DISTRIBUTED SOIL DISPLACEMENT AND PRESSURE ASSOCIATED WITH SURFACE LOADING

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ABSTRACT

Soil compaction is an inevitable result of agricultural practices. It alters physical properties of soil and tends to be undesirable as it adversely affects water and nutrient penetration. Furthermore, additional energy is spent to till the soil. Although a tremendous amount of research has been conducted in the area of soil compaction, the focus has been primarily on surface soil displacement. Realizing that the observed soil displacement is the cumulative effect from the compaction of subsurface layers, this research discusses the displacement and distributed pressure through the soil from a surface load. A given volume of soil of known density and moisture content was loaded at the surface with a slowly applied force using an Instron® testing machine. The distribution of the pressure and displacement profile from the surface to depth was measured to provide insight into the formation of the subsurface soil structures. The nonlinear exponential decay of the soil displacement (compaction) from the surface to a given depth converges to zero at the location of a hard, compact layer or a point where no soil movement occurs, regardless of the initial soil compaction. By increasing soil moisture content and decreasing soil bulk density, the vertical soil displacement increased at the surface and within the soil profile, and the pressure distribution decreased with depth. Changing the shape of loading surface had minimal effect on soil displacement.

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LIST OF SYMBOLS

Symbol	Definition	Units
A	Area of loading surface	m^2
A_c	Theoretical vertical soil displacement at surface	m
B	Exponential decay constant	m^{-1}
Bd	Soil bulk density (dry basis)	kg m^{-3}
b	Smallest dimension of the loading surface	m
C_v	Cumulative vertical soil displacement at depth di	m
$c_1 – c_4$	Coefficients for soil properties	Dimensionless
c_p	Soil cohesion	N m^{-1}
d	Tire diameter	m
di	Depth of layer before loading	m
df	Depth of layer after loading	m
E_m, λ_m, E_k, λ_k	Rheological parameter of the soil	kPa
F	Effective soil resistance	kg
K_f	Constant for the soil physical properties	N s^2 m^{-3}
K_c	Cohesive modulus of displacement	N $m^{-(n+1)}$
K_p	soil parameter	N m^{-3}
K_φ	Frictional modulus of displacement	N $m^{-(n+2)}$

K_{cc}	Cohesive displacement modulus	Dimensionless
$K_{\varphi\varphi}$	Frictional displacement modulus	Dimensionless
K, K_p, K_d	Coefficients of proportionality	N m^{-3}
K_1	Coefficient for cohesion property	N L^{-2}
K_2	Coefficient for soil unit weight	N L^{-3}
Ko	Static modulus of soil deformation	N s m^{-4}
K_p	Coefficient depends on soil parameters	N m^{-3}
K_s	Modulus of sinkage	N m^{-3}
M	Mass of water to be added to the container	kg
M_1	Mass of water in the soil after adding water	kg
M_2	Mass of water in the container before adding water	g
MC_1	Moisture content before adding water (wet basis)	%
MC_2	Desired moisture content (wet basis)	%
M_d	Mass of dry soil	kg
m_1	Mass of wet soil	g
m_2	Mass of dry soil	g
m_3	Mass of container	g
n	Coefficient of sinkage	Dimensionless
n_p	Soil parameter	Dimensionless
P	Applied pressure	N m^{-2}
P_o	Imposed stress on the soil surface	N m^{-2}
P_z	Soil surface resistance to penetration at any depth	N m^{-2}
P_c	Pressure in sublayers at depth df	kPa

Q	Applied pressure	kPa
q	Constants for the soil physical properties	$N\ m^{-1}$
r	Distance from load to centre of volume element	m
S	Loading surface perimeter	m
T	Loading time	s
V	Velocity of plate	$m\ s^{-1}$
v	Angle between load centerline and centre of volume element	degrees
W	Wheel load	N
Z_s	Actual vertical soil displacement at the surface	m
Z_v	Sinkage of vehicle wheel	m
Z	Soil surface vertical displacement	m
Z_d	Depth below the surface	m
$\dot{Z}$	Plate velocity	$m\ s^{-1}$
$\ddot{Z}$	Plate acceleration	$m\ s^{-1}$
$\overset{\otimes}{Z}$	Penetration depth	m
α_a	Shape factor of loading surface	Dimensionless
α,β	Geometric constants	Dimensionless
λ	Constant for the soil	$N\ m^{-2}$
ν	Poisson ratio of soil	Dimensionless
σ_z	Horizontal stress on the volume element	kPa
ξ	Concentration factor	Dimensionless

1.0 INTRODUCTION

Most agricultural practices result in soil compaction as surface loads due to equipment movement or actual loads from various agricultural tillage processes occur (Taylor and Gill 1984). The resulting compaction is observed as sinkage at the surface, which is the cumulative effect of displacement beneath the surface.

Soil compaction reduces pore space and closely packs particles in the soil and alters its physical properties (Harris 1971). For most agricultural production systems, soil compaction has undesirable effects, as increased energy is required to till the soil. Water and nutrient penetration, subsequent root growth and development of crops are adversely affected (Raney and Warkentin 1971). However, achieving various degrees of compaction is essential in forming stable foundations for construction purposes in civil engineering applications, and surface packing in Prairie region of North America has proven to be beneficial in seed germination (Alberta Farm Machinery Research Centre 2000).

Soil compaction at depth may result in forming a compact, sub-layer called a hard pan, which affects soil drainage, infiltration, root penetration, aeration and utilization of nutrients in soil. Hard pans can also cause soil erosion and prevents surface water penetration. A hard pan tends to isolate the soil beneath it from further displacement above it and affects load transfer through the soil.

Understanding the effects of sub-surface behavior has implications not only for agricultural and environmental sustainability, but also for landmine neutralization. Specifically, to activate a buried, antipersonnel landmine from a surface load requires a certain magnitude of force to be transferred and the soil to displace at least 2 mm in the vicinity of the trigger (King Colin 1999).

The soil pressure distribution from an applied load is affected by soil properties, such as moisture content and bulk density. A surface load is transferred not at a point but over a finite area to the soil (Söehne 1958). To understand the process of soil compaction a study of pressure distribution for different soil properties is required.

To explain the displacement from a surface load, an understanding of the sub-surface soil behavior is required. The displacement of the soil below the surface, which cumulatively defines the observed surface displacement, and the vertical load transferred through the soil should be investigated. By determining, the depth below which the vertical soil movement ceases may define the

development of hard pans. Understanding the effects of moisture content (dry basis[1]), initial soil compaction (as measured in terms of soil bulk density on dry basis[2]), and the loading surface interface may also lead to developing reliable, predictive models for soil compaction.

The next chapter provides a review of reported work regarding soil vertical displacement, factors affecting soil displacement due to an applied load. The pressure distribution inside soil profile is also included.

The methodology for the experimental work conducted is detailed in chapter three. The results and discussion of the effects of moisture content, bulk density and shape of load interface on sub-layer displacement, and the effect of moisture content on bulk density on transferred pressure follows. Data of tests appear in Appendix D. Conclusions and recommendations complete the thesis.

[1] Throughout the thesis soil moisture content is presented as dry basis
[2] Throughout the thesis soil bulk density is presented as dry basis

2.0 LITERATURE REVIEW AND OBJECTIVES

A review of pertinent research conducted for measuring soil surface and sub-surface vertical displacement due to an applied pressure is provided. Also, the model used to predict the pressure transmitted to the sub-surface layers and the shape of pressure distributed profile is discussed.

2.1 Vertical soil displacement due to an applied load

When a load is applied to the surface of a soil a reduction of soil pore volume (void ratio) occurs. Also soil shear at the edges of the loading plate takes place. The loaded area sinks into the soil to a certain depth until the soil's resistive force is in equilibrium with the applied force; therefore, compaction of soil occurs. It is obvious that by minimizing sinkage, soil compaction would be minimized.

Resistance of soil to applied pressure can be characterized in terms of two parameters: cohesiveness, the bonding of the soil particles, and the angle of internal friction which is the resistance of movement between soil particles.

Vertical displacement at the soil surface or soil surface sinkage depends on the resistance of soil and its elastic stiffness to applied pressure, which depends on soil properties such as soil moisture content, soil bulk density, soil type, depth of hard pan, as well as the load properties such as magnitude, direction (Reece and Adams 1966), speed (Grahn 1991), acceleration (Emori and Schuring 1966), and the shape and area of the loading surface (Youssef and Ali 1982).

Considerable progress has been made in predicting the sinkage of soil surface from an applied load such as from vehicle traffic (Bekker 1960). In the following section, previous studies conducted in predicting soil surface and sub-surface displacement are reviewed.

2.1.1 Soil surface vertical displacement due to an applied load

Plate–sinkage or plate-pressure method is used to model the vertical stress-strain relationship in soil, and also to predict sinkage due to vehicle traffic.

The traditional models started with Bernstein and Lestoshnev in 1913 (reported by Bekker 1957), which Bekker (1957) and Reece (1964) modified to be more suitable for applications to agricultural soils. The other models considered the velocity (Grahn, 1991), acceleration (Emori and Schuring, 1966) and shape of the loading surface (Youssef and Ali, 1982).

2.1.1.1 Traditional models

The strain-stress relationship of soil cannot be easily expressed due to the diversity of soil in nature. The least accurate relationship is the one that represents a straight-line relationship between soil surface sinkage *(Z)* and applied pressure *(P),* as if soil were elastic as shown in Equation (2.1).

$$Z = K_s P \tag{2.1}$$

Kougre et al. (1983) stated that the relationship between load and sinkage was better represented by a hyperbola because as the pressure increased, the soil resistance to sinkage increased and at greater depths, the pressure was not able to increase sinkage.

Bernstein and Lestoshnev presented a non-elastic deformation model in 1913 (reported by Bekker 1957). They suggested that pressure *(P)* applied on a plate was an exponential function of certain soil property (n_p) and the depth of sinkage *(Z).*

Soil parameters were (K_p) and (n_p). Parameter (K_p) was function of the size of loading surface, which determines the soil resistance to load sinkage and its

dimension varies with changes in (n_p), which depends on the type of soil and is equal to ½ for average conditions.

$$Z = \left(\frac{P}{K_p} \right)^{\frac{1}{n_p}} \tag{2.2}$$

Equation (2.2) is simple and suitable for description of relationships of various forms, yet the disadvantages of this formula are that (K_p) and (n_p) are assumed to remain constant for a given soil, but they vary depending on the amount of surface loading and load range (Ageykin 1973). Since the effect of plate dimensions is not taken into considerations in Equation (2.2), (K_p) and (n_p) are constants for specific conditions of soil plate-sinkage.

The coefficient of proportionality (K_p) is affected by and/or depends on the plate size. Bekker (1957) modified this relationship (Equation 2.3) by introducing soil property constants (K_c) and (K_φ) to account for cohesion and internal friction of soil, respectively, and these constants were independent of the plate geometric properties.

$$Z = P^{\frac{1}{n_p}} \left[\left(\frac{K_c}{b} \right) + K_\phi \right]^{-\frac{1}{n_p}} \tag{2.3}$$

Equation (2.3) has shown to be reasonably accurate in measuring the soil resistance to penetration over a wide range of soils and offers the best means of predicting trends when no direct experimental data are available (Cohron 1971).

Bekker (1960) further modified Equation (2.3) to determine the wheel sinkage of a vehicle, where *(W)* is the wheel load and *(d)* and *(b)* are the tire diameter and tire width, respectively.

.

$$Z = \frac{3W}{\left((3-n)(K_c + bK_\phi) d^{1/2} \right)^{\frac{2}{2n+1}}} \tag{2.4}$$

Reece (1964) modified Bekker's plate sinkage equation by means of best curve fitting of laboratory test data, where (K_{cc}) and $(K_{\varphi\varphi})$ in Equation (2.5) are soil values and they are dimensionless.

$$Z = bP^{1/n}\left(c_p K_{cc} + \gamma b K_{\phi\phi}\right)^{1/n} \tag{2.5}$$

This equation considered soil shear strength and cohesion, and showed a good agreement with experimental results (Reece 1964).

2.1.1.2 Cohron model for predicting soil sinkage

Cohron (1971) proposed a simple model by modifying Equation (2.2) by changing *(P)* to *(P_z)*, which represented the soil resistance to penetration at any depth rather than at the surface. The modified equation was:

$$Z = \left(\frac{bP_z}{K_d} \right)^{\frac{1}{n_p}} \tag{2.6}$$

This equation relates the resistance of soil to vertical loads with depth. The equation represented the experimental data reasonably well (Cohron 1971).

