PROCESSING AND VIBRATORY COMPACTION OF NATURAL SOILS FOR LABORATORY PLANTER RESEARCH

by

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INTRODUCTION

Agriculture today is a far cry from that existing in the era of the horse or ox drawn plow. Crops are no longer completely at the mercy of nature. As man has improved his understanding of this world, he has learned to alter the less desirable aspects of the environment to capitalize on the more desirable qualities.

Probably one of the earliest attempts to create conditions more favorable for the crop involved the use of the plow for preparing the seed bed. Irrigation was also an early attempt to provide a more desirable environment for plant growth. Although use of commercial fertilizers as we know it is new, the use of natural fertilizer is not.

Today these basic improvements which have evolved are necessary for competitive crop production. But static ideas alone are not enough as each concept must be refined and improved toward more efficient production. Progress must, therefore, be continued at all levels within many interrelated disciplines.

Better fertilizers and herbicides are becoming available creating the demand for specialized distribution equipment. Hybrid plants are proving to be well worth the cost of expensive seed. The full potential of hybrid crops, however, cannot be obtained unless seed placement is precise and the environment created for the seed is ideal. The irrigation of a soil which was previously under a semi-arid condition may also require different tillage techniques as well as different equipment. It will, therefore, continue to be necessary to provide new implements which fill the need created by the advances in related fields.

The development of farm machinery is becoming more exact with each new model. As the cost of items such as fuel, seed, and fertilizer continue upward, the demand for precision is also certain to increase accordingly. If this challenge is to be met, it will be necessary to find methods of testing which eliminate or control certain parameters while others are allowed to vary by the desired amounts. This is usually relatively simple in the mechanical analysis of implement components. But the difficulties arise when one tries to evaluate the performance of the machine under varying field conditions.

As a result of field testing difficulties, laboratories are being used to a much greater extent. The soil bin has become a popular facility for much of the test and development work involving agricultural and construction equipment. Although far from perfect, when used properly this device permits the control of more variables than can be regulated in field tests.

PROBLEM

Problems involved in the preparation of soil samples with uniform, reproducible properties have not been completely solved. There are several solutions which seem to work fairly well in most applications but these still have limitations. Many of the more promising techniques utilize what is known as an artificial soil, however, this approach is not satisfactory for actual seed germination and emergence.

A natural soil would probably be the most desirable to use in studies which involve the effects of planters on early seedling growth. There is some information available on the preparation of uniform natural soil samples, but most of this is restricted to small containers of about flower pot size. In order to use actual planter components, it would be necessary to use larger samples through which full-sized planters could be pulled. At the same time, however, it would be quite beneficial if these samples could be removed in an undisturbed condition and placed in an environmental control chamber while the seeds are germinating. This would make it possible to study effects of soil types and different planter components under various conditions of temperature, humidity, and air flow over the surface of the soil.

OBJECTIVES

The objectives of this project were:

1. To devise soil sample boxes which met the following requirements:
   A. Accommodate field sized planter components without imposing boundary effects.
   B. Capable of being moved to an environmental control chamber for germination and emergence studies.
2. To develop techniques of soil preparation yielding bulk densities and moisture contents which are:
   A. Uniform within all areas of a sample box.
   B. Uniformly reproducible between sample boxes.

REVIEW OF LITERATURE

Theoretical Considerations

Yong and Warkentin (1966) described soils as being made up of constituents which exist in three physical states--solids, liquids and gases. The solid materials consist primarily of minerals along with varying amounts of organic material. The liquid phase is a solution of various salts in water. The gaseous phase is air, although not always with the same proportions of nitrogen, oxygen, and carbon dioxide as is normally found above ground.

The variability of these soil components causes a high degree of nonuniformity of physical properties and characteristics. In addition to the variation among constituents, one also finds some interaction between different phases. Therefore, what is true for one soil may not be true for another; it would probably not even be true for that same soil at different moisture contents.

Vanden Berg (1961) concluded that theories of elasticity were far more practical for highly compacted soils common to Civil Engineering than for tilled soils common to Agricultural Engineering. There is practically always a significant volume change when tilled soils are loaded making it impossible to use theories which assume no volume change. He also pointed out that soil strength changes with compaction while the strength of most other materials is fairly constant over a much wider range of stresses.

A general theory of rheology, presented by Gupta and Pandya (1966), "assumes similar processes of deformation can be produced in different materials by varying intensity of loading; its character; its rate of application; and the temperature, shape, and dimensions of the loaded body."

Rheology is defined by Yong and Warkentin (1966) as "the study of deformation-time characteristics of materials." One might then infer that the mechanical behavior of materials is determined by a few basic characteristics present in all materials, but which are combined in various ways.

The basic forms of deformation considered in most soils theory are elastic, viscous, and plastic. An ideal elastic deformation is about the same as one expects from a spring, i.e. it is linear to the applied stress and completely recoverable. Ideal viscous and plastic deformation are fully irrecoverable, similar to an isolated dash pot.

Gupta and Pandya (1966) described soil as a deformable body exhibiting non-linear visco-elastic behavior, possessing both of these deformation responses in varying degrees. Therefore, a soil would exhibit both viscous and elastic deformation according to the conditions at the time of loading.

Soils tend to creep under constant stress, and tend to allow a relaxation of stress when under a constant strain. Gupta and Pandya (1966) decided that compressive strain could be divided into an instantaneous strain, a transient or delayed-elastic strain, and a steady state creep strain. They also stated that "behavior of soil under static loading is characterized by moduli of instantaneous elasticity, plasticity, and fracture; delayed elasticity and retardation time; and flow constant and yield stress, as well as rate of strain at yield." It was concluded that the stress-strain-time relationship depends upon various physical constants including moisture content, air content, and the structural and mechanical composition of the soil.

Sample Size Considerations

There has been a good deal of laboratory research with regards to the effects of soil condition on germination and seedling emergence. But all of the studies reviewed involved samples which were flower pot size. In these cases it appeared that no attempt had been made to measure actual soil conditions and their consistency before tests were performed. Most apparently felt that as long as the preparation techniques were consistent the uniformity of samples would be sufficient for their purposes.

George Abernathy (1967), in a study of furrow openers, used larger soil samples. He started testing with natural soils, which were compacted with a baseplate and drop hammer. However, after encountering several difficulties, the natural soils were abandoned in favor of artificial soils consisting of sand, clay, and oil. These artificial soils did appear to work quite well for studying the forces on the furrow openers as well as for measuring the effects of the openers on the density of the soil.

For these tests the sample boxes were thirty-six inches long, twelve inches wide, and eight inches deep. Abernathy's only recommendation regarding this size was that a wider box might be desirable because of edge effects. As far as could be determined from the discussion, the other dimensions were satisfactory for their intended purpose.

Addition of Water to Soils

Abernathy attempted to increase moisture content by soaking the samples with water in a manner similar to furrow irrigation. Then the samples were air dried until ready for planting. Problems were encountered with this technique because of shrinking and swelling of the soil with changes in moisture content due to the presence of montmorillonite clay. He later tried using soils prepared to the desired moisture content prior to placement in the sample boxes and compacting with the drop hammer. However, he concluded that these remolded soils were weaker than the naturally prepared ones.

There seems to be at least two or three main satisfactory techniques for adding water to natural soils in the laboratory. These methods include spraying the water on thin layers of soil, mixing ground ice with the soil, and misting water into soil as it is being mixed. Each of these procedures has its advantages and disadvantages, as well as being more applicable in one case than in another.

After spraying water on thin layers of soil, Johnson and Henry (1964) sealed the soil containers and let them set overnight to allow the moisture to equilibrate. However, it is doubtful that enough moisture migration would occur to bring about uniform conditions within the sample in this amount of time. Morton and Buchele (1960), when using this approach, also screened the soil to break up clods which might have been formed. This would also tend to mix the soil further giving a more uniform distribution of moisture. The amount of soil to be handled would probably be an important factor in determining whether or not to use this approach. A small amount of soil could be easily sprayed in thin layers and then screened or mixed, but this could be time consuming for large volumes.

Mixing of crushed ice with the soil appears to be a promising solution to the problem, but again only under certain conditions. The primary requirement for using frozen water would, of course, be that the soil is maintained at a temperature below freezing until the ice is uniformly distributed. The soil-ice mixture can then be allowed to warm up. This process could also be time consuming, especially if it were necessary to obtain temperatures in the sixty to seventy degree Farenheit range for seed germination. On the other hand, if it were desired to add fairly large amounts of water to the soil, this could be the only way to keep from forming mud balls during mixing.

The final approach for adding water to soil was misting the water into the batch of soil as it was being mixed. An obvious method for applying this technique utilizes a cement mixer and some form of atomizer. This method appeared to be well suited for mixing larger batches of soil, depending upon the size of mixer available. Accurate control of moisture content did not seem likely, however, because it was necessary to make allowances for losses due to evaporation. These losses would be quite variable due to differences in atomizers, temperatures, and the nature of the soil itself.

Soil Compaction Methods

Soil compaction methods described in the literature included: (1) the application of pressure at the surface, (2) the use of a drop hammer device, (3) a system of dropping the container several times from heights of an inch or less, and (4) the use of vibration to induce settling. A smooth-drum roller has also been successfully used in laboratory soil bins as well as for some types of field compaction. The sheep's foot roller has been used in the field for several years as a common piece of soil compaction equipment. As with the methods of water application, each of these techniques were limited in application by the quantity of soil to be treated and by the final condition which was desired.

The use of surface pressure was popular among those working with crust formation and other emergence problems. Surface compaction was usually accomplished by using some type of hydraulic ram to apply the required forces, especially if high surface pressures were desired. Therefore, it appeared that surface pressure alone would be practical means of compaction only for small samples. Another characteristic of this method was the tendency toward higher densities in the surface region, making it better suited for studies where a region of localized compaction was desired. Where deep uniform samples are required, it would be necessary to compact in layers or lifts.

Some form of drop hammer has also found its place in several applications, as was mentioned briefly in an earlier part of this report. A drop hammer, as the name implies, is simply a weight with some type of base plate. The hammer is dropped from a given height several times thereby packing the soil. A deep sample would again require packing in layers to obtain the desired density and uniformity.

A kneading compactor was used in studies by Bodman and Constantin (1965). The objective of their work was to determine the effect of particle size distribution on the maximum bulk densities that could be produced. Measurements obtained in this study indicated that minimum bulk volumes were related to an ideal pattern resulting from the proportions of different size classes present. Maximum and minimum bulk volumes were created by using different moisture contents.

For bulk densities and water contents between maximum and minimum bulk volumes the following relationships were indicated:

$$y = a_o + a_1 x + a_2 x^2 + a_3 x^3$$

Where: y = dry bulk density
x = water content (gm water/gm solids)
a_o, a_1, a_2, a_3 are constants.

For maximum bulk density:

$$\frac{1}{y} = ax + b$$

Where: a = specific volume of water
b = specific particle volume of solids

For minimum bulk density:

$$y = ke^{cx}$$

Where: e = base of natural logarithms

It was noted that the values of b, k, and c varied slightly from one mix to another. No further explanation was given for k or c.

