the 1.2 psi pressed treatment, 0.263 inch clod size with no radiant energy applied, the range between the two moisture content ratio - time curves shown in Figure 35 represents the difference which could be detected 95 percent of the time with the variation experienced in the data of the experiment. Assuming that the sampling of P and K were simultaneously inaccurate, the range proposed in Figure 35 represents the difference required between treatments before there is assurance a true difference exists based on the 95 percent confidence level.

From a practical viewpoint, a decision must be made whether the treatments differ in their ability to permit full emergence. Since the emergence zone was quite large as compared to the range

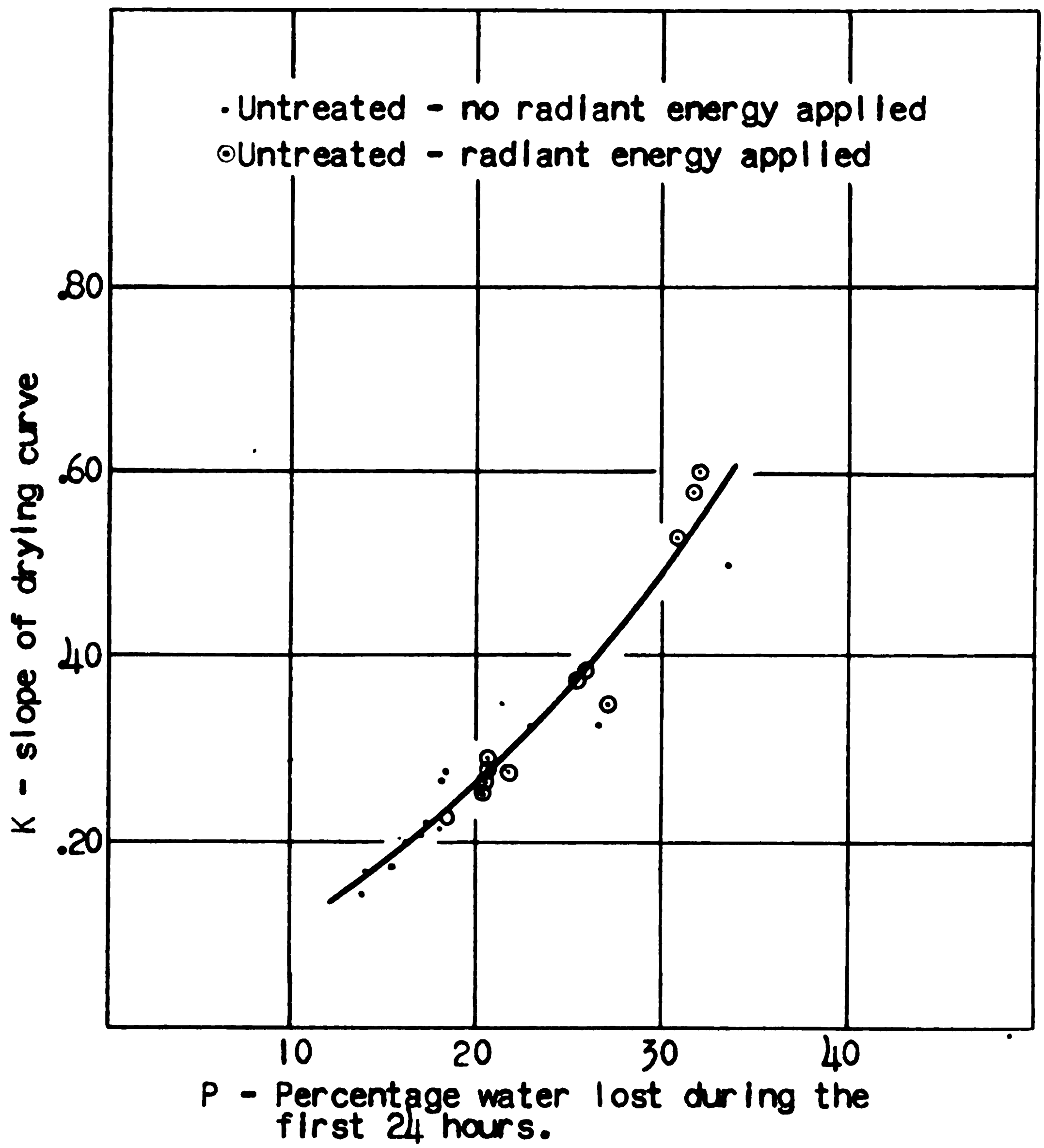


Fig. 34 - Correlative curve P vs K for the one soil studied.

required for a true difference, it was concluded that the experiment had the necessary power to judge treatments within the emergence zone, therefore the experiment had the necessary power to measure practical differences between treatments.

SUGGESTIONS CONCERNING FUTURE WORK

A better method of placing the soil in the sample container would be helpful in reducing the experimental error. This would involve a standard mechanical process of dropping the soil into the sample container or of vibrating the sample.

Overall, it is believed that methods similar to those used in this experiment must be used in future tillage work. Many field experiments have yielded good information; however, this information can almost never lead to an adequate mathematical characterization which will also be applicable for predictive purposes. Instead, careful laboratory study with adequate control of variables is required.

CONCLUSIONS

(1) Newton's equation, $\frac{M - M_e}{M_o - M_e} = e^{-K\theta}$, plotted in the form of the moisture content ratio - time curve with slope K, provided an adequate means for characterizing the rate of soil drying after a stable diffusion system was established (normally within 24 hours after the sample was prepared.) A parameter P, percentage of water

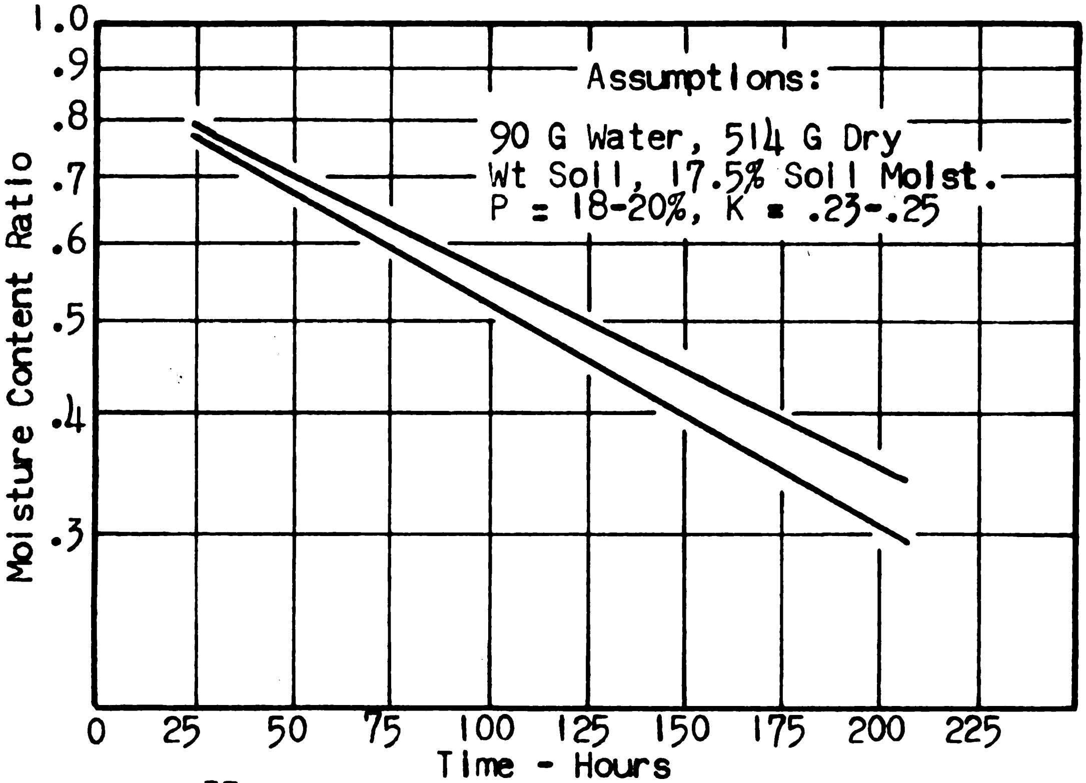


Fig. 35 - Illustration of the Difference That Can Be Discovered 95% of the Time

lost during the first 24 hour period, effectively characterized this initial drying period.