To predict the amount of sinkage at the soil surface, Cohron (1971) derived Equation (2.7) for the vertical distribution of stresses under the center of a loaded area.

$$Z = 0.3b\left(\frac{P_o}{P_z} \right) \tag{2.7}$$

By equating Equation (2.6) and (2.7), the formula in Equation (2.8) represents the value of the vertical displacement of the soil surface *(Z)* when a stress *(P_o)* is applied at the soil surface.

$$Z = \left[\frac{0.3 P_o b^{n+1}}{K_d} \right]^{\frac{1}{1+n}} \qquad (2.8)$$

Cohron (1971) represented this equation as a hypothesis since no data were available to validate it, but concluded that it will offer a new approach to the compaction problem if verified.

Bekker's models did not take into consideration plate shape. However, circumference of the plate and characteristic length of the plate govern the pressure-sinkage relationship in the soil. Moreover, the coefficient of friction between plate and soil, depth of soil layer, and the velocity of penetration would also influence sinkage. The next two sections illustrate the effect of loading speed, acceleration and shape of loading area on soil surface sinkage.

2.1.1.3 Effect of load speed and acceleration

Emori and Schuring (1966) proposed that the force required to push a plate was a function of penetration depth $(\overset{\otimes}{Z})$, plate velocity $(\dot{Z})$ and plate acceleration $(\ddot{Z})$ as shown in Equation (2.9), however no experimental evidence was presented.

$$F = f_1(\overset{\otimes}{Z}) + f_2(\overset{\otimes}{Z}, \dot{Z}) + f_3(\overset{\otimes}{Z}, \ddot{Z}) \qquad (2.9)$$

Grahn (1991) stated that under a constant load, the soil surface sinkage was smaller at higher penetration velocities and the modulus of soil deformation in Bekker's equation was equal to ($K_0 \ \dot{Z}^m$) where $(\dot{Z})$ is the vertical velocity, (K_0) is the static modulus of soil deformation, and *(m)* the exponent of the penetration velocity.

$$Z = \left[\frac{P}{K_o \left(\dot{Z} \right)^m} \right]^{\frac{1}{n}} \tag{2.10}$$

Figure 2.1 represents the data for different load speeds. This dynamic relation is not valid for penetration velocities below 10 mm/min, which are defined as a static condition.

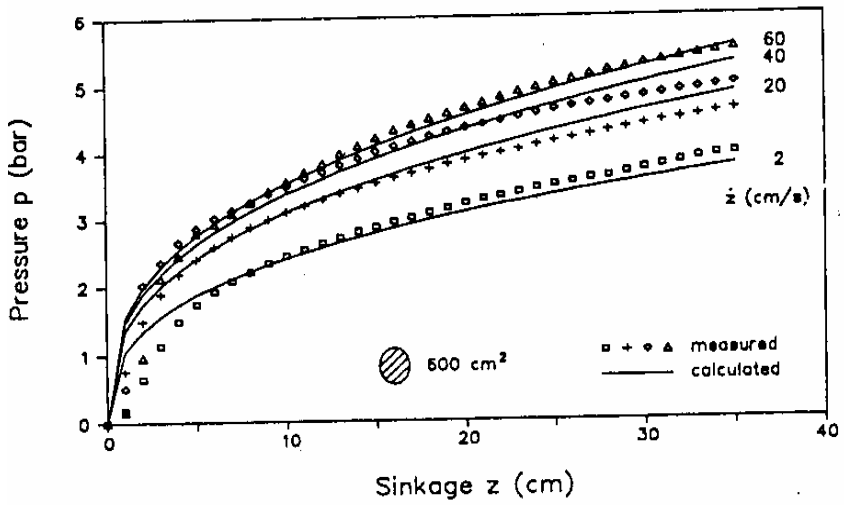


Figure 2.1 Correlation of measured and calculated pressure-sinkage curves for different penetration velocities under a loading surface plate of area 500 cm^2 (Grahn 1991).

2.1.1.4 Effect of plate size and shape

Youssef and Ali (1982) modified the plate-sinkage relation by taking into consideration the effect of both plate size and shape. The predicted soil response compared favorably with the measured results. By modifying Bekker and Reece models, they proposed Equation 2.11, where β is a geometric constant depending on the shape of loading surface as in Figure 2.2.

$$Z = \frac{bP^{1/n}}{\left[(K_1 + 0.5bK_2)\beta^n\right]^{1/n}} \tag{2.11}$$

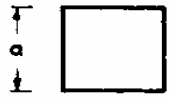
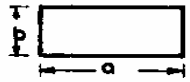
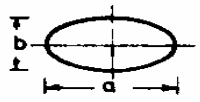
Plate Shape	A/S [L]	β [L]°
Circular 	$\frac{d}{4}$	4
Square 	$\frac{a}{4}$	4
Rectangular 	$\frac{ab}{2(a+b)}$	$\frac{2}{a}(a+b)$
Ellipse 	$\frac{ab}{2(a+b)}$ min $\frac{ab}{4\sqrt{\frac{1}{2}(a^2+b^2)}}$ max	$\frac{2}{a}(a+b)$ max $\frac{4\sqrt{\frac{1}{2}(a^2+b^2)}}{a}$ min

Figure 2.2 Plate geometric constants, β vs. A/S (Youssef and Ali 1982).

The model of Kogure et al. (1983) also took into account the effect of plate size on soil response to sinkage. However, it is better to depend on semi-empirical methods to obtain suitable description of this process rather than to extend the theory of elasticity and plasticity (Kogure et al., 1983).

2.1.1.5 Effect of load direction and plate inclination

Xuewu et al. (1996) proposed a pressure sinkage relation under horizontal plate-inclined load and found that (K_p) in equation (2.2) decreased with increase in angle α (angle between centerline of plate and the horizontal line) and β (angle between direction of force and horizontal line). In other words, the sinkage under an inclined load is greater than that under a vertical load, and the sinkage of an inclined plate under an inclined load is less than that of a horizontal plate under inclined load.

2.1.2 Sub-surface vertical displacement due to an applied load

Wood and Wells (1985) performed an experimental test to characterize soil deformation by measuring grid point displacement and converting the measurements to volumetric strain using different soil densities. The results on soil bulk density determination were close to those obtained from gamma ray density gauge reading and confirmed that the work could supplement density gauge readings.

Ohtomo and Andy tan (2001) measured vertical soil displacement under an axial compressive load using average moisture content of 36% and a bulk density of 1380 kg/m^3. The vertical displacement of the soil was examined under a circular plate of diameter 160 mm at 30, 40 and 50 mm penetration depths. The vertical displacement was found to be dependent of the initial depth of penetration of the loading plate and the maximum deformation was independent of initial compressive load. Soil density remained fairly constant for all loading conditions after a depth of more than 270 mm.

2.2 Pressure distribution within soil profile due to an applied load

Pressure distribution under the soil surface depends on the magnitude of load, size of loading surface, and the distribution of surface pressure within this loading surface as well as on the nature of soil, its moisture content and density (Soehne 1958). No adequate means exist to clearly predict the distribution of pressure or resultant soil compaction. However, the experimental measurements of soil stress distribution indicated that the classical Boussinesq equation (Equation 2.12, Figure 2.3), developed in 1913, serves reasonably well in predicting stresses in the soil (Spangler 1951).

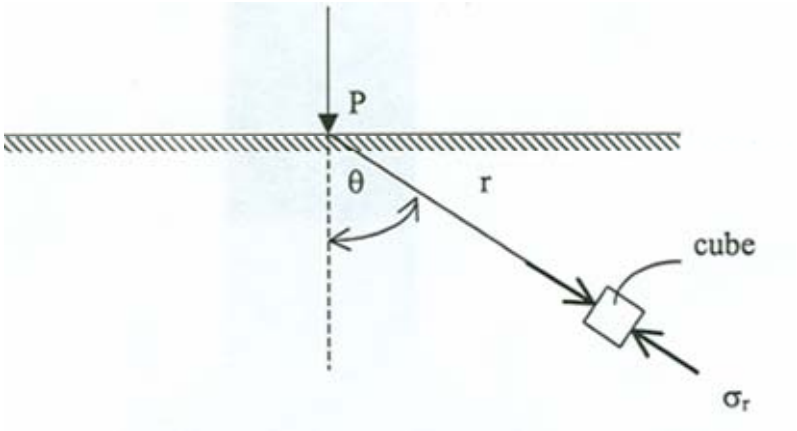


Figure 2.3 Stress in a volume element by a point load in a semi-infinite solid (Soehne 1958).

The pressure distribution in the soil considering elastic soil behavior can be determined by this equation with sufficient accuracy (Soehne 1958).

$$\sigma_r = \frac{\xi P}{2\pi r^2} \cos^{\xi-2} \theta \qquad (2.12)$$

The factor ξ is called the concentration factor. The value of ξ increases as soil becomes softer. Suggested values for ξ are 4 for hard soil, 5 for normal soil and 6 for soft soil. The effects are shown in Figure 2.4. In soil with high ξ value, soil can flow aside so that the pressure distribution is concentrated toward the load axis (Soehne 1958).

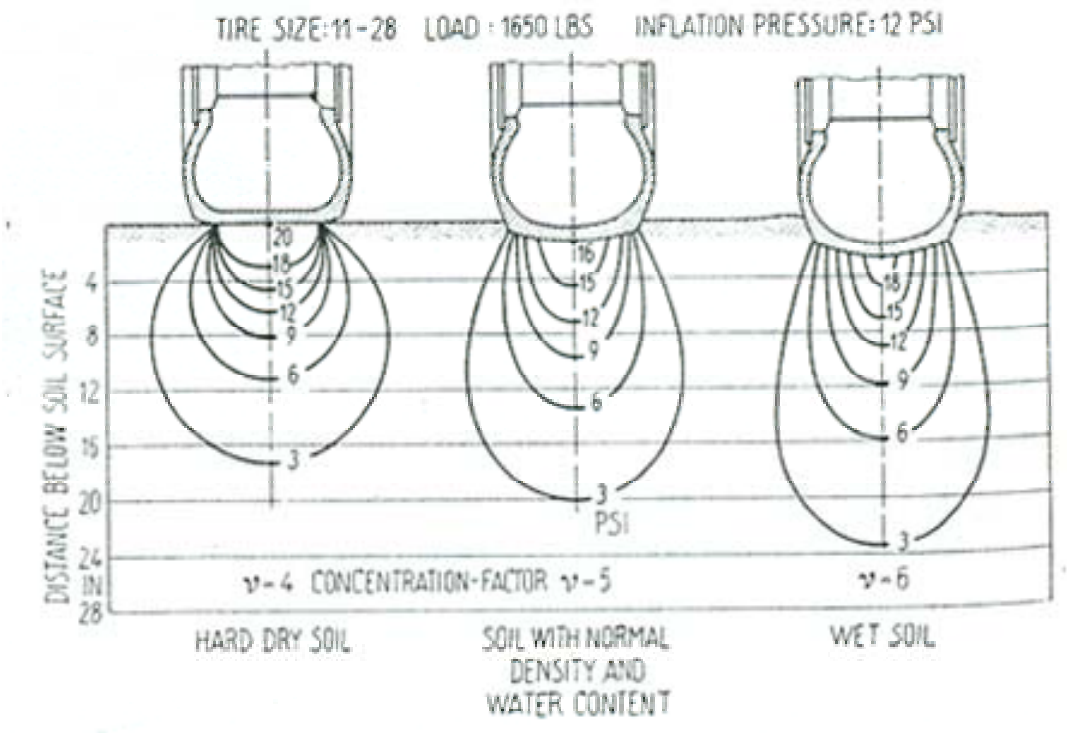


Figure 2.4 Curves of equal pressure (pressure bulbs) under a point load at different concentration factors (Soehne 1958).

2.3 Summary and objectives

Most research reviewed indicated vertical displacement of the top layer. Wood and Wells (1985) and Ohtomo and Andy tan (2001) studied vertical displacement of sub-layers. However these results were limited. There is no existing literature which models soil vertical displacement with depth. In this project, the protocol was designed to measure the vertical displacement of the

sub-surface vertical displacement due to an applied load which can be further related to the soil moisture content and bulk density.

The pressure distribution within soil profile in the literature was done by using Boussinesq equation for pressure distribution. There is a lack of measurement of pressure within soil profile.

The method used in this research involved measuring the pressures within soil profile after the subsurface layers were displaced, which changed the final compaction level (bulk density). The methods used in the review were at the elastic state where the level of compaction was the same before and after the load.

As reported, many factors affect soil sinkage primarily soil type, soil moisture content and soil bulk density and load properties such as shape and velocity. In this research the effect of soil type and loading speed was controlled, but the effect of moisture content and bulk density and shape of loading surface was studied.