This paper also contained further theoretical analysis which tended to become quite involved. Only the simpler relationships were given here as a limited insight into the variability found in soil compaction.

The idea of dropping a container of granular material to pack the particles is certainly not new. However, a system was needed whereby a sample could be dropped from the same height and in a similar manner each time. Richard et al. (1965) developed such an instrument for compacting small core samples. Their device consisted of an eccentric which would lift and drop one end of the plate to which the sample was secured. It was driven by an electric motor at the rate of 180 times per minute. In addition to the dropping action, this core compactor had provisions for applying a constant spring load to the soil surface. This group also concluded that different bulk densities were best obtained by varying the moisture content.

Yaron et al. (1966) described a method for packing soil columns which they judged to be quite successful. Their technique essentially consisted of an auger operating in reverse to press the soil into the column as it filled. A downward force on the auger would cause pressure on the soil surface. It was stated that the density could be varied by adjusting the pressure on the soil surface if layers of different density were desired. The force on the auger was supplied by weights so that the pressure on the soil surface would not change as the auger moved upward with the filling of the column. The pressure could be varied by changing the amount of weight acting on the auger.

The final laboratory technique reviewed involved the use of vibration to induce settling or compaction. This method was used by Rosenberg (1959) for packing soil in fifty-five gallon drums. A measured weight of soil was used to get the desired bulk density at a certain depth. Densities obtained ranged from 1.05 to 1.95. Vibration was induced by a vibrator tube which consisted primarily of an internal rotor driven by a flexible shaft. The soil was packed by inserting the head of the vibrator into the middle of the barrel. The time required to reach the desired bulk density never exceeded five minutes.

Core samples taken from these drums after compaction, in all but one case, yielded uniformities which were equal to or better than those which had been undisturbed for eighteen years. A check was made to determine if any translocation of colloids had taken place. However, no significant differences were found when the soils were compared for clay content of the soil column as a whole, or when the A and B horizons were compared.

Rosenberg (1960) in another paper reports on the "vibro-compaction" of small greenhouse sized samples in a cast iron pot, nine and one-half inches in diameter by eight inches high. In this method the container was vibrated while weights were in place on top of the soil. These samples were compacted dry and then wet by allowing water to flow in from the bottom, followed by a two day period of draining to approximate field capacity. He concluded from these tests that the uniformity of the soil mass increases with increasing compaction.

Soil compaction must be performed for practically every large construction project. The most common types of packers used for this work are the sheep's foot packer and the roller packer. The sheep's foot packer is used to get a kneading effect on the soil. This effect produces a random orientation of the platelike clay particles. This type of orientation gives the soil the ability to better withstand lateral stresses, a necessary requirement for certain applications such as earthen dams. The degree of compaction obtained with this machine depends upon a number of variables including soil moisture content, weight in relation to the number and size of feet, the number of passes over the soil, and the thickness of each additional layer.

The roller packer would be used where a smooth surface is desired and the main concern is for surface compaction. Although it is usually thought of as a piece of construction equipment, smaller models have also been used in laboratory soil bins. Soil would have to be treated in layers if a fairly uniform, deep sample is desired, i.e. over six inches.

PROCEDURE AND EQUIPMENT

Sample Container

Before concrete plans could be laid for actual testing of compaction methods, it was necessary to decide upon sample box dimensions. To arrive at the final size, a number of factors were considered.

Depth of compacted soil was set between seven and eight inches based on the results of Abernathy's investigations. It was assumed that would allow for opener operation without boundary effects from the bottom. This should also provide ample room for root growth until emergence has taken place.

The depth of the sample box itself had to be considerably more than eight inches, however, due to the loose condition of the soil prior to compaction. A ten-inch deep trial container was built and found to be too shallow for the unpacked soil. After this failure, the bulk density of the loose soil was roughly determined. Using that value, the required depth was found to be about twelve inches, which proved to be satisfactory.

There were three primary considerations in determining the width of the sample. Abernathy's density distribution curves, in addition to his recommendation that the samples be wider than twelve inches, gave a minimum value. The maximum width was limited by the door width of the environmental control chamber. In allowing external clearance, it was necessary to account for the angle iron frame and the box wall thickness.

It was decided that the sample size should not be much wider than twelve inches due to weight considerations. Therefore, the internal width of the containers was set at fourteen and one-half inches.

After the width and depth of the sample box were determined, a length was chosen based on the weight of the sample and the length of usable furrow per sample. The length of usable furrow was important so that a number of seeds could be planted in each sample to help reduce random errors. A length of seventeen and one-half inches was finally chosen, which should allow roughly ten inches of length for planting.

The sample size of $17\frac{1}{2}$ x $14\frac{1}{2}$ x 7 inches deep contained slightly over one cubic foot by volume. This quantity of soil weighed about ninety-five pounds at a bulk density of 1.2 and a moisture content of 18 percent dry weight basis. The total weight for each sample, including frame and box, was approximately 125 pounds, which could be easily handled by two men.

The sample containers (shown in Plate I) were constructed so that the angle iron frame could be lifted from around the box. The ends of the boxes could then be removed and several boxes lined up end to end in a suitable frame, forming a small soil bin. (Plate II shows two of these boxes as an example.) The planter component or type being studied could then be pulled through this series of containers.

Upon completion of the tests, the boxes would be separated and the ends and frames replaced. The sample could then be moved to an environmental control chamber for germination or to another location for checking other characteristics such as compaction effects. This ability to remove samples from the main test apparatus will prevent the equipment from being tied up for long periods of time by one trial.

Preliminary Preparations

After the dimensions of the sample box had been chosen it was necessary

EXPLANATION OF PLATE I

Two sample boxes, before compaction on the left and after compaction on the right. (Rulers in inches.)

PLATE I

EXPLANATION OF PLATE II

Two prepared sample boxes with frames and ends removed as they would fit to make up the proposed soil bin. (Six inch ruler shown.)

PLATE II

to decide upon a soil for testing. It was desired to obtain a soil type common to a large area of the state of Kansas as well as one which was available near the campus. The further requirement that our sample be similar to soils found on one of the university experiment fields was also added. This would make it possible to check laboratory results with those produced in the field.

In checking with Dr. O. W. Bidwell and Dr. Guy E. Wilkinson of the Agronomy Department at Kansas State University two soils met the requirements. A Crete soil was selected since it is common to north central Kansas and is one of the main soils on the Irrigation Experiment Field near Scandia, Kansas. This soil was also available within twenty miles of the campus of Kansas State University.

The Crete soil used in these tests was silt loam obtained near Junction City, Kansas. Since the primary interest was for eventual use with planters, only soil from the top four inches was used. The sample was placed in air tight containers (surplus ammunition cases) to prevent moisture loss.

Before using the soil in any tests, it was sieved (two-tenths inch grid) to remove any rocks or large particles of organic matter. Although the soil structure was altered considerably by the screening, it was felt that a uniform soil particle size would eliminate variations caused by larger secondary particles.

The entire batch of soil, which amounted to about eight cubic feet, was then spread on a large sheet of plastic and thoroughly mixed. At this time the soil was weighed and slightly more than enough for one sample box was placed in each container. From here on, the small batch of soil in each container will be referred to as a sample. Subsamples were taken from each sample to obtain the moisture contents and to get a rough comparison of how well the entire lot had been mixed.

A small sample was also taken at this time for determination of field capacity and permanent wilting point moisture percentages. Field capacity, the point at which hydraulic conductivity approaches zero, was assumed to occur at a capillary potential of approximately one-third atmosphere. Permanent wilting point, which is that moisture content at which a plant wilts and does not recover, was assumed to be in the vicinity of a capillary potential equal to fifteen atmospheres (gage pressure 220 psi). Particle size distribution, a Procter density curve, Atterburg limits, and organic matter contents were also obtained and are given in Appendix A.

Moisture Control

Before each treatment, an effort was made to create standard soil conditions. Particle size and moisture content were the two main items of concern. Moisture loss was minimized by using the air tight containers between treatments. The soil was exposed during the actual testing. So there was some moisture loss, which varied depending upon temperature and humidity.

Moisture content was fairly well controlled by keeping a continuous record of the amount of change between tests and adding water accordingly. A procedure of misting water onto the soil as it was tumbling in a small cement mixer seemed to work adequately. A trial and error method was used to determine how much moisture to allow for evaporation and other losses. This technique, however, was limited to a range of moisture contents below twenty percent, dry weight basis, for the soil used.

Distilled water was used to prevent a build up of any materials contained in tap water which could effect the condition of the soil. The fine mist spray was obtained using an automotive solvent sprayer. A paint sprayer should also work just as well, or even better.

The mixer was just large enough to hold one sample at a time. Therefore, by letting it continue to operate for about ten minutes after the desired amount of water had been added, a good moisture distribution was obtained within the sample. However, the procedure of handling only one sample at a time did cause some problems with between samples moisture variation.

For moisture contents around 18 percent, dry weight basis, the tumbling action of the mixer did an adequate job of breaking up clods formed in the previous trial. However, as moisture contents increased to above 20 percent, the results were reversed and soil particles began to stick together forming small balls of soil. These balls increased in size rapidly as the moisture content was increased.

Soil Compaction

After the moisture had been added and the soil thoroughly mixed, a certain weight of soil was placed in the sample box. (See Plate I.) The box was then secured in position on the vibrator stand, as shown in Plate III. A sheet of three-quarter inch thick plywood was placed on the soil surface. A one-half inch thick steel plate, which was restrained so that it remained in a level plane but could move up and down as the soil volume changed, was placed over the plywood sheet. The desired amount of weight was then added

EXPLANATION OF PLATE III

Vibrator stand with a sample in place.

PLATE III

and a predetermined vibration applied.

The vibrator used for these tests was a "Vibrolater" 1000 Series, Model CCV3, produced by the Martin Engineering Company, Neponset, Illinois. (See Plate IV.) This unit consists primarily of an eccentric driven by a hydraulic motor. The rate of vibration, which is the same as the speed of the eccentric in revolutions per unit time, is therefore governed by the flow rate of hydraulic fluid passing through the motor.

A Continental "Polypac" (Model R-20) was used as the source of hydraulic power. (See Plate V.) This is a self-contained unit produced by Continental Hydraulics Division, Continental Machines Incorporated of Savage, Minnesota.

Flow rate to the vibrator motor was controlled by a pressure compensated flow control valve made by Racine Hydraulics and Machinery Incorporated, Racine, Wisconsin. This valve was mounted on the control panel of the power unit along with the electric switches. The vibration rate was regulated by adjusting the flow control valve. A "Strobotac" (type 1531-A) strobe light was used to monitor the rate of vibration.

The vibrator stand consisted of a steel platform set on two saw horses. A frame was constructed above the platform for restraining the plate horizontally on the soil surface. The vibrator itself was bolted to the underside of the platform. During compaction, the sample box was bolted to the top of the platform directly above the eccentric. (See Plates III and V.)

A steel weight box (shown in Plates III and V) was constructed which fit on top of the restrained plate. The combined weight of the plate and the steel box was approximately 138 pounds or the equivalent of slightly over five-tenths of a pound per square inch surface pressure. Tests

EXPLANATION OF PLATE IV

Vibrolator, inverted from its mounting position (scale in inches).