(2) This method of characterizing the soil drying rate provided an effective basis for comparing the influence of various soil treatments: alteration of clod size, degree of compaction, and location of various clod sizes in the tilled profile.

(3) As clod size increased and compactive effort decreased, the overall rate of soil drying increased and total emergence of the corn was less complete.

(4) The application of compactive pressure to the soil had little or no effect on reducing F.

(5) The application of compactive pressure tended to reduce the slope, K, of the moisture content ratio - time curve. A slight and uncertain difference was found between the 1.2 and 5 psi pressure treatments.

(6) The effect of clod size on K tended to reduce as the application of pressure was increased.

(7) Under the climatic conditions of the experiment when no radiant energy was applied to the soil surface, complete emergence was gained in the fine clod seedbed (0.046 inches in diameter) without the application of compactive pressure.

(8) The 5 psi pressure treatment delayed or inhibited emergence because a dense, dried layer was formed above the seed. Initial soil moisture content was relatively high, however.

(9) Large differences were observed in K between 0 and 1.2 psi pressure treatments while small differences were found between 1.2 and 5 psi. This suggested that low compactive pressures can effectively reduce the drying rate. A slight vibration of the sample also reduced drying rates.

(10) The stratified treatments, 0.046 inch clods placed and compacted in the 1 - 2 inch level, materially reduced the value of K and P over the no treatment condition.

(11) The fine, compacted clod layer in the stratified treatment provided a layer of soil highly resistant to the diffusion of water vapor, yet capillary movement was broken.

(12) No compacted or stratified treatment, which used the 0.263 inch clods as the primary soil, was as effective in reducing the drying rate as a reduction in clod size to 0.046 inches. Even so, based on the possibility of soil crusting when an entire seedbed is prepared of fine clods, a stratified treatment appears to be a desirable compromise treatment.

(13) The lowest drying rate occurred when the 0.046 inch clods were subjected to a compactive pressure treatment.

(14) Completely covering the surface of the sample with a water permeable material (the resistance of the material to vapor diffusion was inherently higher than the fine clod size) erased any effect of clod size on the rate of drying and effectively reduced the overall drying rate.

(15) The application of radiant energy to the surface of the soil increased the rate of drying. The heat applied on the soil surface induced 1/3 to 1/4 of the water lost from the upper 3 inches of soil to move downward to deeper depths. The quantity of downward water movement was independent of clod size whereas the water lost from the soil surface was dependent on clod size.

(16) For the soil and the climatic conditions used in this experiment, a definite relationship was found between P and K for any one degree of compaction.

(17) Once the relationship is known between P and K, possibly the entire drying curve, and thus the water loss characteristics of the treatment, can be predicted by determining P.

(18) The control of temperature, humidity, wind flow and radiant energy on or around the sample as practiced in this experiment provided an effective basis by which multiple samples and soil treatments could be compared under common environmental conditions.

(19) Three sub-samples for each treatment allowed sufficient precision to measure practical differences.

APPENDIX

Table 1 Mechanical Analysis of Soil Used

Sample No.	Clod Size ins.	Wt. of dry soil grams	At 40 sec. Reading	At 40 sec. Temp.	At 40 sec. Corrected reading % clay + silt	At 2 hrs. Reading	At 2 hrs. Temp.	At 2 hrs. Corrected reading % clay	silt %	sand %
1	.263	47.0	12.5	88.7	35.9	5.1	83.6	17.9	18.0	64.1
2	.263	47.0	12.0	87.8	34.5	5.0	83.5	17.7	17.8	65.5
3	.046	46.9	13.0	88.7	37.0	5.2	83.5	18.1	18.9	63.0
4	.046	46.9	13.5	86.9	35.2	5.5	83.3	18.7	16.5	64.8
5	.093	47.0	12.0	86.9	34.2	5.1	83.3	17.8	16.4	65.8
6	.093	46.9	13.0	85.1	35.4	4.7	82.6	16.7	18.7	64.6
Av.								17.8	17.7	64.6

Table 2 - Aeration Porosity of Soil

Sample	Clod size, ins.			
	.263 %	.185 %	.093 %	.046 %
1	44.8	45.0	46.4	48.3
2	44.8	45.7	46.0	47.3
3	43.0	45.4	46.4	48.3
4	43.0	46.3	46.5	48.1
5	45.4	46.7	45.2	49.3
Av.	44.2	46.0	46.1	48.3

Analysis of variance

	SS	df	MS	F
Between means	41.39	3	13.80	23.79**
Within groups	9.28	16	.58	
Total	50.67	19		

Arrayed means @ 1% level

44.2 $\overline{46.0 \quad 46.1}$ 48.3

Difference for significance $\approx$ 1.5%

Estimate of aeration porosity at the 5 psi pressure condition was determined to be $\approx$ 37%

Table 3. Observed and Calculated Data for Upper 3 inches of soil, sample number 19.

Clod size .093 inches
Uncompacted
No radiant energy applied

Sample covered
Equilibrium moisture content 2.7%

Hours	Total water lost		Water remaining	Soil Moist.	Moist. Content Ratio
	grams	%	grams	%	
0	0	0	74.4	17.6	1.0
2.0	.8	1.1	73.6	17.4	.987
6.5	2.5	3.4	71.9	17.0	.960
12.0	4.0	5.4	70.4	16.7	.940
23.5	5.9	7.9	68.5	16.2	.906
35.5	8.0	10.7	66.4	15.7	.873
47.8	9.8	13.1	64.6	15.3	.853
60.0	11.4	15.3	63.0	14.9	.819
71.8	13.1	17.6	61.3	14.5	.792
83.5	14.8	19.8	59.6	14.1	.765
95.5	15.9	21.3	58.5	13.8	.745
107.5	17.3	23.2	57.1	13.5	.725
119.5	18.3	24.5	56.1	13.3	.711
132.0	19.8	26.5	54.6	12.9	.685
143.3	21.6	28.9	52.8	12.5	.658
155.5	22.0	29.5	52.4	12.4	.651
167.3	22.9	30.7	51.5	12.2	.638
179.5	23.9	32.0	50.5	11.9	.618
191.8	24.8	33.2	49.6	11.7	.604
215.5	26.3	35.2	48.1	11.4	.584
239.8	27.2	36.4	47.2	11.2	.571

Table 4. Observed and Calculated Data for Upper 3 inches of Soil Sample number 24

Clod size .093
Compacted at 5 psi

No radiant energy applied
Equilibrium moisture content 2.7%

Hours	Total water lost grams	Total water lost %	Water remaining grams	Soil Moist. %	Moist. Content Ratio
0	0	0	96.5	17.6	1.0
2.0	6.9	7.2	89.6	16.3	.913
5.0	7.0	7.3	89.5	16.3	.913
7.0	8.1	8.4	88.4	16.1	.900
10.5	10.7	11.1	85.8	15.6	.865
22.3	14.3	14.9	82.2	15.0	.826
34.5	19.6	20.4	76.9	14.0	.759
46.3	21.6	22.5	74.9	13.7	.739
58.5	25.0	26.0	71.5	13.0	.681
70.0	26.6	27.7	69.9	12.7	.671
82.0	28.9	30.0	67.6	12.3	.645
94.0	29.9	31.1	66.6	12.1	.631
106.0	33.2	34.5	63.3	11.5	.591
118.0	34.0	35.4	62.5	11.4	.584
130.0	36.0	37.4	60.5	11.0	.557
142.0	37.9	39.4	58.6	10.7	.536
154.0	38.3	39.8	58.2	10.6	.530
178.3	41.7	43.4	54.8	10.0	.490
202.0	44.1	45.9	52.4	9.5	.456
226.0	46.4	48.3	50.1	9.1	.430
250.0	48.3	50.2	48.2	8.8	.410

Table 5 - Observed and Calculated Data for Upper 3 inches of Soil Sample number 30.