In conducting an investigation of displacement and pressure transfer through soil of various conditions from a surface load, the following are the objectives:

1. To study the effect of soil moisture content, bulk density and shape of loading surface on the vertical soil displacement; and

2. To study the effect of soil moisture content and bulk density on the vertically transferred pressure directly below the centre of a loading surface, at different depths.

3.0 METHODOLOGY

In this chapter, the materials and devices, experimental procedures and data acquisition used to complete the experiments are presented.

3.1 Materials and devices

The materials, instrumentation and tools used to conduct the experiments included:

1. Soil
2. Containers
3. Compaction devices
4. Loading interface surfaces and equipment
5. Data acquisition systems

3.1.1 Soil

The soil type used in this study, according to USA soil classification, was a clay loam soil with 47% sand, 24% silt and 29% clay.

3.1.2 Containers

Two types of containers were used. A wooden container was used to prepare all the soil used in the experiments. A uniform soil moisture content was achieved within this container. Secondly, three containers were fabricated from acrylic sheets (Plexiglas®). These containers were used for preparing sample soil with uniform bulk density and moisture content across its profile. During the experiments, a surface load was applied to the soil in these containers and measurement of sub-surface pressure and sub-layer displacement were completed.

3.1.2.1 Wooden container

A wooden container with dimensions of 1.2 m wide, 1.2 m long and 0.3 m high was partially filled with soil with total volume of 0.27 m^3. This was sufficient to fill three Plexiglas® containers. Soil was prepared in the wooden container with the same moisture content and the same load history (since soil was compacted

after each test the soil was then made loose inside the wooden container) was available for filling three acrylic containers.

To insure the uniformity of soil moisture content, the moisture content of the soil in the wooden container was increased to a higher level by adding calculated amount of water and mixing it thoroughly and leaving it for 24 h. The container was covered with a plastic sheet (polyethylene) to reduce moisture loss by evaporation.

The amount of water added to the soil in the wooden container was calculated using this formula:

$$M = M_1 - M_2 \tag{3.1}$$

where,

$$M_1 = MC_1 * M_d \tag{3.2}$$

$$M_2 = MC_2 * M_d \tag{3.3}$$

Three samples were taken from the wooden box at three different locations. The moisture content of each test was recorded by averaging the moisture contents of the three samples. The moisture content of soil was calculated using this formula (as determined by the oven-drying method on dry basis):

$$\text{Moisture content (\%)} = (m_1 - m_2) / (m_2 - m_3) * 100 \quad (3.4)$$

Soil moisture content calculation before the start of each experiment is shown in Appendix D.

3.1.2.2 Plexiglas® containers

Three custom-designed, soil containers shown in Figure 3.1 were fabricated using Plexiglas®. Each container had a base of 200 mm x 400 mm and 760 mm height. The width and height were limited by the access space of the Instron® testing machine (Model 1011) (Instron Corp., Canton, MA). The material was selected because it is durable and lightweight. It is also smooth which is an important consideration in minimizing friction between soil and the sides of the container.

Since Plexiglas® had a very smooth surface, the friction coefficient between soil and Plexiglas® was minimum. Most of the experiments had small displacement at the sides, except for the least resistance soil (soil with high moisture content and low bulk density). Since the soil used had a moisture content ranging from 14 to 20 %, for those experiments, this friction was not considered.

The other side effect was the effect of shear at the sides of the box which had some influence on the pressure distribution. Cohesion soils have less pressure

at the centre and more pressure under the edges of the loading plate (McKyes 1989). By adding the shear stresses would have increased the pressure under the centre of the plate. The other reason the pressure was maximum at the centre of the plate was that the soil under the centerline of the loading plate was more compacted than soil under the sides of the loading plate since it was able to move aside.

The soil was unsaturated using a maximum moisture content of 20%. The final moisture content was not calculated at the end of the test and was not considered in these experiments since it is believed that the final moisture content did not change much to be taken into consideration.

The containers base was 200 mm x 400 mm. The rectangular loading surface area was 56.8 mm x 113.8 mm. The minor/major dimensions of the elliptical loading surface were 127.5 mm x 64 mm. The aspect ratio of the loading surfaces and the container were proportionally similar, which is equal 2 to minimize the boundary effects. Thus, when the loading surface was placed on the soil surface, the effect of the lateral side would be approximately equal to the effect of the longitudinal side.

The height of the container (760 mm) was limited by the Instron® testing machine (Model 1011). One side of the container was removable; this enabled

the soil to be removed in order to measure the vertical soil displacement under the centerline of the load as shown in Figure 3.4.

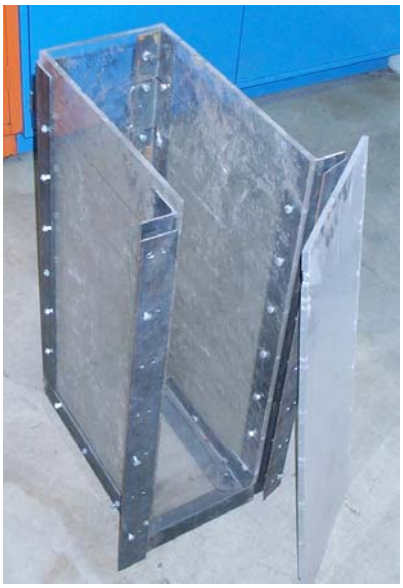


Figure 3.1 Custom-designed Plexiglas® container

3.1.3 Compaction devices

Soil compaction is the process of increasing the density of soil by packing the particles closer together. Compaction reduces the volume of air (Harris 1971).

Three different soil dry bulk densities (990, 1070 and 1127 kg/m^3) were used in this experiment. These densities were achieved by manually packing layers of soil inside the Plexiglas® containers. Layers of 110 mm thick inside the Plexiglas® containers were packed using a 22.5 kg weight and a metal plate as shown in Figure 3.2. The plate was placed above the soil layer and the weight

was dropped from a height of 80 to 100 mm to achieve the desired bulk density. By increasing the number of drops, the bulk density increased.

Figure 3.2 Compaction devices used to increase soil bulk density

3.1.4 Loading interface surfaces and equipment

Two shapes of loading surfaces were used to apply pressure on the soil surface. The plates had the same surface area of 6.4 x 10^{-3} m^2 so as to maintain the same applied pressure on top of the soil. An oval (127.5 x 64 mm) and a rectangular (113.5 x 56.8 mm) loading surfaces were used as shown in Figure 3.3. Both plates were manufactured from 13 mm thick steel.

The ratio of the loading surface area to the surface of the soil was 3.2 for the rectangular and elliptical.

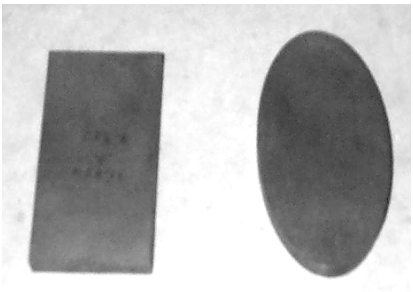


Figure 3.3 Loading plates.

The square and the circular plates were not used since the aspect ratio of the container with the plates will not be equal.

A metal rod of length 350 mm and 55 mm diameter was used to transfer the load vertically from the Instron® crosshead to the plate surface. Since the cumulative soil vertical displacement of 320 mm was predetermined for the given soil conditions, the rod permitted 320 mm of crosshead displacement before interference with the container top edge occurred as shown in Figure 3.4.

The Instron® machine had a working height of 1.2 m. A rode of length 320 mm was attached to the loading device, because the loading device of the Instron® testing machine sinks into the soil to a maximum depth of 270 mm, which will give space for the Instron® loading device to move down until it touches the top of the container (as shown in Figure 3.4).

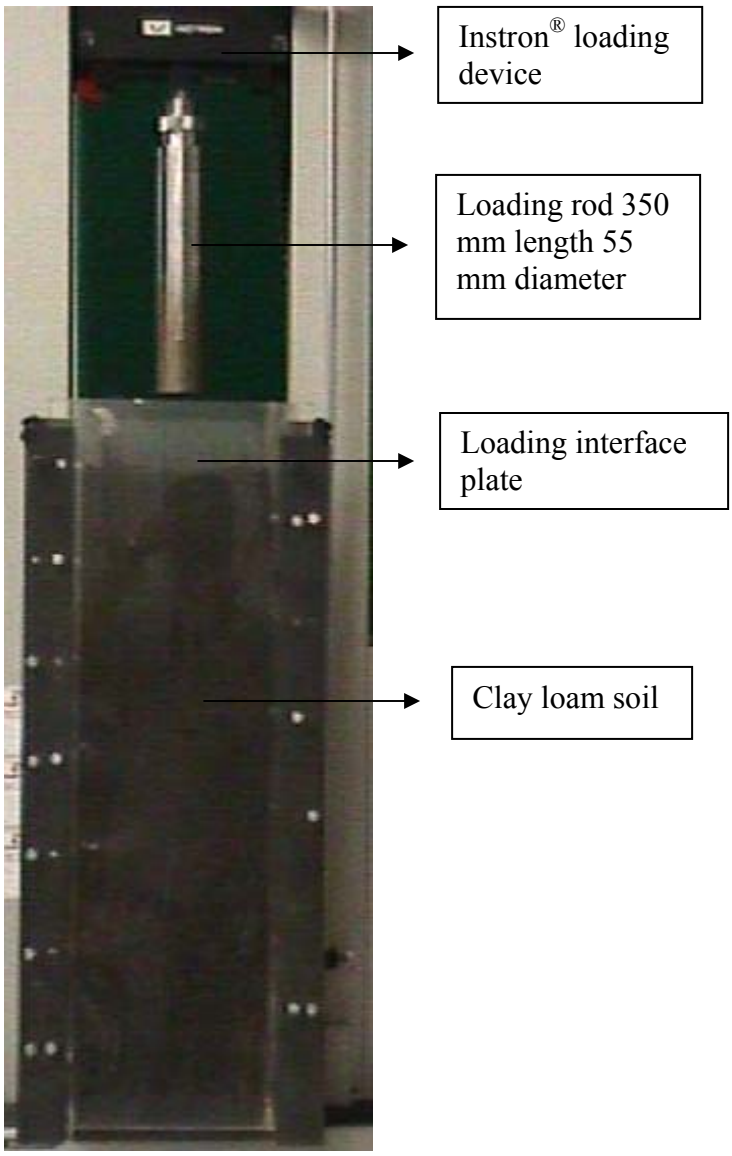


Figure 3.4 Soil in Plexiglas® ready for loading by the Instron® testing machine

Speed and direction of the applied load affects soil vertical displacement as indicated in the review (Grahn 1991 and Xuewu et al. 1996). The Instron® testing machine was used for loading the soil to control the position and the speed of the vertically applied load. The vertical load was applied with a displacement rate of 6 mm/min. The 6 mm/min load was chosen to neglect the

effect of vertical speed on soil vertical displacement, since a higher speed will give less vertical displacement and a lower speed will give the same vertical displacement of the 6 mm/min, as speed less than 10 mm/min is considered static loading (Grahn 1991).

3.1.5 Data acquisition systems

The data acquisition devices consisted of costume-designed sensors, which were used for measuring the pressure distribution inside the soil, and a ruler for measuring soil vertical displacement.

3.1.5.1 Sensors

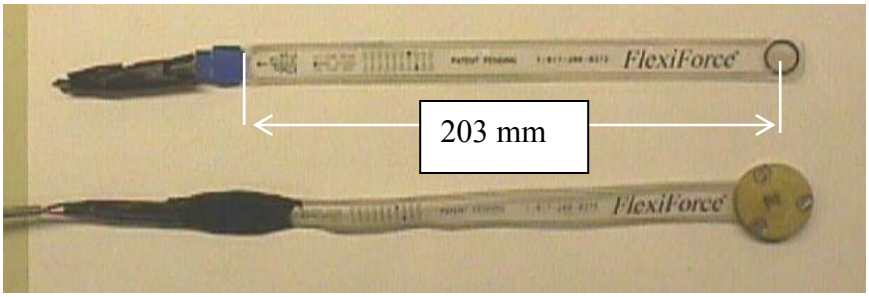
The transferred pressure through the soil profile from the surface load under the load centerline was measured using a custom-designed sensor. Shown in Figure 4.5 is the thin-film, pressure transducer of dimensions 203 mm length and 14 mm width.

Figure 3.5 FlexiForce® thin film pressure sensors. (Tekscan Inc., South Boston, MA).