PLATE IV

EXPLANATION OF PLATE V

Compaction equipment: the vibrator stand (left), weight box (lower center), and hydraulic pump unit (right).

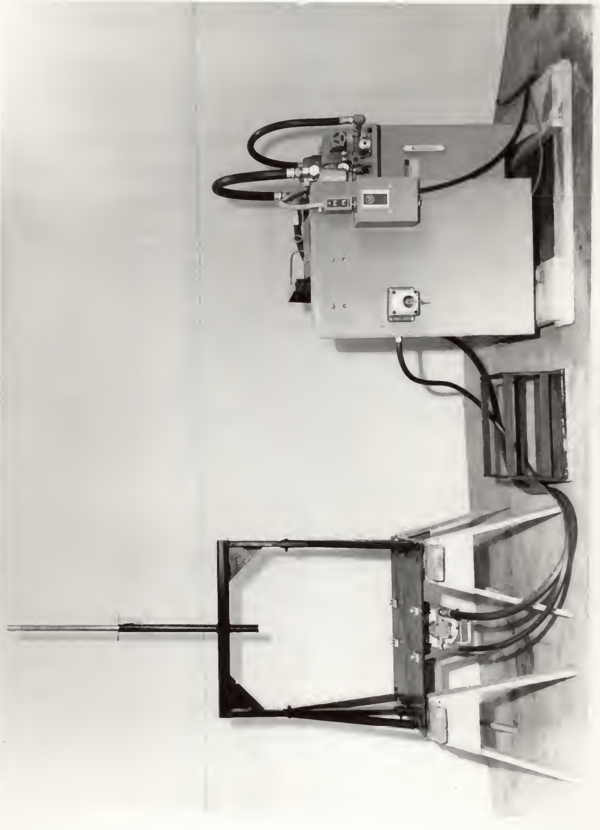

PLATE V

involving vibration were conducted at 1.6 and 2.2 pounds per square inch which required total weight of about 410 and 565 pounds respectively. Lead bars were added to the weight box to provide the required loading. (See Plate III.) After a sample had been vibrated it was set aside and covered with a sheet of plastic to retard evaporation until five replications of a test had been finished.

Two surface pressures (1.6 and 2.2 psi) were used at two different rates of vibration, 1600 and 2500 cycles per minute. Vibration time for these tests was five minutes. An additional test was conducted at 3200 cycles per minute for three minutes with 2.2 surface pressure. Moisture contents were about 18 percent (dry weight basis). It was originally planned to repeat the tests just described at about 22 percent moisture, but it was discovered that our methods of adding water to the samples were satisfactory only in the dryer ranges. Therefore, tests in the wetter ranges were abandoned. However, one set of data was taken at a moisture content of 20 percent to get an indication of variations due to moisture.

In addition to checking soil compaction by vibration, a foundry sand packer was also tested on a more limited basis. The sample is placed on a flat plate which is raised about one inch and then dropped. The source of power for this device is compressed air and the frequency was about 180 drops per minute. The time of application for each box was one minute with a surface load of about seventy pounds (0.2 - 0.3 psi). A reduced pressure and shorter time were used to obtain densities similar to those produced by the other tests.

One set of boxes was given this treatment for purposes of comparison, from the standpoint of both uniformity and the degree of compaction which could be obtained. The preliminary addition of water and tumbling in the cement mixer was carried out in the same manner as with other tests.

A table of tests performed and average densities obtained will be given in the summary.

Subsampling

After all samples had been compacted, subsamples were taken from each box to check moisture and uniformity of compaction. Subsamples were taken from six horizontal locations and at two depths from each location making a total of twelve from each sample box. The six locations were set up in two rows of three. A template was cut to insure that data was taken from nearly the same place in each sample. A one-inch diameter core was pulled from each location and one subsample taken from the top three inches along with one from the next three inches.

The core subsamples were obtained using a sampler of the author's own construction based on criteria set forth by Brown (1965). This device was cut from a length of one-inch electrical conduit. The wall of the conduit was tapered in to give a sharp cutting edge with a diameter slightly less than that of the inside of the conduit. Beginning about three inches back and moving away from the tapered end for about ten inches, one-half of the tube was cut away as shown in Plate VI. This left an opening for easy removal of the core by pushing the soil further into the sampler with a dowel rod until the entire length of the sample was in the cut away section.

The core was then rolled gently from the sampler onto a small holder for cutting the two subsamples. These were each placed in a sample can. When the twelve subsamples had been collected from each of the five samples, the cans and wet soil were weighed to the nearest one-hundredth of a gram.

EXPLANATION OF PLATE VI

Core sampler (foreground), sample holder, and a surface subsample divided from the core. (Marks on holder are three inches apart for dividing the core.)

PLATE VI

The cans were placed in an oven at about $100^{\circ}C$ for at least twelve hours. A ten-hour drying time was sufficient; however, since scales were not in the same laboratory as the oven it was decided to allow the two extra hours instead of making two hour spot checks. The cans of dry soil were weighed and the soil screened back into its respective sample. Tare weights of the empty cans were also obtained. All weighing was done on Mettler scales in the USDA Grain Research Laboratory which is located with the Agricultural Engineering Department.

These data were then used to calculate bulk densities and moisture contents. A Wang Calculator with card programmer was used to greatly reduce the calculation time. Since it was necessary to keep close account of moisture, calculations were performed prior to beginning the next series of tests. It would not have been necessary to calculate densities at that time. However, since the same items of data were used for moisture and density, the calculator was programmed to compute both.

Equations used for these calculations were:

$$\text{Percent Moisture} = \frac{(\text{Wet Weight} + \text{Can}) - (\text{Dry Weight} + \text{Can})}{(\text{Dry Weight} + \text{Can}) - \text{Tare Weight}}$$

$$\text{Bulk Density} = \frac{(\text{Dry Weight} + \text{Can}) - \text{Tare Weight}}{\text{Volume per Subsample}}$$

The volume of a three-inch long core obtained with the constructed sampler was 38.98 cubic centimeters. Since all weights were in grams, bulk densities were in grams per cubic centimeter.

RESULTS AND DISCUSSION

Statistical Analysis

An objective of this project was to develop a technique for preparing soil samples which were uniform both within the sample and among several replicated samples. Therefore, statistical analyses were performed which would give an indication of whether or not subsamples came from the same population. Each treatment was evaluated individually using bulk density and moisture content data. These analyses were performed on an IBM 360/50 digital computer using an n-way analysis of variance program.

The results of each test are presented and discussed in order to point out how well the objectives were accomplished. After the tests have been examined individually, the overall results will be compared. Tests are considered in the order that they were conducted.

By using a four-way analyses of variance, it was possible to compare values obtained from given locations within a sample box as well as to compare corresponding points between boxes. Three factors were necessary to define locations within the sample box while the fourth was used to designate the sample number itself. The locations factors were rows, columns, and depths. The fourth factor designated the replication and is abbreviated rep. in the table. Therefore, in this discussion rep. and sample mean the same thing. Columns and depths were also abbreviated as col. and dep. respectively.

The analysis of variance tables were presented with the calculated "F-Test" along with an indication of whether or not the value obtained from the "F-Test" was significant. The "F" values were taken from statistical tables in Fryer (1966) at an level of 0.05. These values were:

for 4 and 44 degrees of freedom F = 3.12
2 and 44 degrees of freedom F = 3.23
1 and 44 degrees of freedom F = 4.08

When significant differences were observed, a Least Significant Difference (LSD) test was used to determine which group or groups of data were statistically different. The computer program arranged the means of the major factors in ordered arrays and calculated an LSD value for each array. But the use of the LSD value is valid only after the analysis of variance test indicates that all means are not equal.

The means which were statistically equal according to the LSD test have been designated by a continuous line under those which were the same at the 5 percent level of rejection. Therefore one can tell quickly which means were statistically different and which were not. It should be noted that more than one group of statistically equal data can occur in an array and the groups may overlap as is noted in the density means for columns of Test I (Table 2, page 38).

No lines will be drawn and no LSD values listed when the entire array was accepted as showing no statistical difference by the analysis of variance table. In cases where none of the means were the same the LSD value will be given both as an indication that significant differences were found and as an indication of how significant these differences were.

Test I
(1600 cycles/minute, 5 minutes, 2.2 psi surface pressure)

Table 1. Analysis of Variance for Test I.

Bulk Density

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Test	Significant Difference
Rep	0.01228	4	0.00307	8.165	yes
Row	1.00011	1	1.00011	0.293	no
Col	0.00427	2	0.00214	5.691	yes
Row x Col	0.00050	2	0.00025	0.665	no
Dep	0.00096	1	0.00096	2.553	no
Row x Dep	0.00267	1	0.00267	7.101	yes
Col x Dep	0.00079	2	0.00039	1.037	no
Row x Col x Dep	0.00002	2	0.00001	0.027	no
Error	0.01656	44	0.00038		

Moisture Content

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Test	Significant Difference
Rep	7.76900	4	1.94225	345.99	yes
Row	0.00817	1	0.00817	1.46	no
Col	0.07900	2	0.03950	7.04	yes
Row x Col	0.00633	2	0.00317	.56	no
Dep	0.93750	1	0.93750	167.00	yes
Row x Dep	0.00417	1	0.00417	.74	no
Col x Dep	0.02100	2	0.01050	1.87	no
Row x Col x Dep	0.00433	2	0.00217	.39	no
Error	0.24700	44	0.00561		

Table 2. Ordered Arrays of Means for Test I.

Sample Means, Density — LSD = 0.019

Sample No.	4	2	5	3	1
Mean	1.080	<u>1.060</u>	<u>1.059</u>	<u>1.056</u>	1.035

Sample Means, Moisture — LSD = 0.06

Sample No.	3	4	2	5	1
Mean	19.57	19.33	19.23	19.03	18.51

Row Means, Density

Row No.	2	1
Mean	1.059	1.056

Row Means, Moisture

Row No.	2	1
Mean	19.15	19.12

Table 2. (cont.)

Col Means, Density LSD = 0.015				Col Means, Moisture LSD = 0.04			
Col No.	3	2	1	Col No.	1	2	3
Mean	1.066	1.061	1.046		19.17	19.15	19.08
Dep Means, Density				Dep Means, Moisture LSD = 0.03			
Dep No.	2	1		Dep No.	2	1	
Mean	1.062	1.054		Mean	19.26	19.01	

The Test I analysis of variance table for density indicated there were significant differences between samples, between columns, and an interaction effect between rows and depth. For moisture contents there was high significance between samples and between depths, while columns also indicated some differences.

The LSD of moisture means for columns separated column three from columns one and two. But it should be noted this separation is less than one-tenth of one percent from column one to column three. The ordered array of density means was reversed and indicated that column two could go with either one or three. Therefore, it could not be stated on the basis of this analysis that moisture was a factor in the column differences.