Clod size 0.093 Radiant energy applied
Uncompacted Equilibrium moisture content AM 2.7, PM 1.7%

Hours	Total water lost grams	Total water lost %	Water remaining grams	Soil Moist. %	Moist. Content Ratio
0	0	0	83.3	17.5	1.0
2.3	9.2	11.0	74.1	15.6	.880
8.0	16.0	19.2	67.3	14.1	.785
11.0	19.8	23.8	63.5	13.3	.735
23.0	21.0	25.2	62.3	13.1	.703
35.0	29.3	35.2	54.0	11.3	.607
47.0	29.7	35.6	53.6	11.3	.581
59.0	37.3	44.8	46.0	9.7	.506
71.0	37.1	44.5	46.2	9.7	.472
83.0	42.5	51.0	40.8	8.6	.436
95.0	42.6	51.1	40.7	8.5	.392
107.3	48.4	57.4	34.9	7.3	.354
119.0	48.3	56.8	35.0	7.4	.318
131.0	53.1	63.0	30.2	6.3	.291
143.0	53.0	61.8	30.3	6.4	.250
155.0	56.3	66.2	27.0	5.7	.253
167.3	55.5	64.9	27.8	5.8	.210
179.0	58.8	69.6	24.5	5.1	.215
191.0	58.7	67.7	24.6	5.2	.169
227.0	62.8	73.6	20.5	4.3	.165
263.3	61.6	73.9	21.7	4.6	.128

Table 6 - Observed and Calculated Data for Upper 3 inches of Soil Sample Number 63

Clod size at 1-0 and 2-3 inch level 0.093 inches uncompacted
Clod size at 1-2 inch level 0.046 inches compacted at 5 psi
Radiant energy applied
Equilibrium moisture content-AM 2.7, PM 1.7%

Hours	Total water lost grams	Total water lost %	Water remaining, grams	Soil Moist. %	Moist. Content Ratio
0	0	0	82.6	17.2	1.0
3.3	10.0	12.1	72.6	15.2	.871
6.3	14.1	17.1	68.5	14.3	.813
10.3	17.3	20.9	65.3	13.7	.774
22.5	19.0	23.0	63.6	13.3	.731
34.0	20.4	31.9	56.2	11.7	.645
46.0	26.4	31.9	56.2	11.7	.621
58.0	32.3	39.1	50.3	10.5	.568
70.0	32.4	39.2	50.2	10.5	.538
81.8	37.7	45.6	44.9	9.4	.497
94.3	37.2	45.0	45.4	9.5	.469
106.0	41.8	50.6	40.8	8.5	.439
118.0	41.8	50.6	40.8	8.5	.400
130.0	46.2	55.9	36.4	7.6	.381
142.8	45.5	55.1	37.1	7.7	.345
154.0	48.2	58.3	34.4	7.2	.355
166.3	47.8	57.8	34.8	7.3	.317
190.3	49.1	59.4	33.5	7.0	.297
202.0	52.5	63.5	30.1	6.3	.297
226.0	55.6	67.3	27.0	5.6	.252
238.0	53.7	65.0	28.9	6.0	.228

Table 7 - Observed and Calculated Data for Upper 3 inches of Soil
Sample Number 65

Clod size at 0-1 and 2-3 inch level 0.093 inches uncompacted
Clod size at 1-2 inch level 0.046 inches compacted at 5 psi.
No radiant energy applied
Equilibrium moisture content 2.6%

Hours	Total water lost		Water remaining, grams	Soil Moist. %	Moist. Content Ratio
	grams	%			
0	0	0	81.1	17.2	1.0
5.8	6.6	8.1	74.5	15.8	.903
9.8	9.0	11.1	72.1	15.3	.869
22.3	11.9	14.6	69.2	14.7	.828
34.0	15.1	18.6	66.0	14.0	.779
46.0	16.2	19.9	64.9	13.8	.766
58.0	19.1	23.5	62.0	13.2	.724
70.3	20.2	24.8	60.9	12.9	.703
82.3	22.2	27.3	58.9	12.5	.676
94.3	23.3	28.6	57.8	12.3	.662
118.3	24.5	30.1	56.6	12.0	.641
130.0	27.6	33.9	53.5	11.4	.600
142.0	28.0	34.4	53.1	11.3	.593
154.0	29.7	36.5	51.4	10.9	.566
166.0	31.0	38.1	50.1	10.6	.545
178.0	31.9	39.2	49.2	10.4	.531
190.0	33.0	40.6	48.1	10.2	.517
201.8	34.4	42.3	46.7	9.9	.497
214.0	34.9	42.9	46.2	9.8	.490
225.8	35.9	44.2	45.2	9.6	.476
238.0	36.7	45.1	44.4	9.4	.462

Table 8 - Observed and Calculated Data for Upper 3 inches of soil, sample number 0 - 4

Clod size - 0.093 inches
Uncompacted
Radiant energy applied
Equilibrium moisture content 1.7%

Hours	Total water lost grams	Water remaining grams	Soil Moist. %	Moist. Content Ratio
0	0	75.0	15.7	1.0
6.5	13.2	61.8	12.9	.800
22.3	23.7	51.3	10.7	.643
31.5	27.6	47.4	9.9	.586
46.8	33.8	41.2	8.6	.493
54.3	36.3	38.7	8.1	.457
70.8	39.4	35.6	7.4	.407
77.5	41.6	33.4	7.0	.378
94.3	44.3	30.7	6.4	.336
103.3	45.3	29.7	6.2	.321
118.5	48.3	26.7	5.6	.278
128.5	50.8	24.2	5.1	.243
144.0	51.6	23.4	4.9	.228
151.5	53.2	21.8	4.6	.207
198.0	59.1	15.9	3.3	.114

Table 9 - Observed and Calcualted Data for Upper 3 inches of Soil
Sample Number O - 5

Clod size - .093 inches
Uncompacted
No radiant energy applied
Equilibrium moisture content 2.6%

Hours	Total Water Lost grams	Water Remaining grams	Soil Moist. %	Moist. Content Ratio
0	0	82.1	17.4	1.0
6.5	7.7	74.4	15.7	.886
22.3	14.4	67.7	14.3	.791
31.5	16.7	65.4	13.8	.757
46.8	20.7	61.4	13.0	.704
54.3	22.4	59.7	12.6	.676
70.8	24.8	57.3	12.1	.643
77.5	25.6	56.5	11.9	.629
94.3	27.8	54.3	11.5	.601
103.3	28.9	53.2	11.3	.589
118.5	30.7	51.4	10.9	.561
128.5	31.0	51.1	10.8	.555
144.0	32.2	49.9	10.6	.541
151.5	33.6	48.5	10.3	.521
198.0	38.2	43.9	9.3	.453

Table 10 - Observed and Calculated Data for Upper 3 inches of Soil
Sample Number 0 - 6

Clod size - 0.093 inches
Uncompacted
No radiant energy applied
Equilibrium moisture content 2.6%

Hours	Total Water Lost grams	Water Remaining grams	Soil Moist. %	Moist. Content Ratio
0	0	83.6	17.8	1.0
6.5	7.6	76.0	16.2	.895
22.3	14.2	69.4	14.8	.803
31.5	16.6	67.0	14.3	.770
46.8	20.6	63.0	13.5	.717
54.3	22.0	61.6	13.2	.697
70.8	23.9	59.7	12.8	.671
77.5	24.7	58.9	12.6	.658
94.3	26.2	57.4	12.3	.639
103.3	27.9	55.7	11.9	.611
118.5	29.1	54.5	11.6	.592
128.5	29.5	54.1	11.5	.586
144.0	31.0	52.6	11.2	.566
151.5	32.4	51.2	10.9	.546
198.0	37.6	46.0	9.8	.474

Table 11 - Observed and Calculated Data for Upper 3 inches of Soil
Sample Number 0 - 10

Clod size - 0.093 inches
Uncompacted
No radiant energy applied
Equilibrium moisture content 2.6%

Hours	Total Water Lost grams	Water Remaining grams	Soil Moist. %	Moist. Content Ratio
0	0	85.4	18.3	1.0
6.0	6.3	79.1	16.9	.911
23.0	13.7	71.7	15.4	.815
45.8	19.6	65.8	14.1	.733
53.5	21.6	63.8	13.7	.708
69.5	24.7	60.7	13.0	.663
77.8	25.9	59.5	12.7	.644
93.5	29.1	56.3	12.1	.606
102.0	29.9	55.5	11.9	.593
118.5	32.0	53.4	11.4	.661
141.8	34.5	50.9	10.9	.529
149.8	35.6	49.8	10.7	.516
169.5	37.8	47.6	10.2	.485
212.8	42.5	42.9	9.2	.421
237.5	44.0	41.4	8.9	.401