The sensor was based on a thin, pressure transducer from Tekscan called FlexiForce® (Tekscan Inc. South Boston, MA). Sensors specifications are provided in Appendix A. The sensor measures the relative pressure within the soil at the location of the sensor. The sensitivity of the sensor was calibrated prior to being placed at pre-determined depths below the centre of the load application. The sensor moved together with the movement of the soil layer. Data were recorded using a computerized data logging system.

The interface attachments were designed and fabricated to ensure the load distribution was applied uniformly to the sensing area of the transducer. The attachments shown in Figure 3.6 consist of two circular plates of thickness 2.5 mm. The lower plate is flat with diameter of 25 mm. The upper plate had a circular extrusion of 0.5 mm in the middle with diameter 8 mm which is 10% less than the sensing diameter of the transducer as recommended by the vendor. The sensing transducer (FlexiForce® strip) is positioned between the two plates and preloaded with three equally spaced screws.

The sensors were not inclined after applying the load but in some cases there was little inclination which may have affected the data output to some extent.



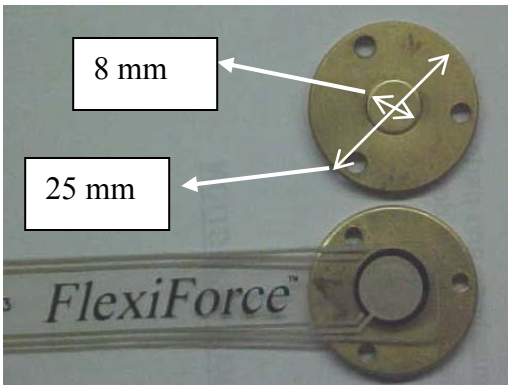


Figure 3.6 Sensors attachments

3.1.5.2 Excitation circuit and voltage supply

The excitation circuit was assembled on an electric board using resistors, capacitors and amplifiers and connecting wires. This circuit was designed based on the recommended excitation circuit by the vendor. Note that the resistor-capacitor was added to provide filtering on the output voltage signal.

The schematic of the circuit is shown in Appendix B. Two voltage supplies were used to establish the input for the amplifier at +12V and –12V and for the input

of the circuit to be –5 V. By changing the magnitude of the resistor, the range of the sensor could be varied.

3.1.5.3 Datalogger

A Campbell 21X datalogger (Campbell Scientific Inc., Logan, UT) was used to collect the data at a rate of 100 Hz. Specifications is shown in Appendix A.

3.1.5.4 Computer program

A computer program written in Edlog programming environment for Campbell 21X datalogger (Appendix E) was used to collect the data from the datalogger and monitored on the computer screen.

3.1.5.5 Displacement measurement devices

A ruler with an accuracy of 0.5 mm was used to measure the marked depth of the soil sub-layers. The measurements of the initial depth of the white powder (chalk) were done with the reference to a datum located at the top of the container. The white powder demarking the various layers can be easily measured using a ruler. Figure 3.7 shows the layers after loading.

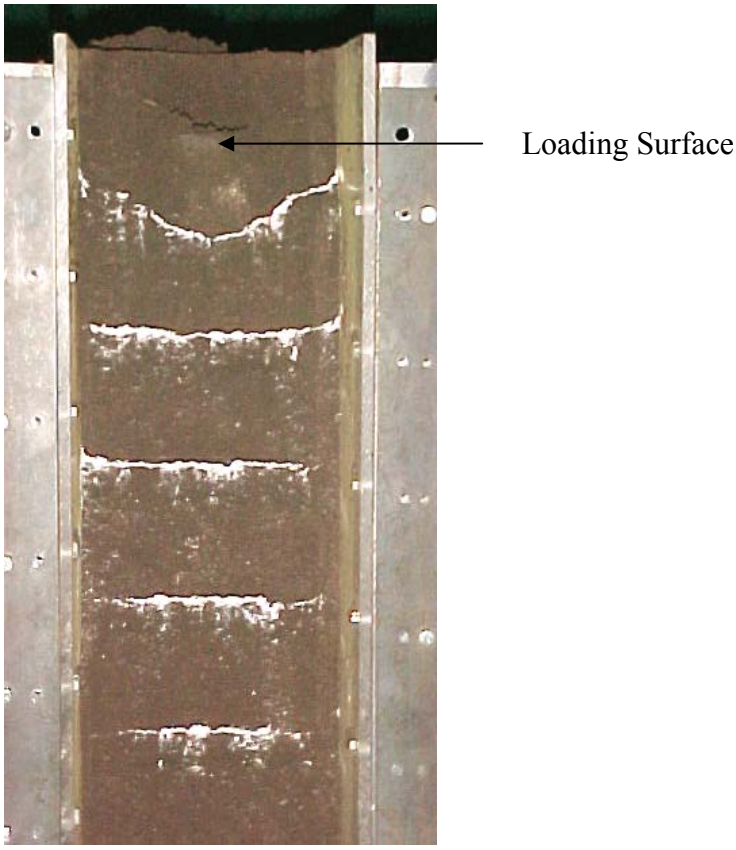


Figure 3.7 Location of displaced layers after compaction was measured using ruler.

3.2 Experimental procedures

To quantify the compaction that occurs at sub-layers from a surface load both the vertical displacement and relative pressure at equally spaced sub-layers were measured. A surface load of 800 N was applied over a loading surface area of 6.4 x 10^{-3} m^2 using the Universal Instron® testing machine with the crosshead speed of 6 mm/min. The relative pressure measurements were taken once the soil had reached an equilibrium state with the applied load. The

relative pressure measurements were recorded with the external surface load and the resulting displacement measurements were taken after the load had been removed.

3.2.1 Calibration of sensors

The calibration of the sensors was conducted using the Instron® machine; the sensor was loaded and unloaded in increment of 30 N from 0 N to a maximum of 280 N. At each increment, the output (in millivolts) was recorded on the datalogger. The data were plotted and using linear regression, the best fit curve using Microsoft Excel® spreadsheet was applied and the calibration equation were obtained automatically.

The sensors were calibrated three times. The first calibration was before starting the experiments using the 14% soil moisture content (Table C1 in Appendix C) the second calibration, before experiments using the 17% soil moisture content (Table C3 in Appendix C) and the last calibration was before experiments using the 20% soil moisture content (Table C5 in Appendix C).

3.2.2 Soil preparation

This section shows how the soil was prepared to achieve three different soil moisture contents (dry basis) and three different soil bulk densities (dry basis).

3.2.2.1 Soil preparation in the wooden container

A large sample of soil (0.27 m^3) was prepared in a specialized wooden container. The soil was mixed with water to obtain the desired moisture contents of 14%, 17% or 20%. The soil was manually tilled using a garden tool and allowed to rest for 24 h for moisture to equilibrate till the moisture content was uniformly equal, that was checked by taking samples from three different location of the wooden box.

3.2.2.2 Soil preparation in acrylic (Plexiglas®) containers

Several tests were completed to analyze various combinations of moisture content and bulk densities. The load range was selected to be 800 N, and comparable pressure sensors were designed. Secondly, the crosshead motion and available clearance with respect to the acrylic container was limited to 320 mm. Since a wide range of soil bulk densities and moisture contents affect the magnitude of the transferred pressure and corresponding local soil deflection profiles, the first step required selecting soil strength to meet the load constraint of 800 N and the available vertical displacement range of 0 to 270 mm.

The process of determining an appropriate combination of moisture content and bulk density was systematic. The soil with the least strength used in the analysis was selected based on the sample supporting a load of 800 N, yet

having a displacement less than 270 mm. Soils with low resistance had high moisture content and low bulk density. The criteria for the other extreme, soil with the highest strength, was that the same load of 800 N must cause a measurable displacement in the sub-layers. Soil that is too hard will not be compacted. In other words, sub-layers will not be compressed under an applied surface load of 800 N.

Furthermore, in filling the acrylic container with soil in order to maintain a uniform bulk density throughout the container required a bulk density greater than 1154 kg/m^3 (wet basis). Attempts to use a less dense sample, such as soil with a bulk density of 1000 kg/m^3 (wet basis) resulted in a density gradient being formed. The loose soil on top had sufficient weight to pack the soil beneath it, hence, the soil at the top was considerably less dense than the soil at the bottom of the container.

Using soil with a minimum bulk density of 1154 kg/m^3 (wet basis) and a moisture content of 20% resulted in a cumulative vertical displacement of 280 mm at the surface for an applied load of 800 N. Soil with moisture content below 14% was found to be too dry for the techniques employed in this study.

Measuring displacement of the sub-layers that have been marked with a white powder (at the centre of the acrylic container) was essentially impossible for dry soil. The technique to measure displacement involved removing the side of the

Plexiglas container, and removing the soil from the edge to the centre where the load was applied. As the dry soil has minimal cohesiveness, the soil layers fall away making manual measurements impossible.

Next, the upper limit for the bulk density was selected. For the lowest moisture content used in this investigation (14%) and the highest bulk density, would result in soil with the highest resistance. Based on sample tests, soil with a bulk density of 1313 kg/m^3 (wet basis) with moisture content 14% was chosen. These samples with an applied surface load of 800 N had a measurable displacement at the third layer (which was originally 200 mm from the surface).

The soil used in this experiment had a range of moisture content from 14% to 20% and a bulk density from 1154 kg/m^3 (wet basis) to 1313 kg/m^3 (wet basis).

In conducting the investigation, the soil densities used were 1154, 1248 and 1313 kg/m^3 (wet basis). The total volume of the soil inside the container was 0.056 m^3. The soil container was filled to a depth of 700 mm and was marked with a powder every 100 mm. The soil had a uniform bulk density and moisture content throughout. The following procedures were followed to achieve different bulk densities.

3.2.2.2.a Preparing the soil in the acrylic container for low bulk density soil

Soil was first prepared to the desired moisture content in the wooden container. When filling the acrylic container, the soil was weighed and manually packed to achieve the desired bulk density using 100 mm thick layers. Each layer was marked using white powder.

A mass of 9.2 kg of moist soil was placed in the container with a height between 100 to 110 mm and a loose bulk density of 1020 kg/m^3 (wet basis)This layer was compacted manually using a metal plate and a weight. When the weight was only placed above the plate the height of the soil was decreased by 9.5 mm, which increased its bulk density to 1154 kg/m^3 (wet basis). The mass of soil added and the height of the layer before and after packing are shown in Appendix D. Also shown are the wet bulk densities of the each soil layer and wet and dry bulk density of the soil column.

After each soil layer was compacted, a thin layer of white powder was placed at the top of the compacted layer as a marker for that depth. Subsequent layers were prepared in the same manner.

A set of three experiments was done for each bulk density to calculate the movement of the layers due to packing of the layers above it. It was found that the layers did not move significantly for the medium and high bulk densities, but

movement downward of 4 mm for layer 6 (depth 500 mm) and 7 (depth 600 mm) and movement of 2 mm for the other layers up to the surface occurred. As shown in Appendix D where the depth of the layer before loading was equal to the measured depth plus the distance it moved.

3.2.2.2.b Preparing the soil in the container for medium bulk density soil

The same steps were done as for the low bulk density, but the soil was packed by dropping the weight once from a height of 80 to100 mm. The resulting soil dry bulk density was 1248 kg/m^3.

3.2.2.2.c Preparing the soil in the container for high bulk density soil

The same steps were done as for the low and medium bulk density, but the soil was packed by dropping the weight from a height of 80 to 100 mm three times. The resulting soil dry bulk density was 1313 kg/m^3.

3.2.2.3 Placement of sensors

While filling the container, sensor 4 was placed at the center of the 2nd layer (from the surface) which is at a depth of 150 mm from soil surface. Sensor 3 was placed at the top of layer 2nd layer which is at a depth 100 mm and sensor 2 was placed at center of layer 1st which is at a depth 50 mm. Finally, sensor 1

was placed at the surface of the 1st layer which was at the soil surface under the loading surface to measure the pressure distribution under the center of the loading surface.

Appendix C shows the calibration for the sensors before each experiment.

3.2.3 Data acquisition

Data acquisition techniques for measuring soil bulk density, soil moisture content, soil vertical displacement and pressure transferred through the soil are presented in this section.

3.2.3.1 Soil bulk density calculation

Soil was placed inside the Plexiglas® container as loose soil. It was packed to a higher bulk density, and the bulk density was calculated by dividing the mass of the soil layer by its volume. The volume of the layer was calculated by measuring the height of the packed soil layer and multiplying it by 0.08 m^2 (the cross-sectional area of the container). Table D1 of Appendix D shows the mass of soil layer added and the bulk density of each layer and the average bulk density.

Soil was then calculated on dry basis by using this formula:

$$\rho_d = \frac{\rho_w}{1 + \left(M_c / 100 \right)} \tag{3.5}$$

where:

ρ_d = Dry bulk density, kg/m^3

ρ_w = Wet bulk density, kg/m^3

M_c = Moisture content, %

The bulk density on dry basis was used to compare the results in chapter four.