The differences with depth were certainly to be expected. It is only natural that more drying would have taken place in the surface layers of soil than in the subsoil. However, an unknown amount of this drying would have taken place after compaction and therefore the effect of moisture on depth compaction would be questionable. The increased density of lower layers was still expected because of the additional weight due to upper layers of soil, although in this case it was not statistically significant.

A significant interaction of density between rows and depths was also indicated. The computer program used did not give additional information on interaction and since that combination was not significant again, no further analysis was performed. As a result, these effects were attributed to random error or the treatment parameters.

As indicated in the between samples array and LSD for moisture, there was a significant difference between every sample box. This variation was not quite so bad for density values. However, due to the variable moisture data these same conditions were repeated in Test V with closer control over moisture.

The results in the later test were much more uniform. The lower degree of moisture variation was undoubtedly a factor in this improvement, although a lack of experience with the equipment may have also contributed to the results obtained in Test I.

Test II
(2250 cycles/minute, 5 minutes, 2.2 psi surface pressure)

Table 3. Analysis of Variance for Test II.

Bulk Density

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Test	Significant Difference
Rep	0.00512	4	0.00128	7.610	yes
Row	0.00001	1	0.00001	0.059	no
Col	0.00124	2	0.00062	3.670	?
Row x Col	0.00009	2	0.00005	0.294	no
Dep	0.00131	1	0.00131	7.790	yes
Row x Dep	0.00000	1	0.00000	0.000	no
Col x Dep	0.00009	2	0.00005	0.294	no
Row x Col x Dep	0.00004	2	0.00002	0.118	no
Error	0.00740	44	0.00017		

Moisture Content

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Test	Significant Difference
Rep	3.97833	4	0.99458	23.114	yes
Row	0.05400	1	0.05400	1.255	no
Col	0.09233	2	0.04617	1.073	no
Row x Col	0.14700	2	0.07350	1.708	no
Dep	0.41667	1	0.41667	9.683	yes
Row x Dep	0.01667	1	0.01667	0.387	no
Col x Dep	0.19233	2	0.09617	2.234	no
Row x Col x Dep	0.13233	2	0.06617	1.538	no
Error	1.89367	44	0.04303		

Table 4. Ordered Arrays of Means for Test II.

Sample Means, Density — LSD = 0.009

Sample No.	4	3	5	2	1
Mean	1.107	1.104	1.094	1.086	1.083

Sample Means, Moisture — LSD = 0.19

Sample No.	3	4	2	1	5
Mean	18.97	18.53	18.35	18.32	18.26

Row Means, Density

Row No.	2	1
Mean	1.095	1.095

Row Means, Moisture

Row No.	2	1
Mean	18.51	18.45

Table 4. (cont.)

Col Means, Density LSD = 0.006					Col Means, Moisture			
Col No.	2	3	1		Col. No.	2	1	3
Mean	1.101	1.094	1.090		Mean	18.53	18.48	18.44
Dep Means, Density LSD = 0.005					Dep Means, Moisture LSD = 0.12			
Dep No.	1	2			Dep. No.	2	1	
Mean	1.100	1.090			Mean	18.57	18.40	

The analysis of variance tables for Test II show some similarities with those of Test I. Although not as extreme, there were differences between samples for both moisture content and bulk density. This time the variation with depth was significant in each group of data. There is also a questionable column effect with density, but none with moisture.

The ordered arrays and LSD's do not correspond well enough to make definite statements as to whether or not between sample density differences could have been caused by moisture differences. There was only slight agreement between the divisions imposed by the least significant differences for density and moisture. Therefore, it was assumed on the basis of this analysis that some of the density differences could have been caused by factors other than moisture content.

The ordered array of density column means for Test I was three, two, one while for this test it was two, three, one; which would neither support nor deny a possibility of trends of column effects at this point. Moisture showed no column effects which supports our conclusion of Test I that density column effects were probably not due to moisture differences.

Depth effects for this Test were fairly representative of those observed throughout the study. In all tests except III there was a significant increase in the moisture content of the lower three inches. Even in that test, where the difference was not significant, the mean moisture content of the subsoil was slightly greater than the mean for the surface soils.

Test III
(2500 cycles/minute, 5 minutes, 2.2 psi surface pressure)

Table 5. Analysis of Variance for Test III

Bulk Density

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Test	Significant Difference
Rep	0.00663	4	0.00166	9.500	yes
Row	0.00014	1	0.00014	0.823	no
Col	0.00080	2	0.00040	2.290	no
Row x Col	0.00043	2	0.00022	1.294	no
Dep	0.00182	1	0.00182	10.700	yes
Row x Dep	0.00048	1	0.00048	2.746	no
Col x Dep	0.00063	2	0.00031	1.770	no
Row x Col x Dep	0.00100	2	0.00050	2.860	no
Error	0.07690	44	0.00017		

Moisture Content

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Test	Significant Difference
Rep	3.59900	4	0.89975	9.975	yes
Row	0.00000	1	0.00000	0.000	no
Col	0.00100	2	0.00050	0.624	no
Row x Col	0.09100	2	0.04550	0.504	no
Dep	0.15000	1	0.15000	1.663	no
Row x Dep	0.00600	1	0.00060	0.067	no
Col x Dep	0.01900	2	0.00950	0.105	no
Row x Col x Dep	0.04900	2	0.02450	0.272	no
Error	3.96900	44	0.09020		

Table 6. Ordered Arrays of Means for Test III.

Sample Means, Density — LSD = 0.010

Sample No.	4	2	5	3	1
Mean	1.110	1.107	1.107	1.102	1.081

Sample Means, Moisture — LSD = 0.25

Sample No.	5	4	2	3	1
Mean	18.85	18.84	18.79	18.62	18.20

Row Means, Density

Row No.	2	1
Mean	1.103	1.100

Row Means, Moisture

Row No.	2	1
Mean	18.66	18.66

Table 6. (cont.)

Col Means, Density				Col Means, Moisture			
Col No.	3	2	1	Col No.	2	3	1
Mean	1.104	1.104	1.100	Mean	18.67	18.66	18.66
Dep Means, Density LSD = 0.006				Dep Means, Moisture			
Dep No.	1	2		Dep No.	2	1	
Mean	1.107	1.100		Mean	18.71	18.61	

The analysis of variance tables for Test III indicated that for the first time the objective of uniformity within the sample had been attained, but differences between samples both in moisture and in bulk density were still indicated.

The performance of the LSD tests on the moisture and density sample box means revealed additional information. Samples two, three, four, and five (both moisture and density) could not be statistically divided at the 5 percent level of rejection as was used here.

In other words, the hypothesis, that "at a given depth, samples two, three, four, and five have uniform density and moisture," cannot be statistically rejected at the 5 percent level. This indicated that if moisture had been better controlled on sample one, density would probably have been uniform at a given depth both within the boxes and between the boxes.

This was a unique test as it was the only time that a significant difference was not found in moisture contents between depths. There was, however, a statistical difference in density between depths. A fact which further supported the theory that the weight of the upper soil layers contributed to the compaction of the lower layers.

Test IV
(3200 cycles/minute, 3 minutes, 2.2 psi surface pressure)

Table 7. Analysis of Variance for Test IV.

Bulk Density

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Test	Significant Difference
Rep	0.00401	4	0.00100	4.726	yes
Row	0.00254	1	0.00254	12.095	yes
Col	0.00836	2	0.00418	19.904	yes
Row x Col	0.00009	2	0.00005	0.238	no
Dep	0.00662	1	0.00662	31.524	yes
Row x Dep	0.00008	1	0.00009	0.381	no
Col x Dep	0.00193	2	0.00096	4.537	yes
Row x Col x Dep	0.00016	2	0.00008	0.381	no
Error	0.00931	44	0.00021		

Moisture Content

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Test	Significant Difference
Rep	1.62933	4	0.40733	7.071	yes
Row	0.02017	1	0.02017	0.350	no
Col	0.09100	2	0.04550	0.790	no
Row x Col	0.12233	2	0.06117	1.062	no
Dep	1.09350	1	1.09350	18.982	yes
Row x Dep	0.02817	1	0.02817	0.489	no
Col x Dep	0.04900	2	0.02450	0.425	no
Row x Col x Dep	0.18033	2	0.09017	1.565	no
Error	2.53467	44	0.05761		

Table 8. Ordered Arrays of Means for Test IV.

Sample Means, Density LSD = 0.013

Sample No.	4	3	2	1	5
Mean	1.110	1.101	1.100	1.095	1.085

Sample Means, Moisture LSD = 0.24

Sample No.	1	4	2	5	3
Mean	18.10	17.93	17.89	17.72	17.63

Row Means, Density LSD = 0.008

Row No.	2	1
Mean	1.105	1.092

Row Means, Moisture

Row No.	2	1
Mean	17.87	17.84

Table 8. (cont.)

Col Means, Density LSD = 0.010

Col No.	1	2	3
Mean	1.115	1.093	1.087

Col Means, Moisture

Col No.	1	3	2
Mean	17.89	17.88	17.80

Dep Means, Density LSD = 0.008

Dep No.	1	2
Mean	1.109	1.088

Dep Means, Moisture LSD = 0.15

Dep No.	2	1
Mean	17.99	17.72

Probably one's first reaction after looking at the analysis of variance table for Test IV would be to declare that the methods used in this particular treatment should be abandoned. Moisture contents were not unduly variable but densities varied quite erratically.

The statistical divisions for the density sample means seem to have no correlation with the divisions in the moisture sample means. For the first time there was a significant difference between rows in the density data. There was also a significant difference between columns, which indicated that column one was probably different from two and three. Surface densities were significantly greater than those of the subsoil and there was a marginally significant interaction between depths and columns.

At this point there just doesn't appear to be any reasonable explanation for this data except the technique used in this particular test. The equipment did not appear very stable at this frequency and the duration was shorter which may have contributed to the variation obtained. It would be safe to say that this treatment should not be recommended without a considerable amount of additional testing and probably some redesign of equipment.

Test V
(1600 cycles/minute, 5 minutes, 2.2 psi surface pressure)

Table 9. Analysis of Variance for Test V.

Bulk Density

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Test	Significant Difference
Rep	0.01058	4	0.00264	17.653	yes
Row	0.00017	1	0.00017	1.137	no
Col	0.00116	2	0.00058	3.878	?
Row x Col	0.00026	2	0.00013	0.869	no
Dep	0.00323	1	0.00323	21.599	yes
Row x Dep	0.00006	1	0.00006	0.401	no
Col x Dep	0.00002	2	0.00001	0.067	no
Row x Col x Dep	0.00043	2	0.00021	1.400	no
Error	0.00658	44	0.00141		

Moisture Content

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Test	Significant Difference
Rep	0.47267	4	0.11817	18.096	yes
Row	0.00417	1	0.00417	0.639	no
Col	0.00900	2	0.00450	0.689	no
Row x Col	0.02033	2	0.01017	1.557	no
Dep	0.30817	1	0.30817	47.193	yes
Row x Dep	0.02017	1	0.02017	3.089	no
Col x Dep	0.00633	2	0.00317	0.485	no
Row x Col x Dep	0.00033	2	0.00017	0.026	no
Error	0.28733	44	0.00653		

Table 10. Ordered Arrays of Means for Test V.