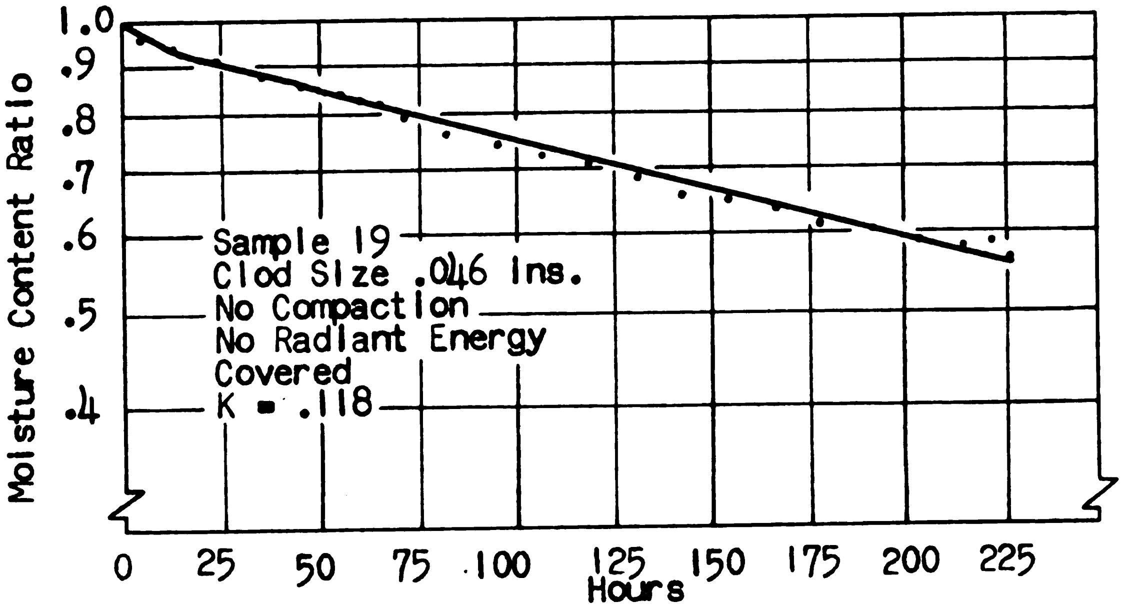


Fig. 1 - Sample Drying Curve
Standard Climatic Cycle

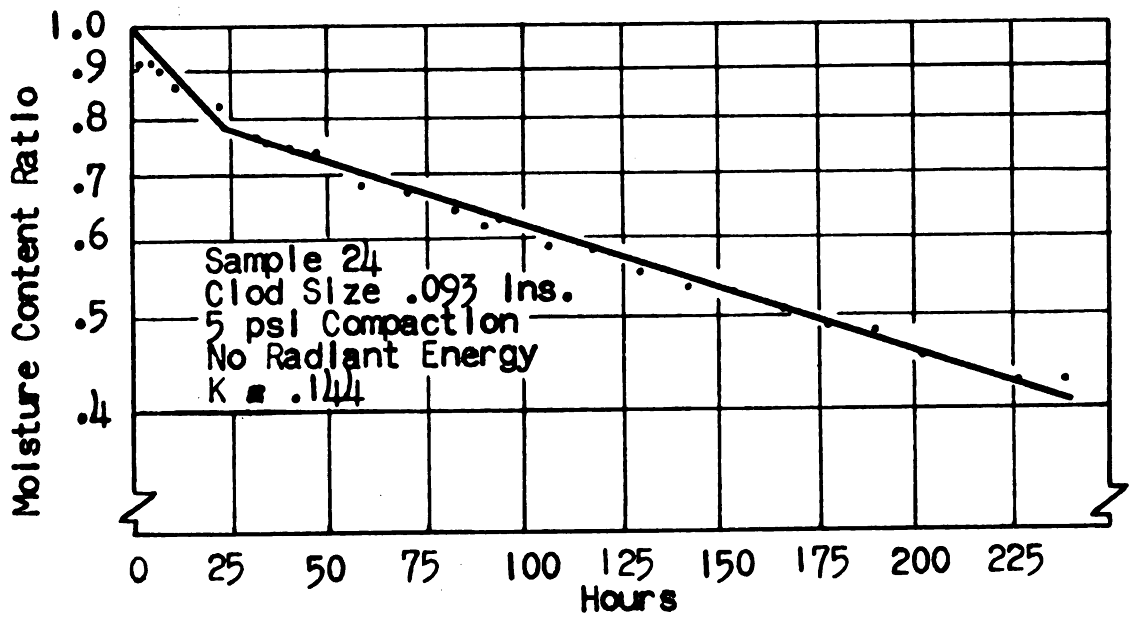


Fig. 2 - Sample Drying Curve
Standard Climatic Cycle

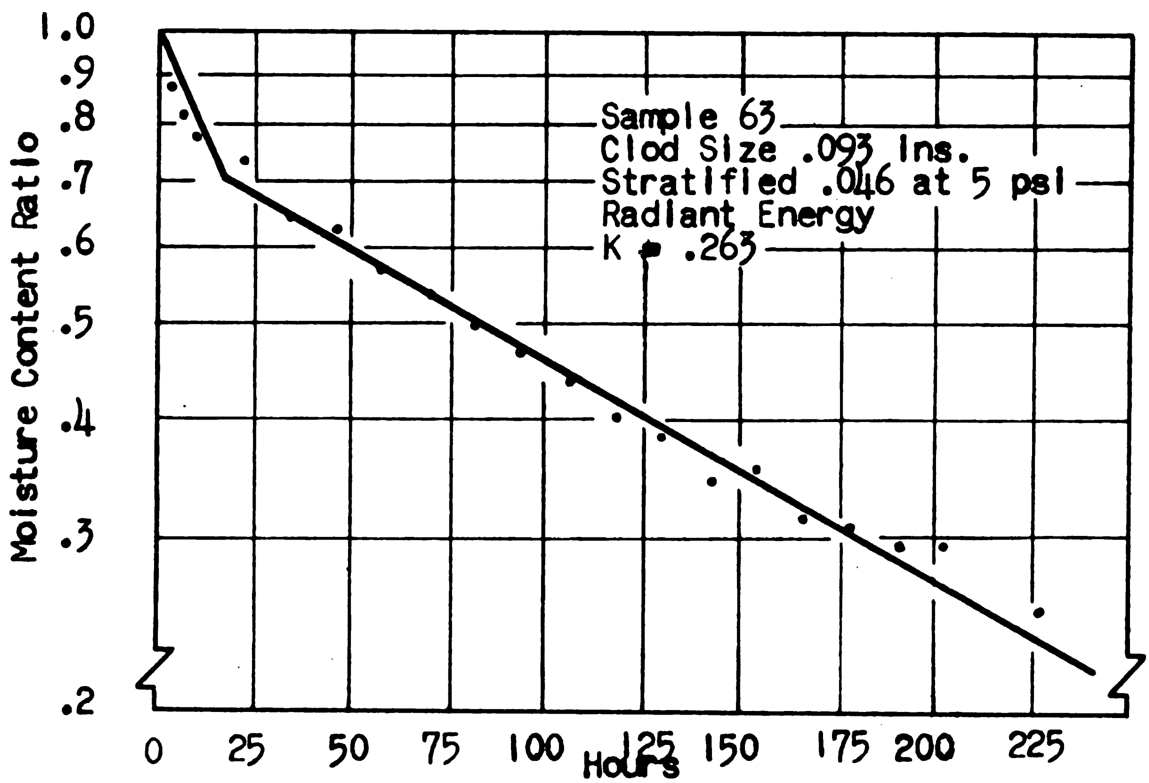


Fig. 3 - Sample Drying Curve
Standard Climatic Cycle

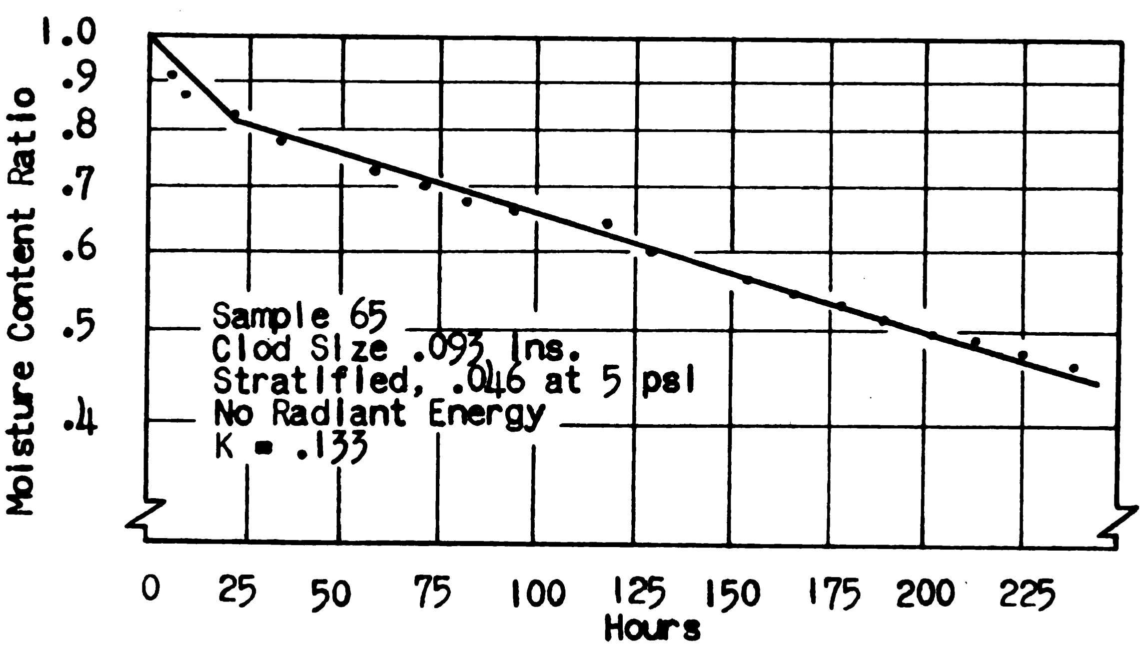