3.2.3.2 Cumulative vertical soil displacement measurement

After the load reached 800 N, the load was removed. The side of the box was removed as shown in Figure 3.8. Next, the soil was excavated to the centerline to measure the depth that the white powder had been displaced after the loading.

The vertical displacements were measured beneath the centerline of the applied load application. The measurements quantified the displacement of each marker (white powder) with respect to its initial position. Measurements were taken from the initial surface to a depth of 600 mm. Appendix D shows how the displacement was calculated.

Figure 3.8 Soil column inside the Plexiglas® container after removing one side of the container.

3.2.3.2 Transferred pressure measurements

To measure the soil pressure on the four sensors, the output voltage was recorded by the datalogger when the load reading of the Instron® reached 800 N. The voltage was substituted in the calibration equation to obtain the force on each sensor. The loading period was 30 seconds. The data rate was 100 Hz. The calculation of the forces is presented in Tables C2, C4 and C6 of Appendix C. The pressures (kPa) corresponding to the various forces, along with the sensors position before and after loading were calculated, as presented in Appendix D for each test.

Each test was repeated three times and averaged to determine the vertical soil displacement. Data from the pressure sensors were averaged over the loading period in determining the pressure transferred to depth and was also repeated three times. The data for each test and the average of the three tests for soil displacement are given in Appendix D.

3.3 Data presentation

Data for each test appear in Appendix D. The cumulative vertical displacement of the soil, for each layer, with respect to the initial depth of the layer was plotted. The displacement decreased from surface to depth, which followed an exponential curve. The pressure transferred to depth was also represented as an exponential decay. The highest value for the vertical displacement and pressure was at the surface of the soil and decayed to nearly zero mm at a depth 600 mm and nearly zero kPa at a depth 150 mm, respectively.

In each test, the following parameters were constant:

- The applied vertical load of 800 N
- The loading speed 6 mm/min
- The loading surface area of 6.4×10^{-3} m^2

The variable test parameters were as follows

- Soil moisture (3 levels) 14, 17 and 20%
- Soil bulk density (3 levels) 990, 1070 and 1127 kg/m^3 (dry basis).
- Shape of loading surface (2 shapes) rectangular and oval
- Number of replicates (3)

Total tests conducted = 3 X 3 X 2 X 3 (replicates) = 54 tests

An analysis of variance using F-test to study the difference between the tests and between treatments were completed and are shown in Appendix F.

3.4 Limitations

3.4.1 Aspect ratio

The size of the Plexiglas container (200 mm x 400 mm) was limited by the access space of the Instron® testing machine. With the rectangular loading plate (56.8 mm x 113.5 mm) the aspect ratio was nearly 1.25. However, with the elliptical loading plate (64 mm x 127.5 mm) the ratio was about 1.06. A higher aspect ratio would have been better to avoid any side effects or friction with the Plexiglas walls. Common practice in engineering application to foundation design recommends an aspect ratio of five as shown in Figure 3.9 (George 1979) However, Ohtomo and Tan (2001) used an aspect ratio of 0.7 in their study of soil deformation.

Therefore, it is difficult to assess the amount of side effects and wall friction on the results reported in this thesis. It is estimated that these effects would be minimum.

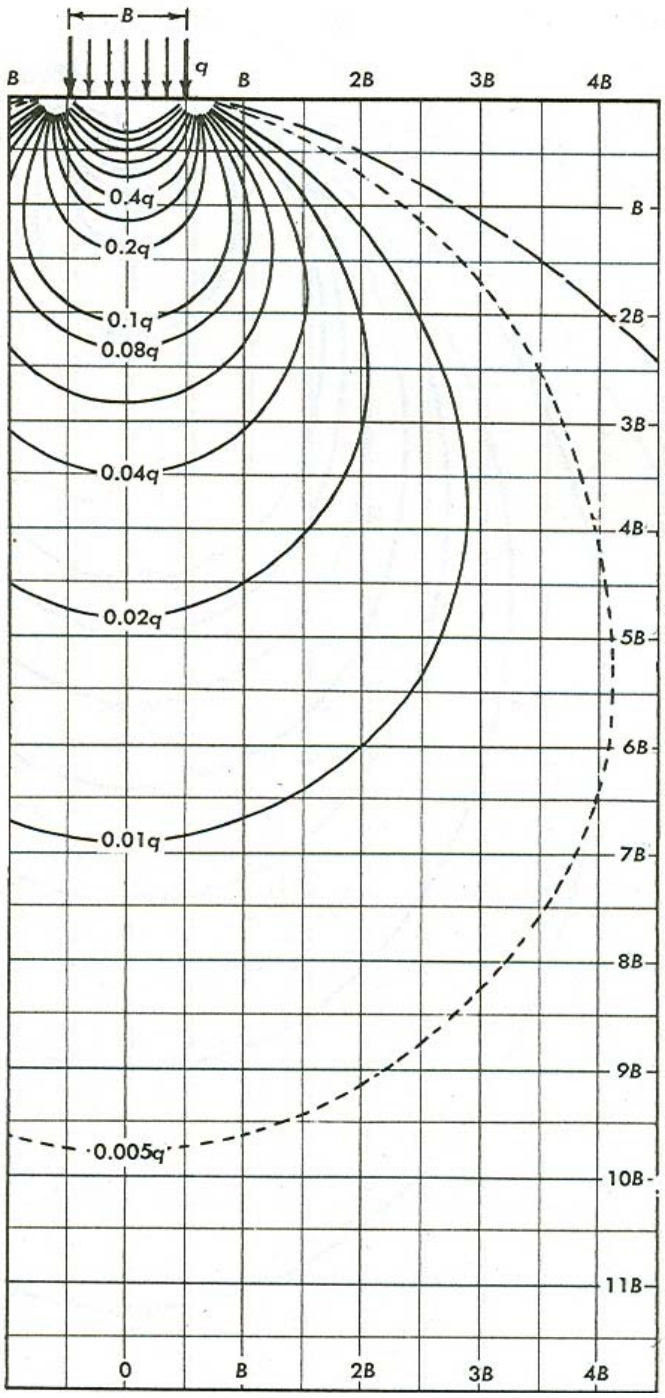


Figure 3.9 Contours of equal stress beneath a foundation on a semi-infinite, homogeneous isotropic elastic solid-the Boussinesq analysis. (George 1979).

3.4.2 Loading speed

The Instron® machine was used rather than the free weights to control the position and the speed of the vertically applied load. Speed and direction of the applied load affects soil vertical displacement as indicated in the review (Grahn 1991 and Xuewu et al. 1996). The 6 mm/min load was chosen to reduce the effect of strain rate on soil vertical displacement as speed less than 10 mm/min is considered static loading (Grahn 1991).

The soil shear along the perimeter of the loading surfaces ceased ones the maximum load was reached and the downward movement of the load stopped.

This caused the applied load to reduce in magnitude. Therefore, to maintain a load of 800 N, initial loading was increased to nearly 850 N. This may indicate some effect of strain rate on soil loading but it was considered to be a minimum for loading a soil column of 760 mm depth. Since the pressure readings were recorded at the steady condition, the effect of loading speed in pressure measurement would be negligible. The displacement of soil layers was taken after the load was removed. Therefore, loading speed would not have any influence on the results.

3.5 Summary

A soil column with uniform bulk density and moisture content was used to study the sub-soil vertical displacement and pressure distribution at various depths. These soil parameters included soil moisture and soil bulk density. Effect of two loading shapes was evaluated. The magnitude, direction and speed of loading were kept constant with the Instron® machine.

An equation relating the vertical soil displacement with depth was determined from the different data combinations, which followed an exponential decay curve. The effect of the soil properties mentioned above was related to the constants of these equations.

The protocol used to measure vertical soil displacement and pressure transferred through soil was to load a soil column with the same moisture content and same bulk density. The layers were demarked using white powder and the pressure transferred was measured by custom-designed sensors. This protocol had excellent repeatability.

In summary the developed methodology for this investigation produced repeatable data. It provides valid data to draw trends to investigate the effects

of soil moisture content, bulk density and load interface geometry on cumulative vertical displacement from the surface at sub-layers to depth of 600 mm.

The developed sensors for pressure measurement had good accuracy as the calibration was repeated and showed no significant difference. The sensors did not alter soil behavior. The sensors moved with the original, adjacent soil. Vertical pressures were measured as the sensor orientation remained constant; the transducer was perpendicular to the applied loading direction.

4.0 EXPERIMENTAL RESULTS AND DISCUSSIONS

The effect of two soil properties, namely, the moisture content and the bulk density using two shapes of the loading surface, on the cumulative vertical soil displacement are discussed in this chapter. The effects of soil moisture and soil bulk density on the pressure transmitted from the surface to different depths are also discussed.

Cumulative soil vertical displacement at depth is the total displacement of the layer at that depth due to the displacement of soil layers underneath it. The results presented herein are the cumulative vertical soil displacement.

4.1 Cumulative vertical soil displacement

In these experiments the soil had a large deformation, where the soil had passed the elastic limit to the plastic limit.

The shape of the chalk marks was parabolic having the maximum deflection under the centerline of the loading plate and minimum deflection at the edges of the container as was shown in Figure (3.4).

The experimental data were plotted on the graph where the x-axis was the initial depth of the layer and the y-axis was the cumulative vertical displacement. It appeared that the data exhibited an exponentially decayed relationship rather than linear one. The curves were also plotted on a semi-log plot and had higher regression coefficients than for the linear one.

The exponential curve had a good coefficient of regression with the data points plotted. The soil with low resistance (high moisture content and low bulk density, Figures 4.1 and 4.13), had its constant (A_c) much higher than the experimental values. This needs to be investigated further for soils with low resistance.

The cumulative vertical soil displacement of the soil column was investigated by controlling two variables and changing the other variable to study its effect. The effect of the variables (soil moisture content, soil bulk density (dry basis) and shape of the loading surface) on the vertical displacements of the soil, at the surface and through the soil profile, from an applied vertical load is discussed in this section.

The data were processed and plotted using a commercial spreadsheet. Curve fitting for the analysis of pressure distribution and displacement profiles resulted in exponential functions, given by the following equation:

$$C_v = A_c\, e^{-B\, di} \qquad (4.1)$$

Where:

A_c = Theoretical vertical soil displacement at surface, m

C_v = Theoretical vertical soil displacement at depth di, m

B = Exponential decay constant, m^{-1}

di = Depth of layer before loading, m

4.1.1 Effect of soil moisture content

By changing the soil moisture content and keeping the other two variables constant (soil bulk density and shape of loading surface), the effect of soil moisture content on the cumulative, vertical soil displacement at the surface and within the soil profile was investigated.

4.1.1.1 Effect of soil moisture content for low soil bulk density

Three levels of soil moisture content (13.7%, 16.5% and 19.8%) were used to investigate the cumulative vertical soil displacement of the soil column with a uniform dry bulk density of 990 kg/m^3 (dry basis) Figure 4.1 shows the cumulative vertical soil displacement of the surface and six of the sub-layers under the loading surface with respect to the depth of this layer before the load was applied. Data are shown in Appendix D (Tables D4, D28 and D52). The coefficients of regression (r^2) for the low, medium and high moisture content soils were 0.96, 0.99 and 0.98 respectively.