Sample Means, Density — LSD = 0.007

Sample No.	1	5	3	2	4
Mean	1.082	1.051	1.050	1.048	1.046

Sample Means, Moisture — LSD = 0.06

Sample No.	5	4	3	2	1
Mean	18.47	18.37	18.37	18.33	18.19

Row Means, Density

Row No.	1	2
Mean	1.057	1.054

Row Means, Moisture

Row No.	1	2
Mean	18.35	18.34

Table 10. (cont.)

Col Means, Density	LSD = 0.006			Col Means, Moisture			
Col No.	2	1	3	Col No.	3	1	2
Mean	1.062	1.053	1.052	Mean	18.36	18.34	18.33
Dep Means, Density	LSD = 0.005			Dep Means, Moisture	LSD = 0.04		
Dep No.	2	1		Dep No.	2	1	
Mean	1.063	1.048		Mean	18.42	18.27	

Test V had the usual significant differences between samples and between depths. In addition there was a rather marginal indication of differences between columns.

In this instance, moisture samples two, three, and four were statistically the same while all density samples except number one were the same. The fact that sample one had the lowest moisture content, but had the highest density, would seem to discount the theories of higher moisture (in this region) increasing compaction. But problems arose in adjusting the frequency of vibration on the first sample of the test which could have been the cause of error. Sample five had a statistically higher moisture content, and although density was not statistically different, it was the highest of the remaining four.

The possibility of significant column effects in the density data was the only bad feature of this test. Column differences were also noted in tests one and two. There was no similarity with the array of Test I. However, in this test and in Test II, column number two was possibility a little more dense than columns three or one. In both of these tests there was no statistical difference between columns one and three.

Since column two was in the center, where a large part of the soil initially fell from the cement mixer, it was possible that some compaction occurred while filling the box. One should again note that the level of significance was low compared to others observed.

There still does not seem to be obvious reasons for the variation in results between Tests I and V except for moisture control and additional experience with the equipment. This difference should indicate the need for very rigid standards and controls on methods for preparation of natural soil.

Test VI
(1600 cycles/minute, 5 minutes, 1.6 psi surface pressure)

Table 11. Analysis of Variance for Test VI.

Bulk Density

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Test	Significant Difference
Rep	0.00176	4	0.00044	1.657	no
Row	0.00001	1	0.00001	0.038	no
Col	0.00006	2	0.00003	0.113	no
Row x Col	0.00019	2	0.00010	0.377	no
Dep	0.01908	1	0.01908	71.877	yes
Row x Dep	0.00048	1	0.00048	1.808	no
Col x Dep	0.00044	2	0.00022	0.829	no
Row x Col x Dep	0.00010	2	0.00005	0.188	no
Error	0.01168	44	0.00026		

Moisture Content

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Test	Significant Difference
Rep	0.47900	4	0.11975	1.478	no
Row	0.02400	1	0.02400	0.296	no
Col	0.00433	2	0.00217	0.027	no
Row x Col	0.06300	2	0.03150	0.389	no
Dep	1.29067	1	1.29067	15.930	yes
Row x Dep	0.19267	1	0.19267	2.378	no
Col x Dep	0.25433	2	0.12717	1.569	no
Row x Col x Dep	0.23433	2	0.11717	1.446	no
Error	3.56500	44	0.08102		

Table 12. Ordered Arrays of Means for Test VI.

Sample Means, Density

Sample No.	5	4	2	1	3
Mean	1.027	1.022	1.014	1.013	1.013

Sample Means, Moisture

Sample No.	3	5	2	4	1
Mean	18.35	18.31	18.28	18.15	18.13

Row Means, Density

Row No.	1	2
Mean	1.018	1.017

Row Means, Moisture

Row No.	2	1
Mean	18.26	18.22

Table 12. (cont.)

Col Means, Density					Col Means, Moisture			
Col No.	1	3	2		Col No.	3	2	1
Mean	1.019	1.018	1.017		Mean	18.26	18.24	18.24
Dep Means, Density LSD = 0.009					Dep Means, Moisture LSD = 0.21			
Dep No.	2	1			Dep No.	2	1	
Mean	1.036	1.000			Mean	18.39	18.10	

Test VI produced the highest degree of uniformity of all treatments. This Test was the example hoped for in our objectives. It has no statistically significant differences in either moisture or density except those of depth. This depth effect amounts to a difference of about 3.6 percent or .036 gm/cu cm for density means.

Test VII
(2500 cycles/minute, 5 minutes, 1.6 psi surface pressure)

Table 13. Analysis of Variance for Test VII.

Bulk Density

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Test	Significant Difference
Rep	0.00608	4	0.00152	7.498	yes
Row	0.00000	1	0.00000	0.000	no
Col	0.00193	2	0.00096	4.735	yes
Row x Col	0.00021	2	0.00010	0.493	no
Dep	0.00131	1	0.00131	6.462	yes
Row x Dep	0.00006	1	0.00006	0.296	no
Col x Dep	0.00074	2	0.00037	1.825	no
Row x Col x Dep	0.00021	2	0.00010	0.493	no
Error	0.00892	44	0.00202		

Moisture Content

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Test	Significant Difference
Rep	1.88267	4	0.47067	76.892	yes
Row	0.00417	1	0.00417	0.681	no
Col	0.01633	2	0.00817	1.335	no
Row x Col	0.00633	2	0.00317	0.518	no
Dep	0.50417	1	0.50417	82.365	yes
Row x Dep	0.01350	1	0.01350	2.205	no
Col x Dep	0.02233	2	0.01117	1.825	no
Row x Col x Dep	0.00300	2	0.00150	0.245	no
Error	0.26933	44	0.00612		

Table 14. Ordered Arrays of Means for Test VII.

Sample Means, Density — LSD = 0.015

Sample No.	4	2	3	1	5
Mean	1.078	1.068	1.067	1.053	1.050

Sample Means, Moisture — LSD = 0.08

Sample No.	3	4	2	5	1
Mean	18.45	18.41	18.38	18.17	17.98

Row Means, Density

Row No.	1	2
Mean	1.063	1.063

Row Means, Moisture

Row No.	2	1
Mean	18.29	18.27

Table 14. (cont.)

Col Means, Density LSD = 0.012				Col Means, Moisture			
Col No.	1	2	3	Col No.	1	2	3
Mean	1.071	1.060	1.058	Mean	18.30	18.28	18.26
Dep Means, Density LSD = 0.009				**Dep Means, Moisture LSD = 0.05**			
Dep No.	2	1		Dep No.	2	1	
Mean	1.068	1.058		Mean	18.37	18.19	

Test VII would have had reasonably acceptable results if it had not been for the density differences between columns. There were differences between samples but these could be at least partially explained by moisture differences. And as usual the density and moisture of the lower three inches was greater than the surface three inches.

The LSD of moisture means for samples indicated that one and five were each from separate populations, but there were no significant differences between two, three, and four. The same test on the density data indicated no differences between samples two, three, and four. It also indicated no significant differences between one, two, and three; and no difference between one and five. As with some of the other tests, a certain amount of frequency adjusting was done during the treatment of sample one, which could account for it being more dense than sample five in spite of their relative moisture contents.

The density differences indicated between columns was not highly significant as can be seen from both the analysis of variance table and the LSD test. However, there was some difference and further testing should be performed if it were desired to use treatments similar to those followed in this Test.

Test VIII
Foundry Packer
(180 drops/minute, 1 minute, 0.3 psi surface pressure)

Table 15. Analysis of Variance for Test VIII.

Bulk Density

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Test	Significant Difference
Rep	0.01921	4	0.00480	23.286	yes
Row	0.00003	1	0.00003	0.145	no
Col	0.00247	2	0.00124	6.019	yes
Row x Col	0.00100	2	0.00050	2.427	no
Dep	0.01873	1	0.01873	90.922	yes
Row x Dep	0.00000	1	0.00000	0.000	no
Col x Dep	0.00016	2	0.00008	0.388	no
Row x Col x Dep	0.00027	2	0.00013	0.631	no
Error	0.00907	44	0.00206		

Moisture Content

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Test	Significant Difference
Rep	1.46167	4	0.36542	52.487	yes
Row	0.02817	1	0.02817	4.040	no
Col	0.00233	2	0.00117	0.168	no
Row x Col	0.02233	2	0.01117	1.600	no
Dep	0.40017	1	0.40017	62.344	yes
Row x Dep	0.01350	1	0.01350	1.939	no
Col x Dep	0.01233	2	0.00617	0.886	no
Row x Col x Dep	0.01900	2	0.00950	1.364	no
Error	0.30633	44	0.00696		

Table 16. Ordered Arrays of Means for Test VIII.

Sample Means, Density (LSD = 0.012)

Sample No.	4	5	2	1	3
Mean	1.131	1.129	1.101	1.098	1.086

Sample Means, Moisture (LSD = 0.07)

Sample No.	4	5	3	1	2
Mean	18.52	18.43	18.23	18.19	18.09

Row Means, Density

Row No.	1	2
Mean	1.110	1.108

Row Means, Moisture

Row No.	2	1
Mean	18.31	18.27

Table 16. (cont.)

Col Means, Density LSD = 0.009				Col Means, Moisture			
Col No.	1	2	3	Col No.	3	2	1
Mean	1.118	1.108	1.102	Mean	18.30	18.29	18.29

Dep Means, Density LSD = 0.007			Dep Means, Moisture LSD = 0.04		
Dep No.	2	1	Dep No.	2	1
Mean	1.127	1.091	Mean	18.37	18.21

The density analysis of variance tables for Test VIII indicated a situation similar to that of Test VII. Samples four and five could be more dense because of their higher moisture contents. But the relative densities of two and three are not as one would have expected from moisture content. The LSD tests indicated that the density of column one was probably not from the same population as columns two and three. This difference cannot be explained by moisture, either, although it should again be noted that there is not a great difference between averages. Further instances of fairly low significance might well show that the differences were due to random error.

Since this was the test performed on the foundry drop packer, there was no method of restraint to keep a level surface. It should also be mentioned that no other tests were performed on this device and a different surface pressure and different length of time might have given more consistent results. The frequency of drops was not readily varied on this particular packer, but could also be a factor.

Test IX
(2500 cycles/minute, 5 minutes, 2.2 psi surface pressure)

Table 17. Analysis of Variance for Test IX.

Bulk Density

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Test	Significant Difference
Rep	0.11522	4	0.02881	20.788	yes
Row	0.00013	1	0.00013	0.094	no
Col	0.00241	2	0.00121	0.873	no
Row x Col	0.00016	2	0.00008	0.058	no
Dep	0.04538	1	0.04538	32.744	yes
Row x Dep	0.00020	1	0.00020	0.144	no
Col x Dep	0.00108	2	0.00054	0.390	no
Row x Col x Dep	0.00133	2	0.00067	0.483	no
Error	0.06098	44	0.00138		

Moisture Content

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Test	Significant Difference
Rep	9.67833	4	2.41958	12.630	yes
Row	0.11267	1	0.00267	0.588	no
Col	0.11700	2	0.05850	0.306	no
Row x Col	0.03233	2	0.01617	0.084	no
Dep	13.44267	1	13.44267	70.167	yes
Row x Dep	0.00600	1	0.00600	0.031	no
Col x Dep	0.32233	2	0.16117	0.841	no
Row x Col x Dep	0.01900	2	0.00950	0.849	no
Error	8.42967	44	0.19158		

Table 18. Ordered Arrays of Means for Test IX.