Fig. 4 - Sample Drying Curve
Standard Climatic Cycle

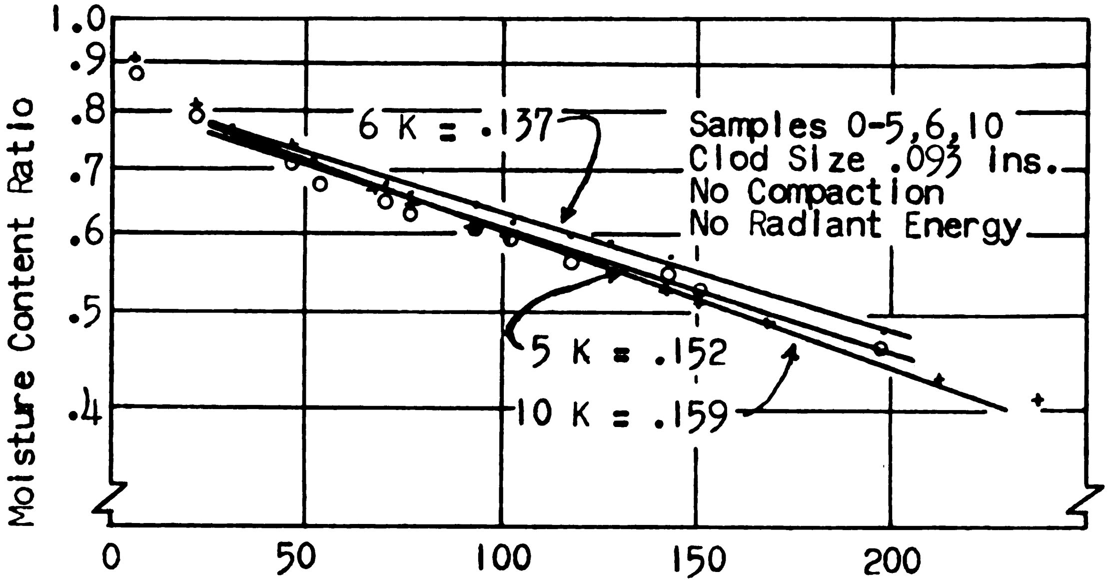


Fig. 5 - Three Drying Curves Resulting From Supposedly Identical Drying Conditions

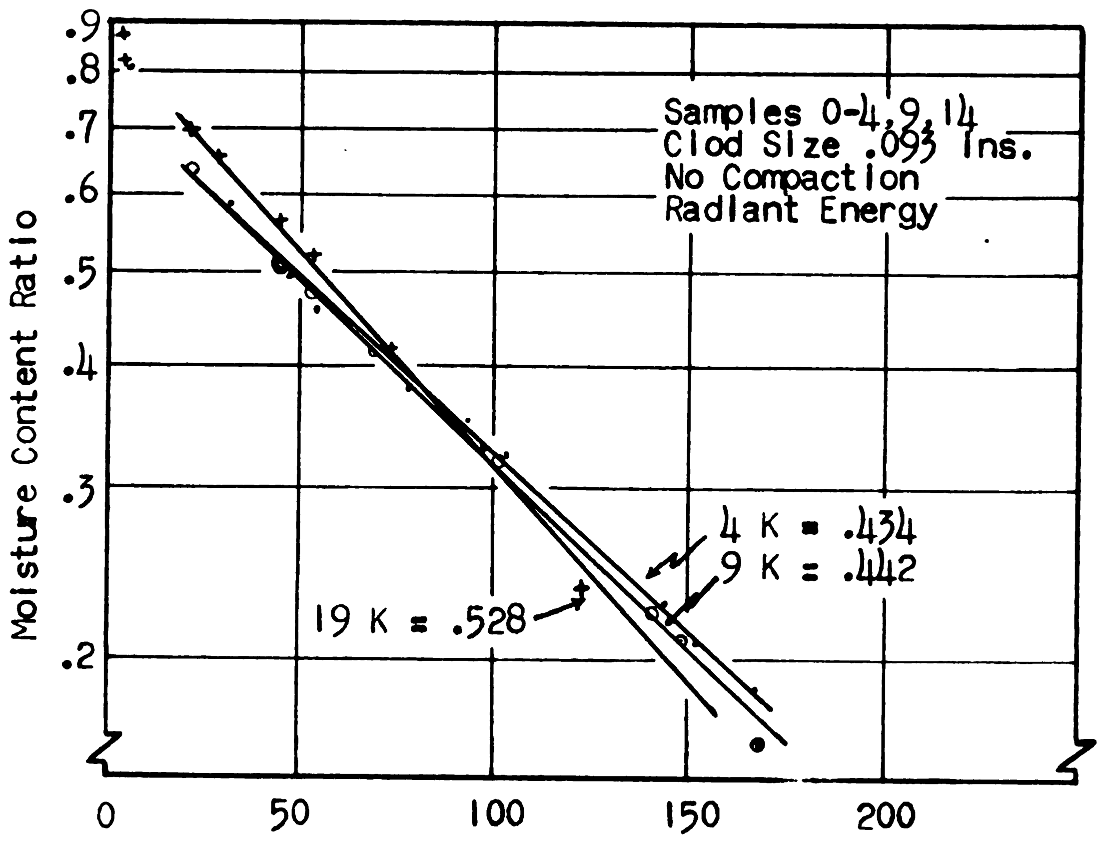


Fig. 6 - Three Drying Curves Resulting from Supposedly Identical Drying Conditions