Figure 4.2 shows a Semi-log plot of the same data when cumulative vertical displacement was plotted on the log scale. The resulting equations of the three curves were

High moisture content (19.8%) $C_v = 42\ e^{(-0.066\ di)}$ (4.2)

Medium moisture content (16.5%) $C_v = 24.3\ e^{(-0.053\ di)}$ (4.3)

Low moisture content (13.7%) $C_v = 12.2\ e^{(-0.066\ di)}$ (4.4)

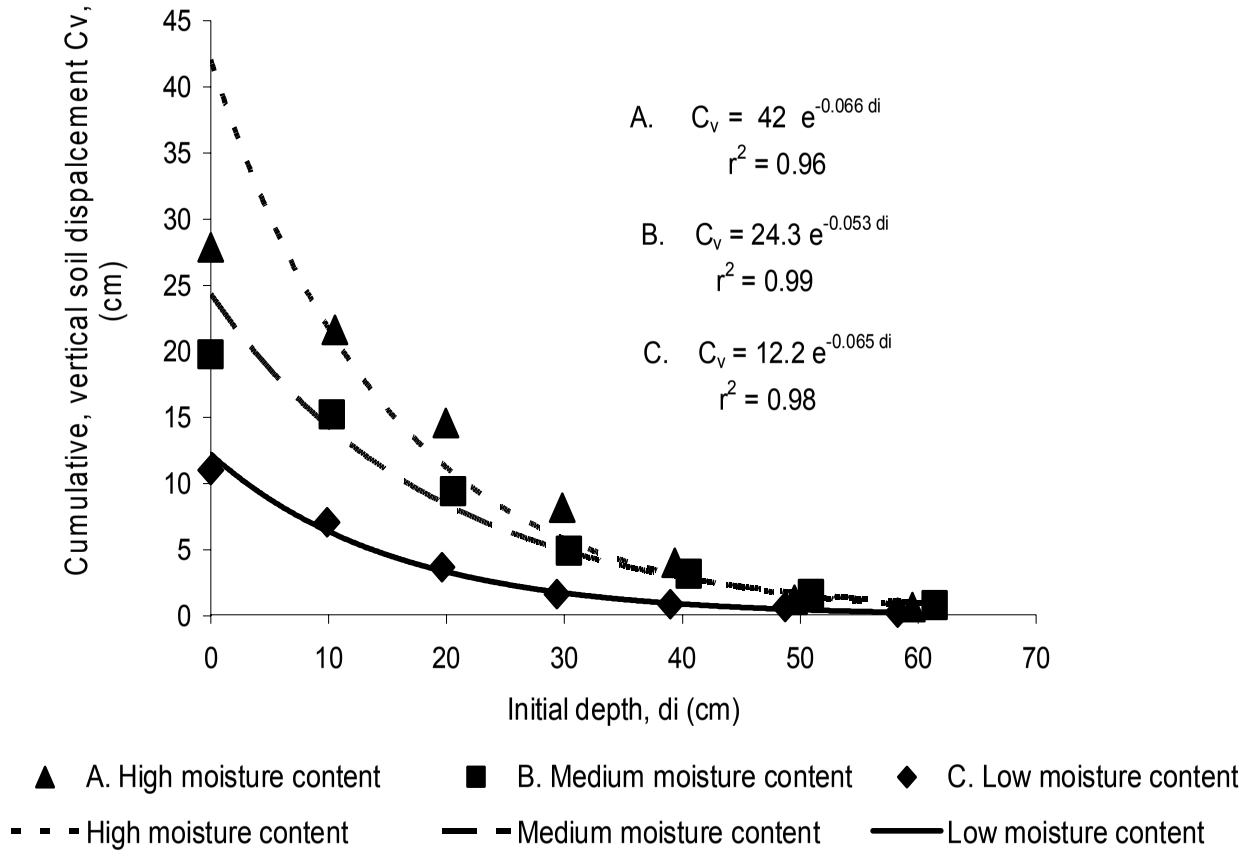


Figure 4.1 Cumulative vertical soil displacements for soil with low bulk density (990 kg/m^3) (dry basis) and three moisture contents (13.7, 16.5, and 19.8%).

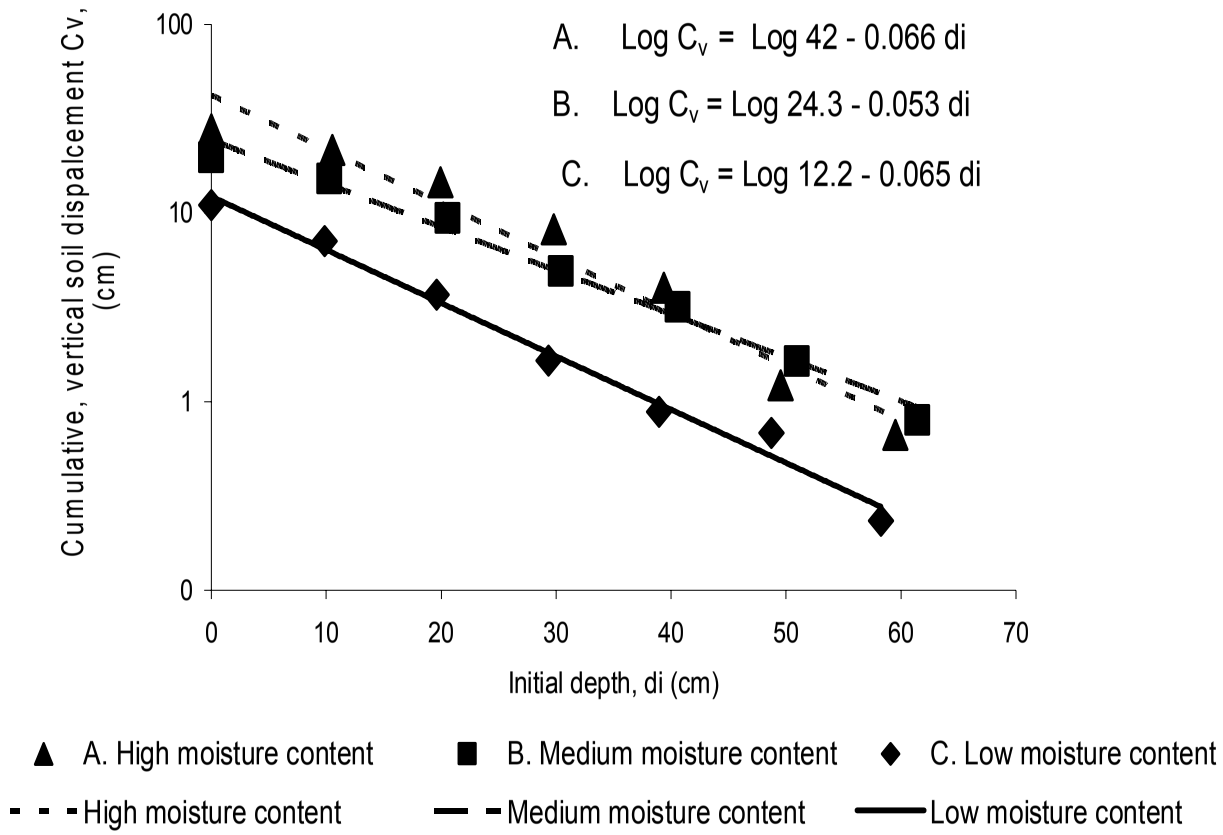


Figure 4.2 Semi-log scale representing, cumulative vertical soil displacements for soil with low bulk density (990 kg/m^3) (dry basis) and three moisture contents (13.7, 16.5, and 19.8%).

The exponential decay rate for the three curves ranged from 0.053 to 0.063. Statistically, there was no significant difference between the tests and the treatments in the value of the exponential decay rate. The only difference among the curves was the y-intercept, which is the theoretical vertical soil displacement at the surface. This value increased with an increase in the moisture content. For the three moisture contents, the vertical soil displacement was approximately zero at a depth of 600 mm below the soil surface.

For the high moisture content and low bulk density soil, the theoretical value of surface displacement (A_c = 42.2 cm) was much higher than the experimental one (28 cm). The other two curves were better represented by the exponential curve where the actual values were nearly equal to the theoretical values. Soil with low bulk density and high moisture content need further investigation.

The statistical analysis (Table F4 in Appendix F) showed significant difference in the displacement at the surface layer (0 mm depth) with respect to different moisture contents, and the significance with depth decreased to the 6^{th} (at depth 500 mm) and 7^{th} (at depth 600 mm) layers for the three different moisture contents.

For the same low soil dry bulk density (990 kg/m^3) the y-intercept increased as the moisture content increased. The soil was displaced more since it had less resistance to the applied load due to the presence of more water in the voids.

4.1.1.2 Effect of soil moisture content for medium soil bulk density

The vertical soil displacement for a soil column with 1070 kg/m^3 dry bulk density and three soil moisture contents (13.5, 17.1 and, 19.6%) is illustrated in Figure 4.3 Experimental data appears in Tables D12, D36 and D60 of Appendix D.

The data represent displacements at the surface and the next 3 layers only, since the 5th, 6th and 7th layers (at depth of 400 mm, 500 mm and 600 mm) showed negligible deflection. The exponential decay rate was consistent among the three moisture contents. The only significant difference was the y-intercept (A_c), which increased with the increase of soil moisture content. The theoretical values of soil vertical displacement (A_c) were close to the experimental values at all different moisture contents. Figure 4.4 shows a Semi-log plot of the same data when cumulative vertical displacement was plotted on the log scale.

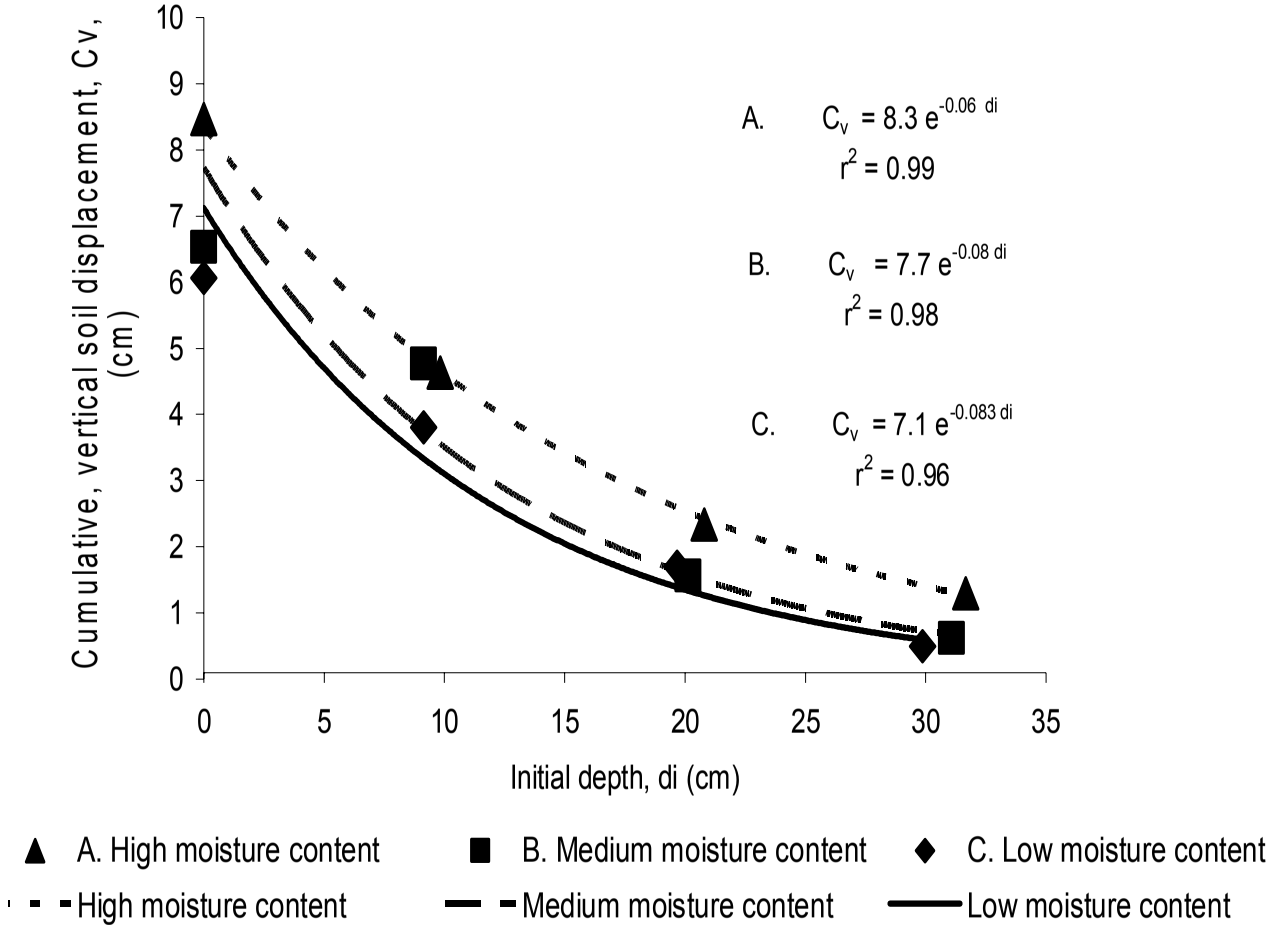


Figure 4.3 Cumulative, vertical soil displacements for soil with medium bulk density (1070 kg/m^3) (dry basis) and three moisture contents (13.5, 17.1, and 19.6%)