Sample Means, Density — LSD = 0.016

Sample No.	1	2	4	5	3
Mean	1.283	1.236	1.187	1.183	1.163

Sample Means, Moisture — LSD = 0.11

Sample No.	1	2	5	4	3
Mean	20.99	20.43	20.23	20.03	19.82

Row Means, Density

Row No.	2	1
Mean	1.212	1.209

Row Means, Moisture

Row No.	2	1
Mean	20.34	20.26

Table 18. (cont.)

Col Means, Density				Col Means, Moisture			
Col No.	2	1	3	Col No.	2	1	3
Mean	1.217	1.213	1.202	Mean	20.36	20.29	20.26
Dep Means, Density LSD = 0.10				Dep Means, Moisture LSD = 0.07			
Dep No.	2	1		Dep No.	2	1	
Mean	1.238	1.183		Mean	20.77	19.83	

Test IX produced one of the most uniform sets of within samples data for both moisture and density. This was quite surprising as the soil began to form balls in the cement mixer as moisture contents reached the 20 percent range.

Water was added until balls began forming accounting for part of the large moisture variation observed in this Test. Then the sample was removed from the mixer, compacted, subsamples taken, and returned to the airtight containers. It was hoped that after setting overnight, more water could be added bringing the moisture contents nearer the 22 percent goal. But this did not work so plans for tests above 20 percent moisture content were shelved, at least for the immediate future.

One can see a fair correlation between moisture and density in the between sample means. The arrays follow the same order except for samples four and five which were not significantly different in density values.

On the basis of these data the procedures used appear to have possibilities for the existing conditions. The high uniformity within samples along with at least some indication that density differences are related to moisture content gave this Test a fairly promising look, in spite of the moisture variation between samples.

Summary

Several general trends were observed in the statistical analysis of the various tests. A comparison of within sample differences for all tests indicated better than anticipated moisture control. There was a significant difference between surface and subsoil water contents but this was expected. It had been hoped that the plastic covers over the boxes would be more effective than they were. But, as was noted earlier, most of this drying probably occurred after compaction and should not have affected the densities produced.

The density results for within sample variation were not as consistent over all tests as those for moisture content. However, only Test IV (3200 cycles/minute), was so variable that it would not be recommended for additional testing unless changes were made in the equipment. Test I also yielded some rather erratic results, but moisture differences were suspected. The same criteria was used again in Test V with good results.

Density data did show a definite trend toward higher densities in the subsoil layers. This additional compaction was assumed to have been caused by weight of the upper layers of soil. It does not seem that enough drying could have taken place before compaction to be significant as samples were compacted within fifteen minutes after being placed in the sample boxes. However, there was always a four-hour interval before the subsamples were taken. The samples were covered with a sheet of plywood during most of the time required for compaction. They were covered with a sheet of plastic between compaction and subsampling.

The most common problem in the within sample density data was column effects. There does not seem to be any trend toward higher densities at one end of the box or the other as all significant arrays show different orders. Since most of these differences are marginally significant, further replications might show these effects to be random errors.

There were three tests which produced no significant within sample variation other than depth effects. These were: Test III (2500 cycles/minute, 2.2 psi, 18% moisture), Test VI (1600 cycles/minute, 1.6 psi, 18% moisture), and Test IX (2500 cycles/minute, 2.2 psi, 20% moisture).

Differences between samples were the largest and most consistent except for the depth variations. Moisture variation between samples were present in all tests except VI. The LSD tests indicated that in some cases there was only one sample different, while in other instances two or three samples or groups of samples were different.

The variation of density between samples was in some ways quite disappointing, but on the other hand these results did indicate a need for such research. Many of the density differences appeared to be related to moisture content. Some, however, did not seem to correspond to moisture effects, especially those of Test IV. The bright spot of the whole project was the results of Test VI, in which the only significant variation of moisture or density was between depths. In spite of the fact that this was only one test, it would seem to indicate the importance of uniform moisture.

Some consideration should be given to the composite means of all tests. Although not proven statistically, the degree of compaction obtained in this study, appeared to be a function of surface pressure, frequency of vibration, and moisture content. There may have also been other factors which were not measured. The factors listed were expected to influence the final densities and appear to have produced the affects that one would have predicted as shown in Table 19.

Table 19. Ordered Array of Test Density Means

Test	Mean	Surface Pressure	Frequency	Moisture Contents
VI	1.018	1.6	1600	18.24
V	1.055	2.2	1600	18.35
I	1.058	2.2	1600	19.14
VII	1.063	1.6	2500	18.28
II	1.095	2.2	2250	18.48
IV	1.098	2.2	3200	17.86
III	1.101	2.2	2500	18.66
VIII (Foundary Packer)	1.109	0.3	180	18.29
IX	1.210	2.2	2500	20.30

According to the trends of these tests, higher surface pressures and higher frequencies of vibration should produce higher densities, if moisture contents do not vary. It might seem that Test III should not have been more dense than IV. But Test IV had a lower moisture content and a shorter time of vibration, either of which could account for the relative mean densities of the two tests.

CONCLUSIONS

Analyses of the data obtained in this study indicate the following conclusions:

1. A technique utilizing a cement mixer and an atomizer produced a statistically uniform moisture distribution within each batch (sample).

2. Mixing each sample individually makes it difficult to maintain uniform moisture contents between samples and between tests. A room in which temperature and humidity were more uniform might help eliminate this problem.

3. Uniform moisture contents are important prerequisites for obtaining statistically uniform soil densities.

4. Uniform moisture content, however, is not the only requirement for the production of uniform densities.

5. Statistically uniform soil samples can be obtained using certain combinations of surface pressure and rates of vibration, if moisture contents are closely controlled.

SUGGESTIONS FOR FUTURE RESEARCH

This study has indicated the importance of and a need for a better method of moisture control between samples. Once this variable is controlled, other soil parameters, such as shear strength and penetration resistance, should also be checked for uniformity. These could be an important factor in the study of both planter and tillage effects on soil conditions.

Other variations of surface pressure, rate of vibration, and moisture content (drier ranges) would certainly be in order to determine what degrees of compaction are obtainable. A means of creating hard pan conditions could be developed by compacting the subsoil to a high density. The topsoil could then be added and compacted to a lower density. These conditions might also be created by using a wetter subsoil and only one compaction.

If finances would permit, some form of nuclear device for measuring density is strongly recommended over mechanical analysis. The time required for weighing and drying subsamples, and the destructive nature of the test are the primary objections to the mechanical method. Nuclear measurements can also be quite precise with regard to location, while a core sample has to be large enough to allow for some errors in volume measurement.

While nuclear moisture measurements are not currently as precise as density measurements, the method should not be disregarded. Future developments will almost certainly make this technique acceptable for laboratory use.

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APPENDIX A

Soil Description

The soil used in this project was a crete silt loam (10% sand, 67% silt, 23% clay) as shown by the particle size distribution curve on the following page.

The organic matter content was 2.6 percent dry weight.

Field capacity for this soil was about 30% dry weight basis, and the permanent wilting point was about 12% dry weight basis.

The Atterburg limits for this soil were:

Liquid Limit (ASTM D423-66) ---------- 35.4%
Plastic Limit (ASTM D424-65) --------- 25.2%
Shrinkage Limit (ASTM D427-61) ------- 19.6%
Plastic Index (ASTM D424-65) --------- 10.2

Standard Procter Density (ASTM D698-66T) was 98.2 pcf at an optimum moisture (ASTM D698-66T) of 19.0%. (See Procter density curve page 69.)

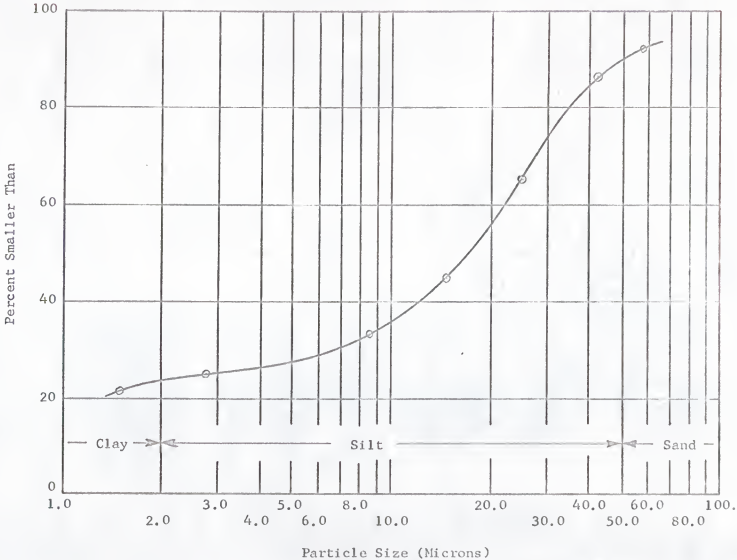

Fig. 1. Particle Size Distribution Curve For Crete Soil

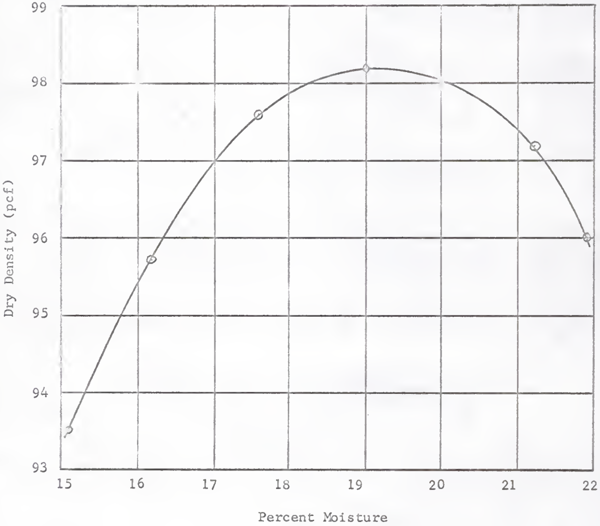

Fig. 2. Procter Density Curve

APPENDIX B

Laboratory Data

Table 20. Basic Laboratory Data

Test No. 1
Frequency of Vibrations: 1650 cycles/minute
Surface Pressure: 2.2 psi
Duration of Test: 5 minutes

Rep	Depth	Row	Col	Moisture Content (Dry basis percent)	Bulk Density (gm/cc)
1	1	1	1	18.3	1.02
			2	18.4	1.01
			3	18.3	1.02
		2	1	18.4	1.01
			2	18.6	1.00
			3	18.4	1.04
	2	1	1	18.6	1.03
			2	18.6	1.07
			3	18.5	1.10
		2	1	18.8	1.02
			2	18.6	1.05
			3	18.6	1.05
2	1	1	1	19.2	1.05
			2	19.2	1.07
			3	19.1	1.06
		2	1	19.0	1.07
			2	19.1	1.09
			3	19.0	1.09
	2	1	1	19.4	1.07
			2	19.4	1.03
			3	19.3	1.07
		2	1	19.4	1.01
			2	19.4	1.07
			3	19.3	1.04
3	1	1	1	19.5	1.02
			2	19.4	1.04
			3	19.5	1.06
		2	1	19.5	1.05
			2	19.5	1.07
			3	19.5	1.09
	2	1	1	19.6	1.06
			2	19.7	1.09
			3	19.6	1.04
		2	1	19.7	1.03
			2	19.7	1.06
			3	19.7	1.06

Table 20. (cont.)