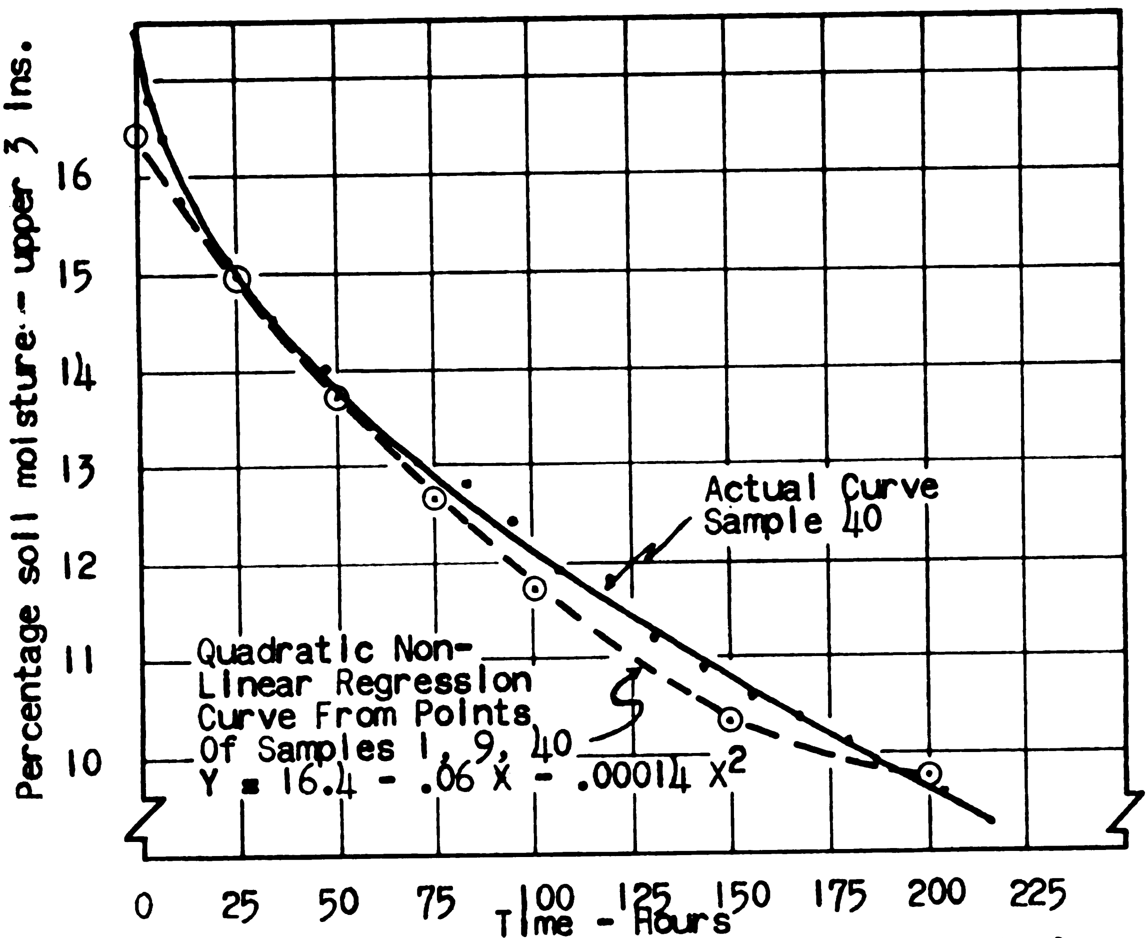


Fig. 7 - Non-linear Regression Method of Combining The Three Sub-sample Drying Curves

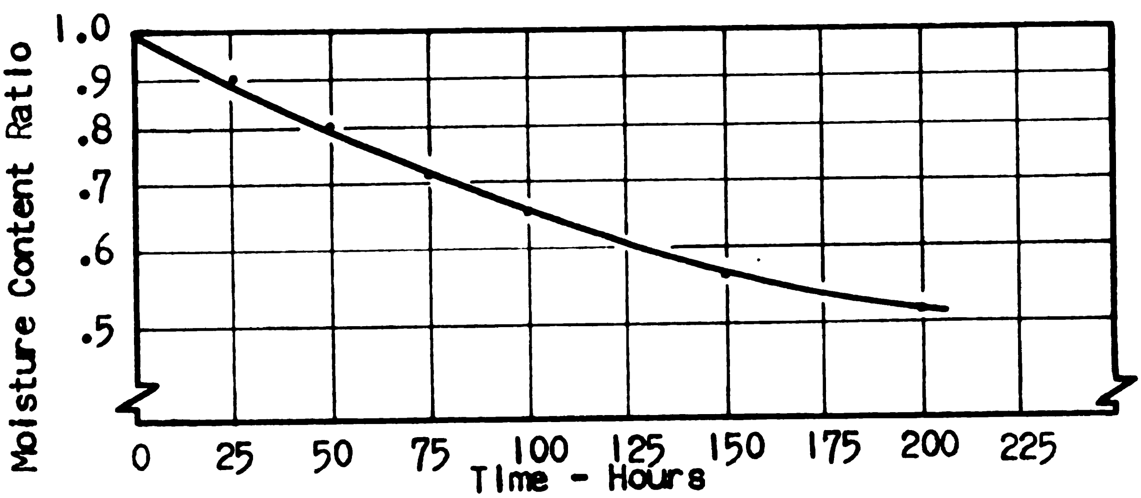
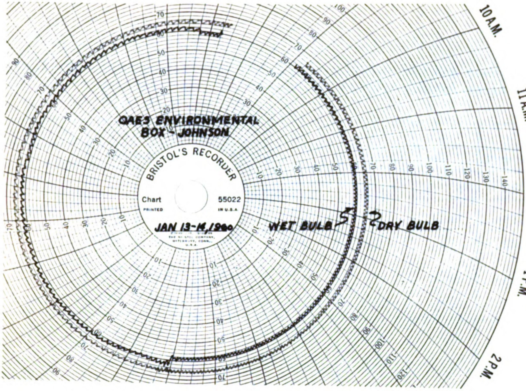


Fig. 8 - Drying Curve Resulting From Non-Linear Regression Method of Combining Drying Curves



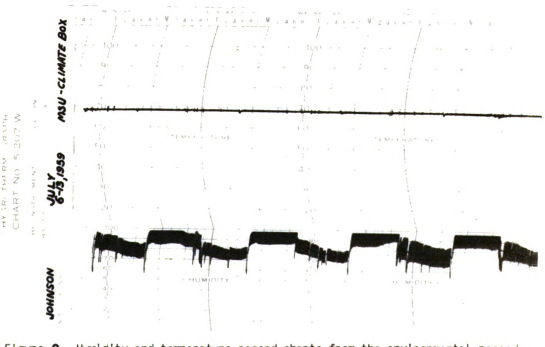


Figure 9 Humidity and temperature record charts from the environmental record charts from the environmental chambers.

Top--Ohio chamber. Bottom--MSU chamber.

Table 12 - Accumulated Data - K values where no radiant energy was applied. (K = slope of moisture content ratio - time curve)

Column No.	1	2	3	4	5	6	7
Clod size ins.	Untreated		Pressed		Stratified		Covered
	0 psi	0 psi	1.2 psi	5.0 psi	1.2 psi	5.0 psi	0 psi
.263	.271	.350	.220	.189	.212	.238	.112
	.256	.331	.290	.225	.240	.231	.120
	.288	.325	.240	.203	.250	.246	.130
av.	.272	.335	.250	.206	.234	.238	.121
.185	.226	.266	.192	.164	.183	.136	.110
	.218	.276	.192	.169	.208	.176	.130
	.201	.220	.210	.210	.175	.169	.125
av.	.215	.254	.198	.181	.189	.160	.122
.093	.152	.216	.147	.144	.160	.144	.112
	.137	.208	.150	.140	.142	.141	.121
	.159	.200	.160	.160	.166	.150	.131
av.	.149	.208	.152	.148	.156	.145	.121
.046	.156	.177	.137	.132	.127	.128	.127
	.147	.168	.128	.143	.120	.133	.118
	.149	.142	.137	.121	.135	.131	.118
av.	.151	.162	.134	.132	.127	.133	.121

Note: Column 1 - Constant climatic conditions. (Ohio)

Columns 2, 3, 4, 5, 6, 7 - Standard climatic cycle.