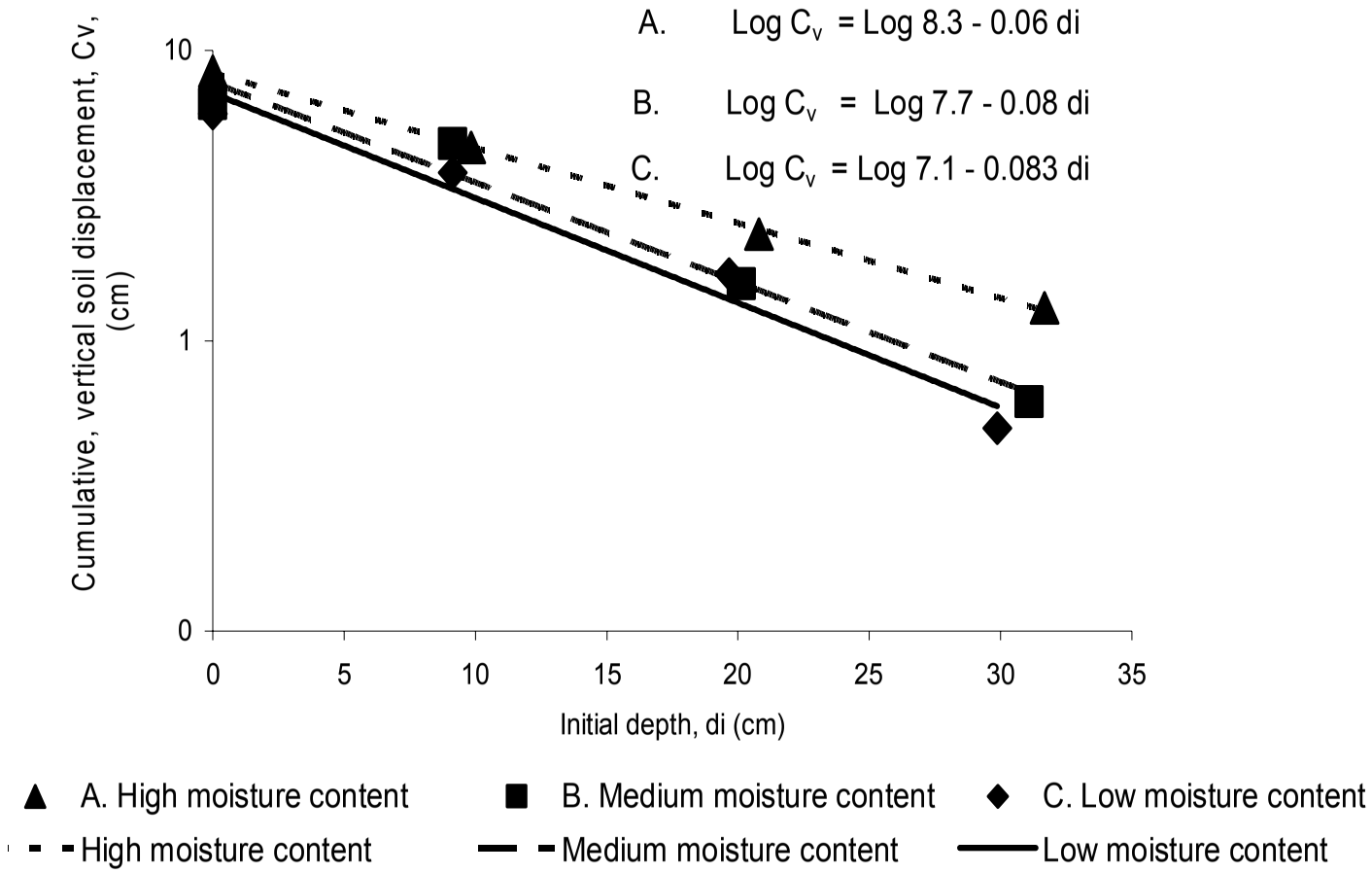


Figure 4.4 Semi-log scale representing, cumulative vertical soil displacements for soil with medium bulk density (1070 kg/m^3) (dry basis) and three moisture contents (13.5, 17.1, and 19.6%).

Once again, based on an analysis of variance (Table F5 of Appendix F), the difference between the vertical soil displacements for the three moisture contents was significant at the four depths shown in the graph. At 400 mm, 500 mm and 600 mm depth the value of the vertical displacement were negligible and were not plotted in the graph.

4.1.1.3 Effect of soil moisture content for high soil bulk density

The vertical soil displacement for a soil sample with 1127 kg/m^3 dry bulk density and three soil moisture contents dry basis (13.5, 16.6 and 19.6%) is illustrated in Figure 4.5. Experimental data appears in Tables D20, D44 and D68 of Appendix D. Figure 4.6 shows a Semi-log plot of the same data when cumulative vertical displacement was plotted on the log scale.

The data were measured at the surface and two layers below the surface to an initial depth of 200 mm. The exponential decay rate was consistent among the three moisture contents ranging from 0.086 to 0.096. The only difference was the y-intercept which increased with the increase of soil moisture content. The theoretical values of soil vertical displacement (A_c) were close to the experimental values at all different moisture contents.

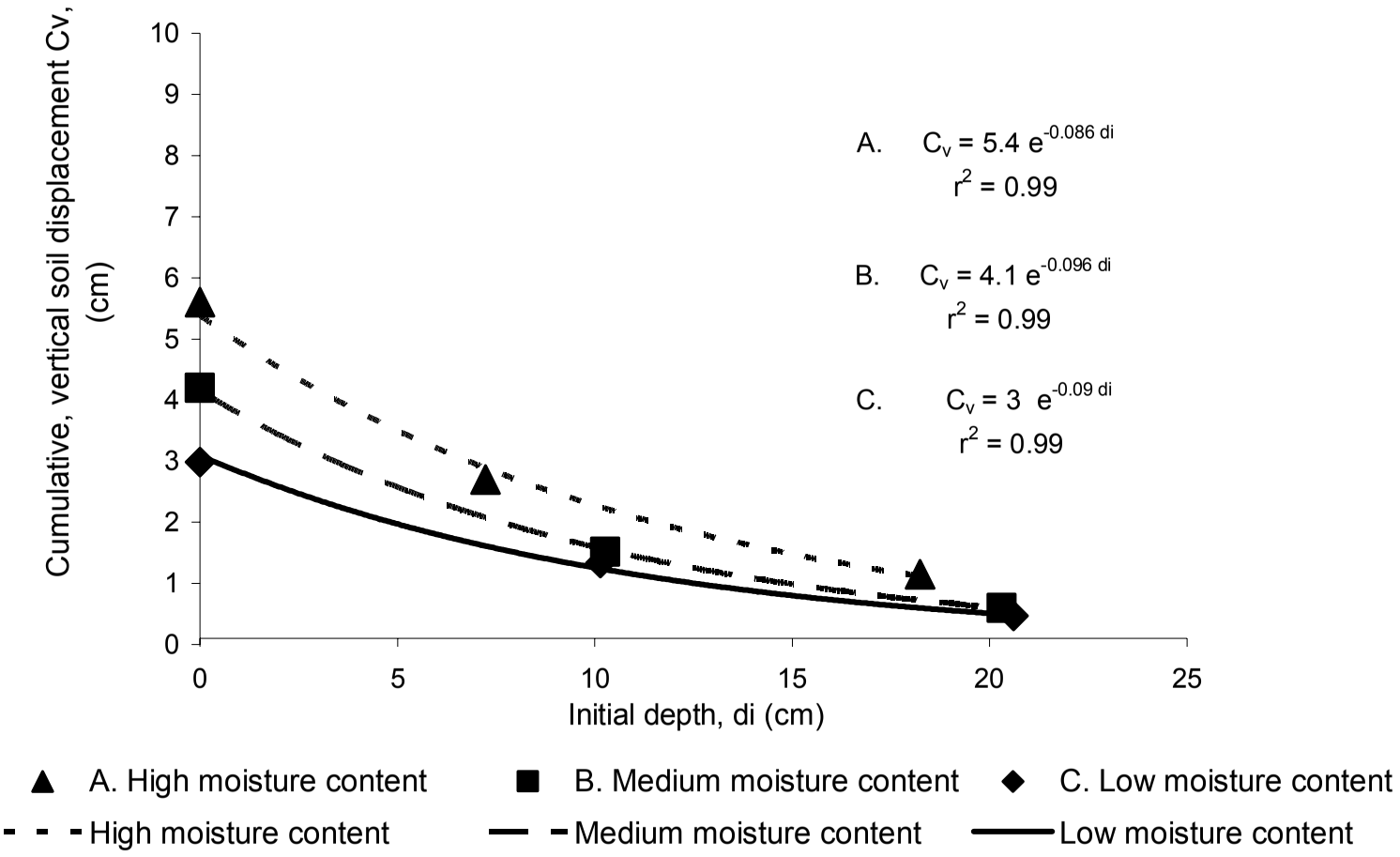


Figure 4.5 Cumulative, vertical soil displacements for soil with high bulk density (1127 kg/m^3) (dry basis) and three moisture contents (13.5, 16.6, and 19.6%).

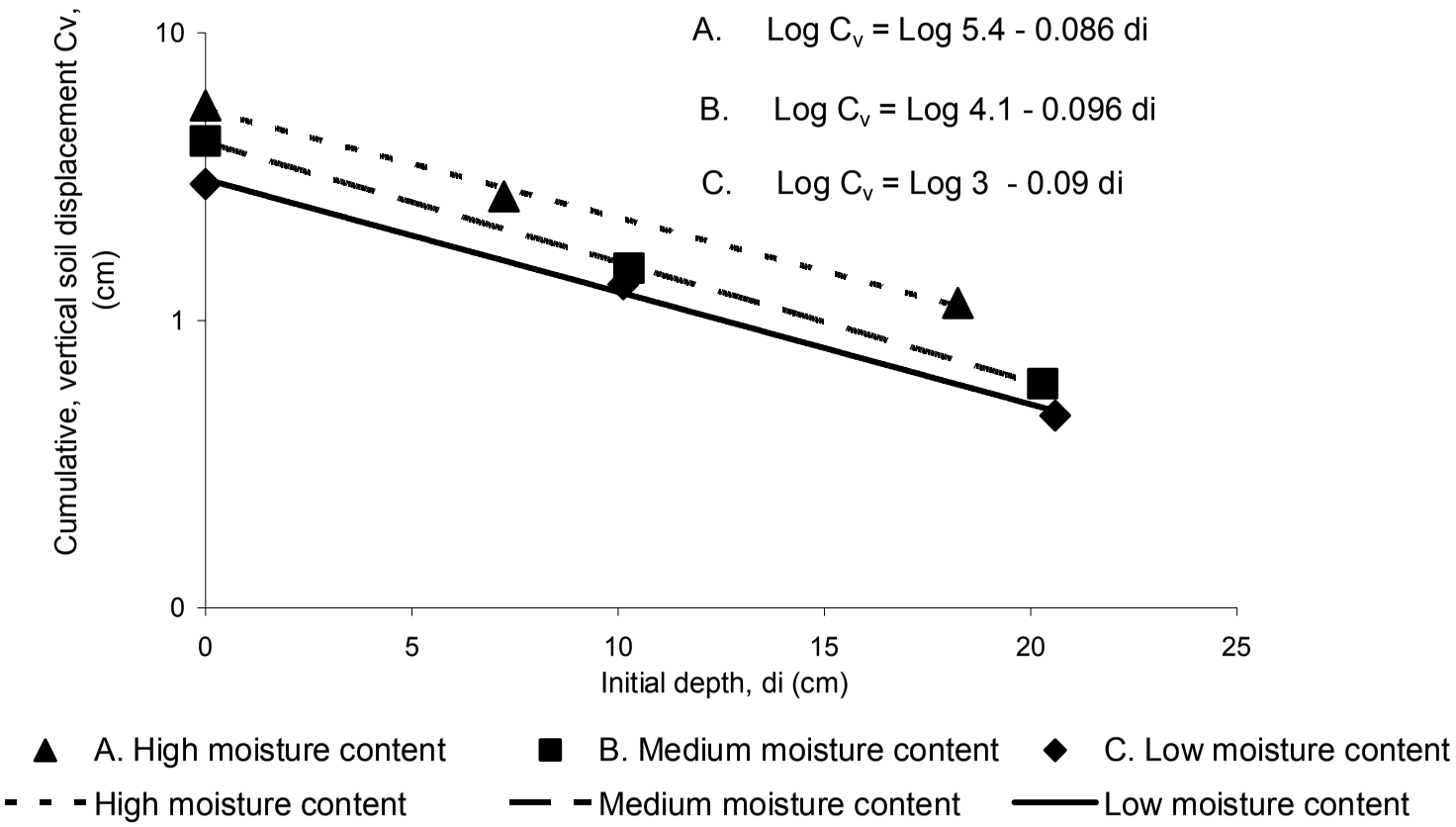


Figure 4.6 Semi-log scale representing, cumulative vertical soil displacements for soil with high bulk density (1127 kg/m^3) (dry basis) and three moisture contents (13.5, 16.6, and 19.6%).