Test No. 1 (cont.)

Rep	Depth	Row	Col	Moisture Content (Dry basis percent)	Bulk Density (gm/cc)
4	1	1	1	19.2	1.06
			2	19.2	1.06
			3	19.2	1.06
		2	1	19.2	1.05
			2	19.1	1.08
			3	19.2	1.10
	2	1	1	19.6	1.08
			2	19.5	1.10
			3	19.4	1.10
		2	1	19.5	1.08
			2	19.5	1.09
			3	19.4	1.10
5	1	1	1	19.0	1.05
			2	18.9	1.04
			3	18.7	1.07
		2	1	18.9	1.06
			2	18.9	1.06
			3	18.9	1.07
	2	1	1	19.3	1.05
			2	19.1	1.08
			3	19.0	1.04
		2	1	19.3	1.06
			2	19.2	1.06
			3	19.1	1.07

Table 20. (cont.)

Test No. 2
Frequency of Vibration: 2250 cycles/minute
Surface Pressure: 2.2 psi
Duration of Test: 5 minutes

Rep	Depth	Row	Col	Moisture Content (Dry basis percent)	Bulk Density (gm/cc)
1	1	1	1	18.2	1.08
			2	18.3	1.07
			3	18.2	1.08
		2	1	18.2	1.09
			2	18.3	1.10
			3	18.1	1.08
	2	1	1	18.4	1.08
			2	18.5	1.09
			3	18.4	1.09
		2	1	18.4	1.06
			2	18.4	1.08
			3	18.4	1.10
2	1	1	1	18.4	1.09
			2	18.4	1.11
			3	17.3	1.10
		2	1	18.4	1.08
			2	18.3	1.09
			3	18.3	1.09
	2	1	1	18.5	1.08
			2	18.6	1.09
			3	18.5	1.07
		2	1	18.5	1.07
			2	18.5	1.09
			3	18.5	1.08
3	1	1	1	18.8	1.14
			2	19.2	1.10
			3	18.8	1.12
		2	1	18.9	1.12
			2	18.8	1.10
			3	18.8	1.11
	2	1	1	18.9	1.10
			2	19.0	1.09
			3	19.0	1.10
		2	1	19.4	1.08
			2	19.0	1.10
			3	19.0	1.09

Table 20. (cont.)

Test No. 2 (cont.)

Rep	Depth	Row	Col	Moisture Content (Dry basis percent)	Bulk Density (gm/cc)
4	1	1	1	18.6	1.10
			2	18.5	1.12
			3	18.5	1.11
		2	1	18.5	1.10
			2	18.6	1.11
			3	18.5	1.12
	2	1	1	17.6	1.09
			2	18.7	1.10
			3	18.7	1.10
		2	1	18.7	1.11
			2	18.7	1.12
			3	18.7	1.10
5	1	1	1	18.2	1.07
			2	18.2	1.11
			3	18.2	1.09
		2	1	18.3	1.09
			2	18.1	1.13
			3	18.1	1.09
	2	1	1	18.3	1.08
			2	18.3	1.11
			3	18.4	1.08
		2	1	18.3	1.09
			2	18.3	1.11
			3	18.4	1.08

Table 20. (cont.)

Test No. 3
Frequency of Vibration: 2500 cycles/minute
Surface Pressure: 2.2 psi
Duration of Test: 5 minutes

Rep	Depth	Row	Col	Moisture Content (Dry basis percent)	Bulk Density (gm/cc)
1	1	1	1	18.1	1.09
			2	18.1	1.07
			3	17.9	1.09
		2	1	18.7	1.05
			2	18.1	1.08
			3	18.2	1.10
	2	1	1	18.2	1.06
			2	18.5	1.08
			3	18.2	1.10
		2	1	18.0	1.08
			2	18.0	1.09
			3	18.4	1.08
2	1	1	1	18.5	1.13
			2	18.8	1.10
			3	18.8	1.11
		2	1	18.7	1.12
			2	18.8	1.12
			3	18.8	1.11
	2	1	1	18.7	1.08
			2	19.0	1.09
			3	18.6	1.10
		2	1	18.9	1.10
			2	18.9	1.11
			3	19.0	1.11
3	1	1	1	18.7	1.11
			2	18.7	1.11
			3	17.5	1.10
		2	1	18.5	1.09
			2	18.6	1.13
			3	18.6	1.13
	2	1	1	18.9	1.07
			2	18.9	1.08
			3	18.7	1.09
		2	1	18.7	1.09
			2	18.9	1.12
			3	18.7	1.10

Table 20. (cont.)

Test No. 3 (cont.)

Rep	Depth	Row	Col	Moisture Content (Dry basis percent)	Bulk Density (gm/cc)
4	1	1	1	18.9	1.13
			2	18.7	1.13
			3	18.8	1.11
		2	1	18.8	1.10
			2	18.6	1.08
			3	18.8	1.11
	2	1	1	19.0	1.09
			2	19.0	1.12
			3	18.9	1.12
		2	1	18.9	1.10
			2	18.8	1.11
			3	18.9	1.12
5	1	1	1	18.6	1.12
			2	18.8	1.11
			3	20.1	1.11
		2	1	18.7	1.12
			2	18.7	1.13
			3	18.7	1.11
	2	1	1	18.7	1.10
			2	18.7	1.10
			3	18.8	1.09
		2	1	18.9	1.09
			2	18.7	1.11
			3	18.8	1.09

Table 20. (cont.)

Test No. 4
Frequency of Vibration: 3200 cycles/minute
Surface Pressure: 2.2 psi
Duration of Test: 3 minutes

Rep	Depth	Row	Col	Moisture Content (Dry basis percent)	Bulk Density (gm/cc)
1	1	1	1	18.0	1.14
			2	18.0	1.08
			3	18.0	1.07
		2	1	17.6	1.14
			2	18.0	1.12
			3	18.0	1.08
	2	1	1	18.1	1.09
			2	18.1	1.08
			3	19.1	1.08
		2	1	18.1	1.11
			2	18.1	1.08
			3	18.1	1.07
2	1	1	1	17.9	1.15
			2	17.8	1.08
			3	17.8	1.07
		2	1	17.8	1.14
			2	17.8	1.12
			3	17.8	1.10
	2	1	1	17.9	1.10
			2	18.0	1.08
			3	17.9	1.06
		2	1	18.0	1.10
			2	18.0	1.10
			3	18.0	1.10
3	1	1	1	17.6	1.11
			2	17.5	1.10
			3	17.5	1.09
		2	1	17.7	1.14
			2	17.6	1.11
			3	17.4	1.12
	2	1	1	17.7	1.08
			2	17.8	1.09
			3	17.7	1.08
		2	1	17.7	1.12
			2	17.7	1.08
			3	17.7	1.09

Table 20. (cont.)

Test No. 4 (cont.)

Rep	Depth	Row	Col	Moisture Content (Dry basis percent)	Bulk Density (gm/cc)
4	1	1	1	17.9	1.15
			2	17.8	1.11
			3	17.9	1.12
		2	1	17.9	1.16
			2	17.7	1.10
			3	17.8	1.09
	2	1	1	18.0	1.10
			2	18.0	1.08
			3	17.9	1.08
		2	1	18.2	1.12
			2	18.1	1.12
			3	18.0	1.09
5	1	1	1	17.7	1.09
			2	16.4	1.08
			3	17.4	1.11
		2	1	17.8	1.11
			2	17.8	1.09
			3	17.7	1.09
	2	1	1	17.8	1.07
			2	17.9	1.07
			3	18.0	1.06
		2	1	18.3	1.07
			2	17.9	1.09
			3	17.9	1.09

Table 20. (cont.)

Test No. 5
Frequency of Vibration: 1600 cycles/minute
Surface Pressure: 2.2 psi
Duration of Test: 5 minutes

Rep	Depth	Row	Col	Moisture Content (Dry basis percent)	Bulk Density (gm/cc)
1	1	1	1	18.1	1.07
			2	18.1	1.07
			3	18.1	1.07
		2	1	18.1	1.08
			2	18.1	1.10
			3	18.0	1.08
	2	1	1	18.3	1.07
			2	18.3	1.09
			3	18.3	1.08
		2	1	18.3	1.09
			2	18.3	1.11
			3	18.3	1.07
2	1	1	1	18.3	1.04
			2	18.3	1.03
			3	18.3	1.05
		2	1	18.3	1.02
			2	18.2	1.04
			3	18.2	1.04
	2	1	1	18.4	1.06
			2	18.4	1.07
			3	18.5	1.06
		2	1	18.4	1.06
			2	18.4	1.06
			3	18.3	1.05
3	1	1	1	18.3	1.04
			2	18.4	1.05
			3	18.3	1.04
		2	1	18.2	1.04
			2	18.3	1.03
			3	18.3	1.04
	2	1	1	18.5	1.06
			2	18.4	1.09
			3	18.5	1.05
		2	1	18.4	1.05
			2	18.4	1.05
			3	18.4	1.06

Table 20. (cont.)

Test No. 5 (cont.)

Rep	Depth	Row	Col	Moisture Content (Dry basis percent)	Bulk Density (gm/cc)
4	1	1	1	18.2	1.06
			2	18.3	1.05
			3	18.3	1.04
		2	1	18.3	1.03
			2	18.3	1.05
			3	18.3	1.03
	2	1	1	18.3	1.05
			2	18.3	1.05
			3	18.4	1.06
		2	1	18.7	1.05
			2	18.4	1.04
			3	18.6	1.04
5	1	1	1	18.4	1.03
			2	18.4	1.05
			3	18.7	1.04
		2	1	18.4	1.04
			2	18.3	1.08
			3	18.4	1.01
	2	1	1	18.5	1.06
			2	18.5	1.06
			3	18.5	1.07
		2	1	18.5	1.06
			2	18.5	1.06
			3	18.5	1.05

Table 20. (cont.)