Table 13 - Accumulated Data - K values where radiant energy was applied. (K = slope of moisture content ratio-time curve)

Column No.	1	2	4	6	7
Clod size, in.	Untreated		Pressed	Stratified	Covered
	0 psi	0 psi	5.0 psi	5.0 psi	0 psi
.263	.624	.580	.247	.302	.411
	.823	.600	.420	.269	.380
	.705	.530	.380	.272	.400
av.	.717	.570	.349	.281	.397
.185	.689	.351	.290	.270	.360
	.629	.380	.280	.270	.370
	.629	.386	.290	.280	.350
av.	.649	.372	.287	.273	.360
.093	.434	.275	.236	.266	.351
	.442	.280	.240	.248	.300
	.528	.290	.250	.263	.320
av.	.468	.282	.242	.259	.324
.046	.392	.256	.182	.271	.264
	.472	.225	.188	.210	.270
	.485	.271	.195	.237	.280
av.	.450	.251	.188	.239	.271

Note: Column 1 - Constant climatic conditions (Ohio)

Columns 2, 4, 6 and 7 - Standard climatic cycle.

Table 14 - Accumulated Data - P values where no radiant energy was applied. (P = % water lost the first 24 hours)

Column No.	1	2	3	4	5	6	7
	Untreated		Pressed		Stratified		Covered
Clod size ins.	0 psi	0 psi	1.2 psi	5.0 psi	1.2 psi	5.0 psi	0 psi
.263	23.1	21.4	20.4	24.5	20.2	18.7	5.0
	23.9	26.5	26.6	26.3	21.0	19.1	6.6
	22.0	23.0	23.3	24.0	20.0	19.9	6.9
av.	23.0	23.6	23.4	24.9	20.4	19.2	6.2
.185	19.7	18.1	18.4	20.6	17.1	14.7	5.4
	20.5	18.3	15.9	16.2	17.0	18.0	7.5
	20.6	17.3	19.9	20.7	17.9	16.5	7.2
av.	20.3	17.9	18.1	19.2	17.3	16.4	6.7
.093	18.2	18.0	16.4	15.6	16.0	13.4	6.5
	17.8	17.0	18.4	20.0	17.7	13.7	5.7
	16.5	16.2	16.8	19.6	16.3	14.2	8.6
av.	17.3	17.1	17.2	18.4	16.7	13.8	6.9
.046	16.9	15.4	14.1	12.6	13.0	12.2	6.4
	16.8	14.0	15.8	19.8	12.7	14.2	8.1
	16.6	13.8	15.0	11.8	12.1	14.0	7.1
av.	16.8	14.4	15.0	14.7	12.6	13.5	7.2

Note: Column 1 - Constant climatic conditions. (Ohio)

Columns 2, 3, 4, 5, 6, 7 - Standard climatic cycle.

Table 15 - Accumulated Data - P values when radiant energy was applied. (P = % water lost the first 24 hours)

Column No.	1	2	4	6	7
Clod size ins.	Untreated		Pressed	Stratified	Covered
	0 psi	0 psi	5.0 psi	5.0 psi	0 psi
.263	41.0	31.6	24.3	27.1	26.5
	36.4	32.0	32.7	30.4	24.6
	36.8	30.8	31.0	27.9	25.5
av.	38.1	31.5	29.3	28.5	25.5
.185	34.0	27.0	25.6	24.4	24.0
	35.6	25.5	25.8	21.9	24.4
	32.4	26.0	26.9	24.0	23.5
av.	34.0	26.2	26.1	23.4	24.0
.093	32.7	21.9	23.0	19.9	22.7
	33.4	20.8	23.1	21.8	21.3
	28.7	21.2	24.0	24.1	21.8
av.	31.6	21.3	23.4	21.9	21.9
.046	30.8	20.8	17.8	21.2	21.5
	29.4	18.5	20.3	17.5	20.5
	28.1	20.9	20.2	21.3	20.0
av.	20.4	20.1	19.4	20.0	20.7

Note: Column 1 - Constant climatic conditions (Ohio)

Columns 2, 4, 6, 7 - Standard climatic cycle.

Table 16 - Summary of the Statistical Analysis. The treatment mean $\bar{x}$, regression slope b, and standard deviations are presented for each treatment.

	1	2	3	4	5	6	7
	Untreated		Pressed		Stratified		Covered
	0 psi	0 psi	1.2 psi	5.0 psi	1.2 psi	5.0 psi	0 psi
$\bar{x}$	.1966	.2399	.1858	.1667	.1765	.1686	.1212
$S_{\bar{x}}$	.00344	.00548	.00561	.0050	.00431	.00335	.00252
b	.0214	.0282	.0196	.0127	.0176	.0169	.0000
S_b	.001539	.002451	.002487	.002236	.001932	.001500	.001125
k values - With radiant energy applied							
$\bar{x}$	.5710	.3687		.2665		.2632	.3380
$S_{\bar{x}}$	.01852	.00686		.01317		.00539	.00473
b	.0492	.0524		.0263		.0070	.0207
S_b	.008283	.003069		.005893		.002409	.002114
Percent water - No radiant energy applied							
$\bar{x}$	19.3833	18.2500	18.4167	19.3083	16.7500	15.7166	6.750
$S_{\bar{x}}$	.20233	.42466	.56928	.83421	.18002	.30553	.33244
b	1.0735	1.4270	1.3136	1.5686	1.2036	.9969	.1667
S_b	.09049	.18992	.2546	.37308	.08051	.13664	.14868
Percent water - With radiant energy applied							
$\bar{x}$	33.2750	24.7500		24.5583		23.4583	23.0250
$S_{\bar{x}}$	.60048	.25455		.68499		.53778	.21577
b	1.4153	1.9537		1.6220		1.3453	.8318
S_b	.26855	.11384		.30635		.24051	.09650

Table 17 - Dry Weight of Soil in Upper 3 inches of Sample
No radiant energy applied

Column No.	1	2	3	4	5	6	7
Clod size ins.	Untreated		Pressed		Stratified		Covered
	0 psi	0 psi	1.2 psi	5.0 psi	1.2 psi	5.0 psi	0 psi
.263	487.9	487.6	510.2	579.7	487.2	490.2	476.6
	490.5	485.0	529.8	573.6	496.2	491.1	489.8
	479.0	488.9	530.0	588.0	495.0	475.5	480.0
av.	485.8	487.2	523.3	580.4	492.8	485.6	482.1
.185	458.8	510.3	488.3	573.0	478.5	477.0	450.2
	473.3	506.8	485.2	539.0	485.3	493.3	494.2
	488.7	475.9	514.1	560.6	524.0	501.6	489.6
av.	473.6	497.7	495.9	557.5	495.9	490.6	478.0
.093	472.2	438.2	501.0	548.3	482.7	486.8	422.9
	468.5	439.3	518.1	578.9	585.5	491.5	471.3
	466.6	438.8	491.9	545.6	490.2	493.5	432.1
av.	469.1	438.8	503.7	557.6	486.1	490.6	442.1
.046	446.1	420.8	433.2	550.3	467.9	474.0	425.5
	436.9	428.6	455.6	551.2	466.0	485.1	422.5
	435.0	418.6	468.1	506.3	472.5	459.1	450.4
av.	439.3	422.7	452.3	535.9	468.8	472.7	432.8

Note: Column 1 - Constant climatic conditions. (Ohio)

Columns 2, 3, 4, 5, 6, 7 - Standard climatic cycle.

Volume of upper 3 inches of sample - 515 cc.

Table 18 - Weight of Water in Upper 3 inches of Soil Sample
No radiant energy applied

Column No.	1	2	3	4	5	6	7
	Untreated		Pressed		Stratified		Covered
Clod size ins.	0 psi	0 psi	1.2 psi	5.0 psi	1.2 psi	5.0 psi	0 psi
.263	88.0	83.5	85.2	95.0	84.0	82.0	81.5
	86.0	82.4	90.6	97.7	85.0	82.6	86.3
	88.0	83.9	90.0	103.8	85.0	82.1	84.0
av.	87.3	83.3	88.6	98.8	84.7	92.2	83.9
.185	88.9	86.7	87.7	100.4	82.1	82.1	81.0
	86.9	86.1	83.9	91.1	83.6	86.3	84.0
	82.0	82.0	91.5	97.5	92.2	87.6	83.2
av.	85.9	84.9	87.7	96.3	86.0	85.3	82.7
.093	82.1	73.7	86.1	96.5	84.5	83.9	71.1
	83.6	77.0	90.6	103.1	83.6	86.5	81.0
	85.4	77.1	86.1	97.0	86.6	86.9	75.6
av.	83.7	75.9	87.6	98.9	84.9	85.8	75.9
.046	79.9	72.6	75.8	96.2	77.7	81.8	71.6
	80.3	72.0	78.3	100.4	80.3	82.3	74.4
	77.9	70.8	83.8	87.5	83.3	80.3	79.3
av.	79.4	71.8	79.3	94.7	80.4	81.5	75.1

Note: Column 1 - Constant climatic conditions. (Ohio)

Columns 2, 3, 4, 5, 6, 7 - Standard climatic cycle.