Test No. 6
Frequency of Vibration: 1600 cycles/minute
Surface Pressure: 1.6 psi
Duration of Test: 5 minutes

Rep	Depth	Row	Col	Moisture Content (Dry basis percent)	Bulk Density (gm/cc)
1	1	1	1	17.6	1.02
			2	18.0	1.00
			3	18.1	.98
		2	1	18.1	.99
			2	18.1	.97
			3	18.0	.99
	2	1	1	18.2	1.02
			2	18.2	1.04
			3	18.3	1.03
		2	1	18.3	1.05
			2	18.3	1.04
			3	18.3	1.03
2	1	1	1	18.1	1.01
			2	18.2	1.00
			3	18.2	1.01
		2	1	18.2	.97
			2	18.2	1.00
			3	16.8	.98
	2	1	1	18.2	1.05
			2	18.3	1.05
			3	18.3	1.04
		2	1	18.8	1.02
			2	18.3	1.03
			3	19.8	1.01
3	1	1	1	18.3	.98
			2	18.3	.99
			3	18.2	1.08
		2	1	18.3	1.01
			2	18.2	.98
			3	18.3	1.01
	2	1	1	18.4	1.03
			2	18.4	1.02
			3	18.5	1.03
		2	1	18.4	1.02
			2	18.4	1.04
			3	18.5	1.05

Table 20. (cont.)

Test No. 6 (cont.)

Rep	Depth	Row	Col	Moisture Content (Dry basis percent)	Bulk Density (gm/cc)
4	1	1	1	18.1	1.02
			2	18.2	1.01
			3	18.1	1.01
		2	1	18.0	1.01
			2	18.0	.99
			3	18.0	.97
	2	1	1	18.2	1.03
			2	18.3	1.03
			3	18.2	1.04
		2	1	18.3	1.05
			2	18.2	1.04
			3	18.2	1.06
5	1	1	1	18.2	.99
			2	18.2	.99
			3	18.2	1.04
		2	1	18.2	1.04
			2	18.2	1.02
			3	18.3	1.02
	2	1	1	18.4	1.03
			2	18.4	1.03
			3	18.4	1.03
		2	1	18.4	1.04
			2	18.4	1.06
			3	18.4	1.03

Table 20. (cont.)

Test No. 7
Frequency of Vibration: 2500 cycles/minute
Surface Pressure: 1.6 psi
Duration of Test: 5 minutes

Rep	Depth	Row	Col	Moisture Content (Dry basis percent)	Bulk Density (gm/cc)
1	1	1	1	17.9	1.03
			2	17.9	1.03
			3	17.9	1.05
		2	1	17.9	1.07
			2	17.9	1.06
			3	17.8	1.01
	2	1	1	18.1	1.06
			2	18.0	1.06
			3	18.1	1.06
		2	1	18.1	1.09
			2	18.1	1.06
			3	18.1	1.06
2	1	1	1	18.4	1.08
			2	18.3	1.07
			3	18.2	1.05
		2	1	18.3	1.08
			2	18.4	1.05
			3	18.3	1.06
	2	1	1	18.4	1.08
			2	18.5	1.08
			3	18.4	1.06
		2	1	18.5	1.07
			2	18.4	1.06
			3	18.5	1.07
3	1	1	1	18.3	1.09
			2	18.4	1.05
			3	18.3	1.06
		2	1	18.3	1.09
			2	18.4	1.07
			3	18.4	1.04
	2	1	1	18.6	1.06
			2	18.5	1.08
			3	18.5	1.07
		2	1	18.5	1.08
			2	18.6	1.05
			3	18.6	1.06

Table 20. (cont.)

Test No. 7 (cont.)

Rep	Depth	Row	Col	Moisture Content (Dry basis percent)	Bulk Density (gm/cc)
4	1	1	1	18.3	1.10
			2	18.3	1.07
			3	18.3	1.07
		2	1	18.3	1.08
			2	18.3	1.06
			3	18.3	1.06
	2	1	1	18.5	1.10
			2	18.4	1.06
			3	18.4	1.09
		2	1	18.9	1.06
			2	18.4	1.10
			3	18.5	1.08
5	1	1	1	18.1	1.03
			2	18.2	1.04
			3	18.1	1.04
		2	1	18.1	1.06
			2	18.0	1.04
			3	18.0	1.06
	2	1	1	18.3	1.06
			2	18.3	1.05
			3	18.2	1.06
		2	1	18.2	1.05
			2	18.2	1.05
			3	18.3	1.06

Table 20. (cont.)

Test No. 8
Foundry Packer: 180 drops/minute from 1 inch height
Surface Pressure:
Duration of Test: 1 minute

Rep	Depth	Row	Col	Moisture Content (Dry basis percent)	Bulk Density (gm/cc)
1	1	1	1	18.0	1.06
			2	18.1	1.11
			3	18.0	1.06
		2	1	18.2	1.08
			2	18.2	1.11
			3	18.1	1.08
	2	1	1	18.2	1.14
			2	18.2	1.11
			3	18.2	1.11
		2	1	18.2	1.12
			2	18.6	1.09
			3	18.3	1.11
2	1	1	1	17.9	1.11
			2	17.9	1.09
			3	17.9	1.05
		2	1	18.1	1.10
			2	17.9	1.07
			3	18.1	1.08
	2	1	1	18.3	1.13
			2	18.2	1.11
			3	18.2	1.10
		2	1	18.2	1.13
			2	18.1	1.13
			3	18.3	1.11
3	1	1	1	18.2	1.08
			2	18.1	1.07
			3	18.1	1.06
		2	1	18.1	1.08
			2	18.2	1.06
			3	18.2	1.08
	2	1	1	18.3	1.11
			2	18.3	1.10
			3	18.4	1.09
		2	1	18.2	1.12
			2	18.3	1.09
			3	18.4	1.09

Table 20. (cont.)

Test No. 8 (cont.)

Rep	Depth	Row	Col	Moisture Content (Dry basis percent)	Bulk Density (gm/cc)
4	1	1	1	18.5	1.14
			2	18.4	1.12
			3	18.4	1.10
		2	1	18.4	1.12
			2	18.5	1.09
			3	18.5	1.10
	2	1	1	18.6	1.17
			2	18.5	1.14
			3	18.7	1.13
		2	1	18.5	1.16
			2	18.6	1.15
			3	18.6	1.15
5	1	1	1	18.4	1.12
			2	18.4	1.10
			3	18.3	1.11
		2	1	18.4	1.09
			2	18.4	1.10
			3	18.4	1.12
	2	1	1	18.5	1.14
			2	18.4	1.17
			3	18.5	1.16
		2	1	18.5	1.15
			2	18.5	1.14
			3	18.4	1.15

Table 20. (cont.)

Test No. 9
Frequency of Vibration: 2500 cycles/minute
Surface Pressure: 2.2 psi
Duration of Test: 5 minutes

Rep	Depth	Row	Col	Moisture Content (Dry basis percent)	Bulk Density (gm/cc)
1	1	1	1	20.2	1.24
			2	20.1	1.26
			3	19.0	1.13
		2	1	20.6	1.27
			2	20.3	1.25
			3	19.7	1.20
	2	1	1	21.4	1.31
			2	22.2	1.36
			3	22.3	1.32
		2	1	21.7	1.35
			2	22.1	1.37
			3	22.3	1.34
2	1	1	1	20.4	1.25
			2	20.4	1.22
			3	20.4	1.24
		2	1	20.4	1.24
			2	20.4	1.24
			3	20.3	1.24
	2	1	1	20.5	1.25
			2	20.5	1.20
			3	20.4	1.22
		2	1	20.5	1.24
			2	20.5	1.24
			3	20.5	1.25
3	1	1	1	19.3	1.13
			2	19.4	1.15
			3	19.3	1.11
		2	1	19.3	1.16
			2	19.5	1.16
			3	19.4	1.16
	2	1	1	20.1	1.17
			2	20.2	1.17
			3	20.3	1.20
		2	1	20.2	1.20
			2	20.4	1.19
			3	20.4	1.15

Table 20. (cont.)

Test No. 9 (cont.)

Rep	Depth	Row	Col	Moisture Content (Dry basis percent)	Bulk Density (gm/cc)
4	1	1	1	19.3	1.17
			2	19.5	1.17
			3	19.5	1.15
		2	1	19.5	1.08
			2	19.5	1.13
			3	19.3	1.13
	2	1	1	20.6	1.27
			2	20.7	1.26
			3	20.7	1.25
		2	1	20.6	1.23
			2	20.6	1.20
			3	20.6	1.20
5	1	1	1	19.9	1.15
			2	20.0	1.17
			3	19.9	1.15
		2	1	19.9	1.19
			2	20.1	1.17
			3	20.0	1.17
	2	1	1	20.4	1.17
			2	20.4	1.21
			3	20.4	1.21
		2	1	20.9	1.18
			2	20.4	1.21
			3	20.4	1.21

PROCESSING AND VIBRATORY COMPACTION OF NATURAL SOILS FOR LABORATORY PLANTER RESEARCH

by

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As the development of agricultural equipment becomes more precise, it is no longer practical to overlook the many soil and environmental variables which cannot be controlled in field research. Therefore, more work must be done in the laboratory where some of these variables can be controlled. Use of the laboratory can also eliminate some of the seasonal nature of agricultural equipment research or at least point up promising trends which would lead to more efficient utilization of time spent in the field.

Laboratory soil bins show promise as a tool for year round tillage and planter research. However, preparation of natural soil for various types of tests has proven to be a real problem. The objectives of this study were therefore: To design soil sample boxes large enough to accommodate field sized planter components, yet small enough to be moved to an environmental control chamber; and to develop procedures for preparing the soil in these boxes for uniform reproducible soil bulk density and moisture content.

Based on predetermined requirements and recommendations in the literature, a sample size of 14" x 18" x 7" deep was selected. Sample boxes were designed so that ends could be removed. This would permit several boxes to be lined up end to end forming a small soil bin. After the desired planter test had been completed, the samples could be moved to an environmental control chamber for germination and emergence.

Moisture was controlled in the silt loam soil by a procedure involving the use of an atomizer and a cement mixer. The tumbling action of the mixer also helped to maintain fairly uniform aggregate size as long as moisture contents were around 18 percent dry weight basis. This technique was found to be unsatisfactory for testing near or above 20 percent as mud balls began to form in the cement mixer.

Compaction was obtained by a combination of surface pressure and vibration applied to the frame of the sample box. Surface loading, frequency of vibration, and moisture content were varied individually to determine their effects on the measured values.

Experimental data consisting of moisture contents and bulk densities were obtained from six horizontal locations in each prepared sample box. A subsample was taken from the surface three inches and another from the next three inches of depth at each horizontal location. Subsample data from the five sample boxes (or replications) of each treatment were then compiled according to their respective sample and location within the sample. This made it possible to evaluate the data for possible differences either between certain areas within the samples or between samples themselves.

Statistical analysis of variance and least significant difference methods were used to study the results of each treatment. Among the trends noted in these investigations was a much lower than expected variation of bulk densities within samples for most tests. This was probably the result of a correspondingly low variation of within sample moisture contents. However, there were indications that with certain combinations of frequency and surface pressure, uniform densities could not be produced even if moisture was uniformly distributed within the sample.

There were bulk density and moisture differences between samples in all but one treatment. In this instance neither of the above parameters varied appreciably. In most, but not all of the other cases differences in bulk density were small and corresponded with differences in moisture content.

It was concluded that, if moisture contents are closely controlled, certain combinations of surface pressure and rate of vibration will produce statistically uniform compaction both within and between replicate samples.

certain combinations of surface pressure and rate of vibration will produce statistically uniform compaction both within and between replicate samples.