Volume of upper 3 inches of sample - 515 cc.

Table 19 - Dry Weight of Soil in Upper 3 inches of Sample. With radiant energy applied.

Column No.	1	2	4	6	7
Clod size in.	Untreated		Pressed	Stratified	Covered
	0 psi	0 psi	5.0 psi	5.0 psi	0 psi
.263	500.6	452.0	579.3	489.6	476.6
	497.0	457.1	577.3	491.1	493.4
	498.7	498.6	578.0	524.7	485.0
av.	498.8	469.2	578.2	501.8	485.0
.185	489.0	499.7	566.4	469.1	478.6
	478.7	457.6	551.3	504.0	481.8
	471.4	475.9	558.4	480.0	479.0
av.	479.7	477.7	558.7	484.4	479.8
.093	478.3	453.2	567.9	454.2	435.0
	462.3	456.0	525.2	480.6	466.5
	485.3	450.9	550.0	478.2	455.0
av.	475.3	453.4	547.7	471.0	452.2
.046	442.7	430.3	520.5	474.0	419.8
	434.0	449.0	562.6	486.0	440.0
	455.0	439.3	552.9	482.5	435.0
av.	443.9	439.5	545.3	480.8	431.6

Note: Column 1 - Constant climatic conditions. (Ohio)

Columns 2, 4, 6, 7 - Standard climatic cycle.

Volume of upper 3 inches of sample - 515 cc.

Table 20 - Weight of water in upper 3 inches of soil sample With radiant energy applied

Column No.	1	2	4	6	7
Clod size ins.	Untreated		Pressed	Stratified	Covered
	0 psi	0 psi	5.0 psi	5.0 psi	0 psi
.263	82.0	83.2	98.9	84.3	81.5
	86.0	80.2	99.7	82.6	84.6
	87.5	83.0	99.5	91.8	83.0
av.	85.2	82.1	99.4	86.2	83.0
.185	78.0	85.0	90.0	79.4	72.0
	78.0	78.5	94.9	77.7	80.7
	83.5	83.3	98.2	78.0	80.0
av.	79.8	82.3	94.4	78.4	77.6
.093	75.0	79.8	99.2	76.4	72.2
	78.5	78.9	94.4	81.3	80.7
	82.5	83.9	98.3	82.6	78.0
av.	78.7	80.9	97.3	80.1	77.0
.046	74.0	75.9	91.1	80.6	73.9
	74.5	78.4	97.5	84.5	77.0
	77.4	77.2	96.2	83.0	75.0
av.	75.3	77.2	94.9	82.7	75.3

Note: Column 1 - Constant climatic conditions. (Ohio)

Columns 2, 4, 6, 7 - Standard climatic cycle.

Volume of upper 3 inches of sample - 515 cc.

Table 21 - Emergence of Corn Planted in the Sample.
No radiant energy applied.

Column No.	1	2	3	4	5	6	7
Clod size ins.	Untreated		Pressed		Stratified		Covered
	0 psi	0 psi	1.2 psi	5.0 psi	1.2 psi	5.0 psi	0 psi
.263	1-190* 2-238	3-335SW	1-190 1-334S 1-D	2-226 1-284C	3-167	2-162 1-186	3-167
	2-190 1-210	1-330 2-310D	X	X	X	X	X
	3-220	X	X	X	X	X	X
.185	3-250	X	3-263	1-238 2-238C	3-167	3-179	3-202
	3-230	3-160	1-167 2-239	3-239	X	1-178 1-202 1-214	1-156 2-179
	3-190	X	X	X	2-167 1-179	1-178 2-202	X
.093	3-198	2-306SW 1-306D	1-178 1-102 1-238C	X	1-142 2-149	3-150	3-192
	3-198	1-154 1-225 1-225SW	3-191	1-214 1-238 1-238C	3-238	1-142 2-166	3-166
	3-213	3-166	X	X	2-155 1-167	3-166	3-165
.046	3-168	3-190	1-166 2-178	3-164	3-149	1-155 1-167 1-179	3-161
	1-168 2-198	3-161	3-226	3-238SC	3-214	X	3-143
	1-212 2-238	3-166	3-191	2-179 1-263	X	3-166	3-155

* Entries indicate number of seedlings emerging and time in hours.
S - Sprouted not through soil surface.
W - Wilty.
D - Seeds dried.
C - Curled due to compact soil.
X - Denotes samples in which seeds were not planted

Note: Column 1 - Constant climatic conditions. (Ohio)
Column 2, 3, 4, 5, 6, 7 - Standard climatic cycle.

Table 22 - Emergence of corn planted in samples.
Radiant energy applied.

Column No.	1	2	4	6	7
Clod size ins.	Untreated		Pressed	Stratified	Covered
	0 psi	0 psi	5.0 psi	5.0 psi	0 psi
.263	3-200D*	3-190D	1-166 2-214D	1-143 1-154 1-238D	1-95S
	3-200D	X	X	X	
	3-200D	X	X	1-215 2-215D	X
.185	3-190D	X	X	3-262D	X
	3-190D	X	X	3-130	X
	3-200D	X	X	X	X
.093	3-198D	1-131 1-156 1-192	2-167 1-179SC	2-143 1-238D	3-167D
	3-237D	X	X	1-262 2-262D	X
	3-190D	X	X	X	X
.046	3-198D	1-287 2-287D	X	X	3-287D
	3-237D	1-155 1-191 1-220	1-167 2-167SC	X	X
	3-190D	X	X	1-143 1-167 1-214	X

* Entries indicate number of seedlings emerging and time in hours.
S - sprouted, not through surface
W - wilty
D - seeds dried (no seedling resulted)
C - curled due to compact soil
X - denotes samples in which no seeds were planted

Note: Column 1 - Constant climatic conditions. (Ohio)
Columns 2, 4, 6, 7 - Standard climatic cycle.

Table 23 - Key relating sample number to treatment
No radiant energy applied

Column No.	1	2	3	4	5	6	7
Clod size ins.	Untreated		Pressed		Stratified		Covered
	0 psi	0 psi	1.2 psi	5.0 psi	1.2 psi	5.0 psi	0 psi
.263	0-20	5	48	42	31	46	2
	0-21	21	0-27	0-29	0-28	52	0-46
	0-26	0-33	0-65	0-48	0-66	64	0-67
.185	0-11	99	55	91	62	68	56
	0-12	100	61	73	75	77	96
	0-19	0-40	0-55	0-38	87	79	0-53
.093	0-5	8	60	24	32	45	7
	0-6	16	93	89	66	78	59
	0-10	23	0-52	0-51	88	80	15
.046	0-2	1	47	44	33	84	6
	0-3	9	54	90	67	86	19
	0-8	22	92	71	0-44	81	97

Note: Column 1 - Constant climatic conditions. (Ohio)
Column 2, 3, 4, 5, 6, 7 - Standard climatic cycle.
0 Samples ran in Ohio

Table 24 - Key Relating Sample Number to Treatment. Radiant energy applied.

Column No.	1	2	4	6	7
Clod size ins.	Untreated		Pressed	Stratified	Covered
	0 psi	0 psi	5.0 psi	5.0 psi	0 psi
.263	0-22	13	28	50	4
	0-23	20	0-31	51	0-47
	0-25	0-32	0-58	57	0-60
.185	0-17	98	0-34	70	0-41
	0-18	0-36	0-37	39	0-54
	0-24	30	0-56	0-59	0-61
.093	0-4	82	94	49	11
	0-9	0-42	0-35	69	0-43
	0-14	0-49	0-50	63	0-62
.046	0-1	17	27	85	18
	0-7	83	95	0-45	0-63
	0-13	41	0-57	58	0-64

Note: Column 1 - Constant climatic conditions.

Column 2, 4, 6, 7 - Standard climatic cycle.

0 samples ran in Ohio

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