Analysis of variance (Table F6 in Appendix F) shows that the difference between vertical soil displacement for the three moisture contents using high bulk density were significant at the surface (0 mm depth) until the third layer (at 200 mm depth). There were no significant differences at the 4^{th} (300 mm depth) through the 7^{th} layer (600 mm depth).

Summary

Comparing the effect of three moisture contents on the vertical soil displacement, it was found that there was no significant effect on the exponential decay term (B) in the regression equation indicating that the soil moisture shifted the cumulative displacement lower or higher depending on the moisture content. However, the term (A_c) representing the surface vertical displacement increased with increase in moisture content.

4.1.1.4 Effect of moisture content on soil surface vertical displacement

Figures 4.7 shows the actual vertical displacement of the soil surface for low, medium and high soil bulk density levels, respectively.

For the experimental data shown in Figure 4.7 the data can not be extrapolated since the soil behavior would change with higher or lower moisture contents.

To quantify the effect of moisture content on the theoretical vertical soil displacement (A_c) Figure 4.8 was plotted with three different bulk densities curves. Each curve was for three different moisture contents. The equation for experimental data was in the form:

$$A_c = c_1 M_c - c_2$$

where:

A_c = Theoretical vertical soil displacement

c_1, c_2 = Constant depends on the soil moisture content and bulk density

M_c = Soil moisture content

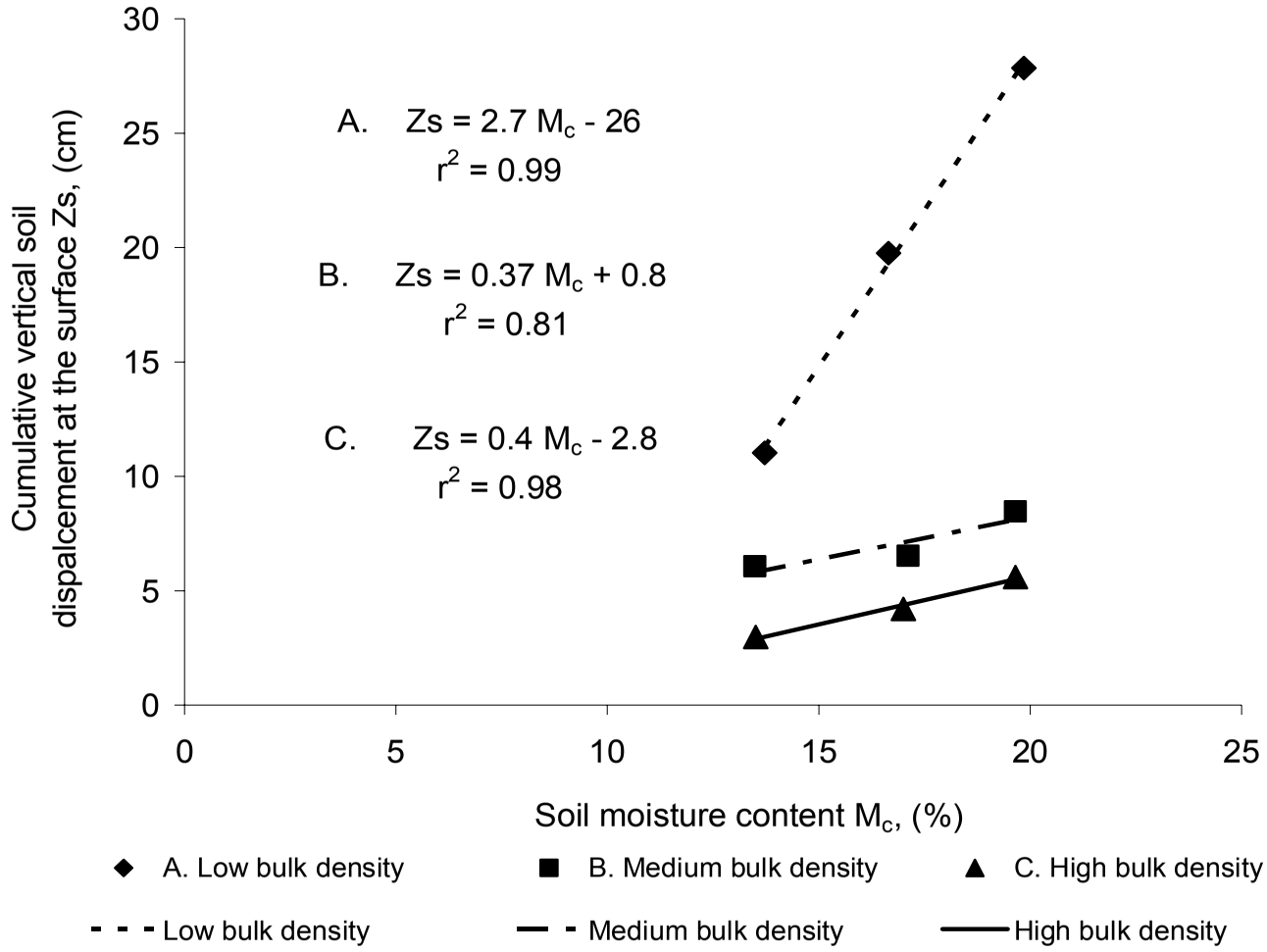


Figure 4.7 Experimental cumulative vertical soil displacement at the surface for different bulk densities.

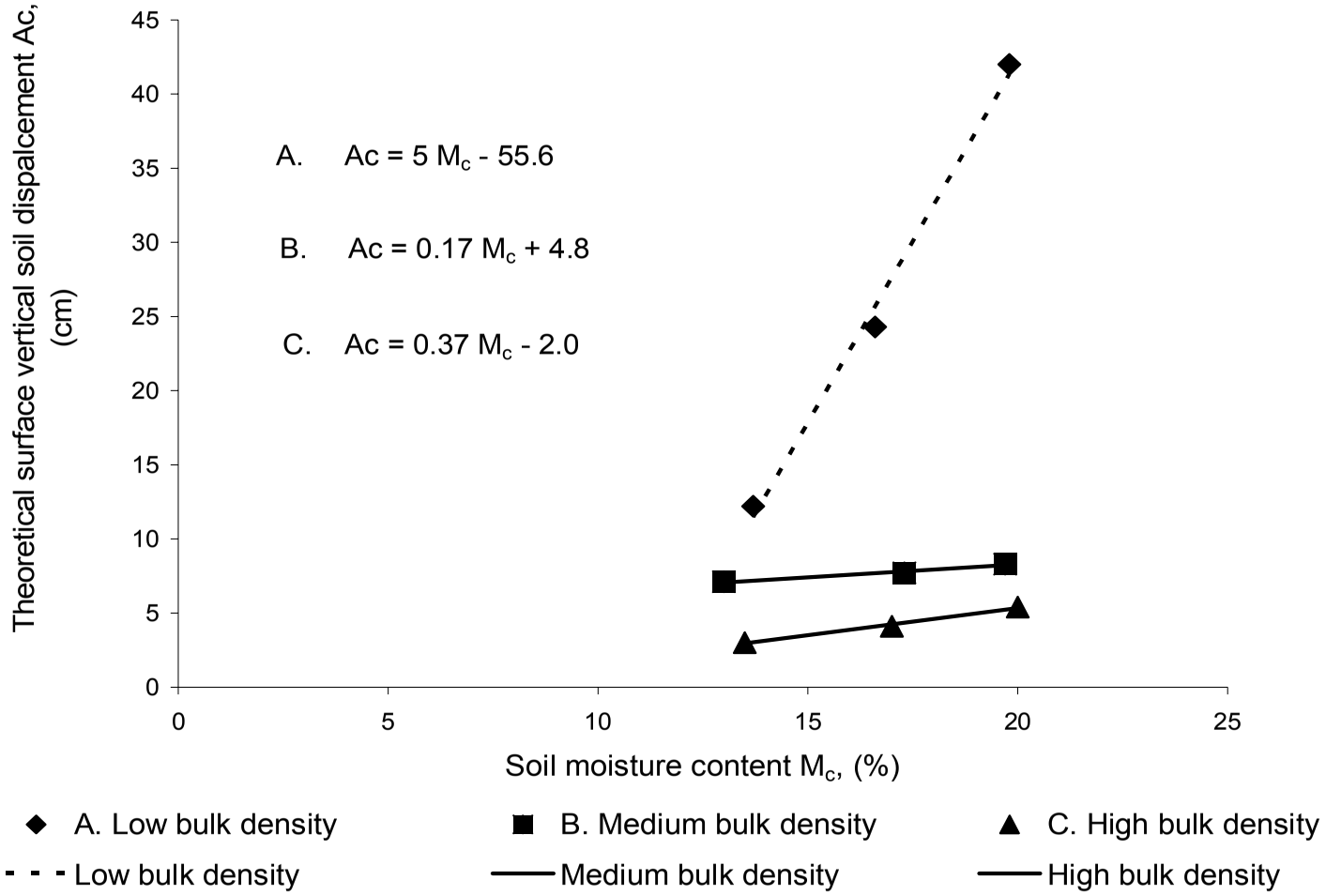


Figure 4.8 Effect of moisture content on the theoretical soil vertical displacement (A_c) for different bulk densities.

From the equations presented in Figure 4.5, A_c had a linear relationship with the soil moisture content. The constants of the equation were the same as for the same bulk density. As the bulk density of soil increased the constants of the equation (c_1 and c_2) decreased for the experimental and theoretical results.

As given in (Tables F4, F5 and F6 in Appendix F). There was a highly significant difference among the displacement at the surface layers.

As shown in Figure 4.7, the surface soil displacement increased in magnitude with an increase in the soil moisture. Note that similar trends for the observed cumulative surface displacement exist for the medium and high dry bulk densities. The behavior of soil at higher or lower moisture contents cannot be predicted outside the range of moisture contents used in this investigation. At lower moisture content (below 14%) the vertical soil displacement would not reach zero even if the soil is totally dry (0% moisture content). However, the load applied will rearrange soil particles that will result in some surface displacement.

The trend indicated in Figures 4.7 showed that a significant reduction in the surface soil displacement occurred as soil moisture decreased and density increased. When comparing the soil surface displacement for the three different bulk densities, the results showed a significant decrease as the bulk density

decreased. This indicated that the moisture content was a less significant parameter for soil with higher bulk densities.

The trend of the surface vertical displacement for the low bulk density soil was different from the medium and high. This should be further investigated in reference to medium and high bulk density soils.

4.1.2 Effect of soil bulk density

By changing the soil bulk density and keeping the moisture content and shape of loading surface constant, the effect of the soil bulk density on the cumulative vertical soil displacement at the surface and within the soil profile were investigated.

4.1.2.1 Effect of bulk density for low soil moisture content

Figure 4.9 (based on data from Tables D4, D12 and D20 in Appendix D) shows the cumulative vertical soil displacement of soil surface to a depth of 600 mm for low soil bulk density, to a depth 400 mm for medium soil bulk density and to depth 300 mm for high soil bulk density. For the medium and high bulk

densities, the vertical soil displacement was close to zero at depths of 500 mm and 400 mm below the soil surface, respectively, and had negligible effect.

Soil columns with uniform moisture content across its profile of 13.6% and three bulk densities (dry basis) (1041, 1112 and 1160 kg/m^3) were used. An exponential decay curve was fitted to the data with the coefficient of regression (r^2) for the three curves ranging between 0.97 and 0.99.

The resulting equations for the vertical soil displacement for each of the various bulk densities are as follows:

Low bulk density (1041 kg/m^3) $C_v = 12.2\, e^{(-0.065\, di)}$ (4.5)

Medium bulk density (1112 kg/m^3) $C_v = 7.4\, e^{(-0.087\, di)}$ (4.6)

High bulk density (1160 kg/m^3) $C_v = 2.7\, e^{(-0.072\, di)}$ (4.7)

The exponential term varied slightly with the different bulk densities; however, it was not statistically significant.

The average exponential term was 0.065, 0.087 and 0.072 for low, medium and high bulk density soils, respectively. The y-intercept varied among the curves

which indicate that the vertical soil displacement at the surface increased as the soil bulk density decreased.

An increase in soil resistance against the applied load is observed as bulk density increased. The analysis of variance (Table F1 in Appendix F) showed that the difference between vertical soil displacement for the three bulk densities were significant to a depth of 300 mm and not significant at depths of 400, 500 and 600 mm. Figure 4.10 shows a Semi-log plot of the same data when cumulative vertical displacement was plotted on the log scale.

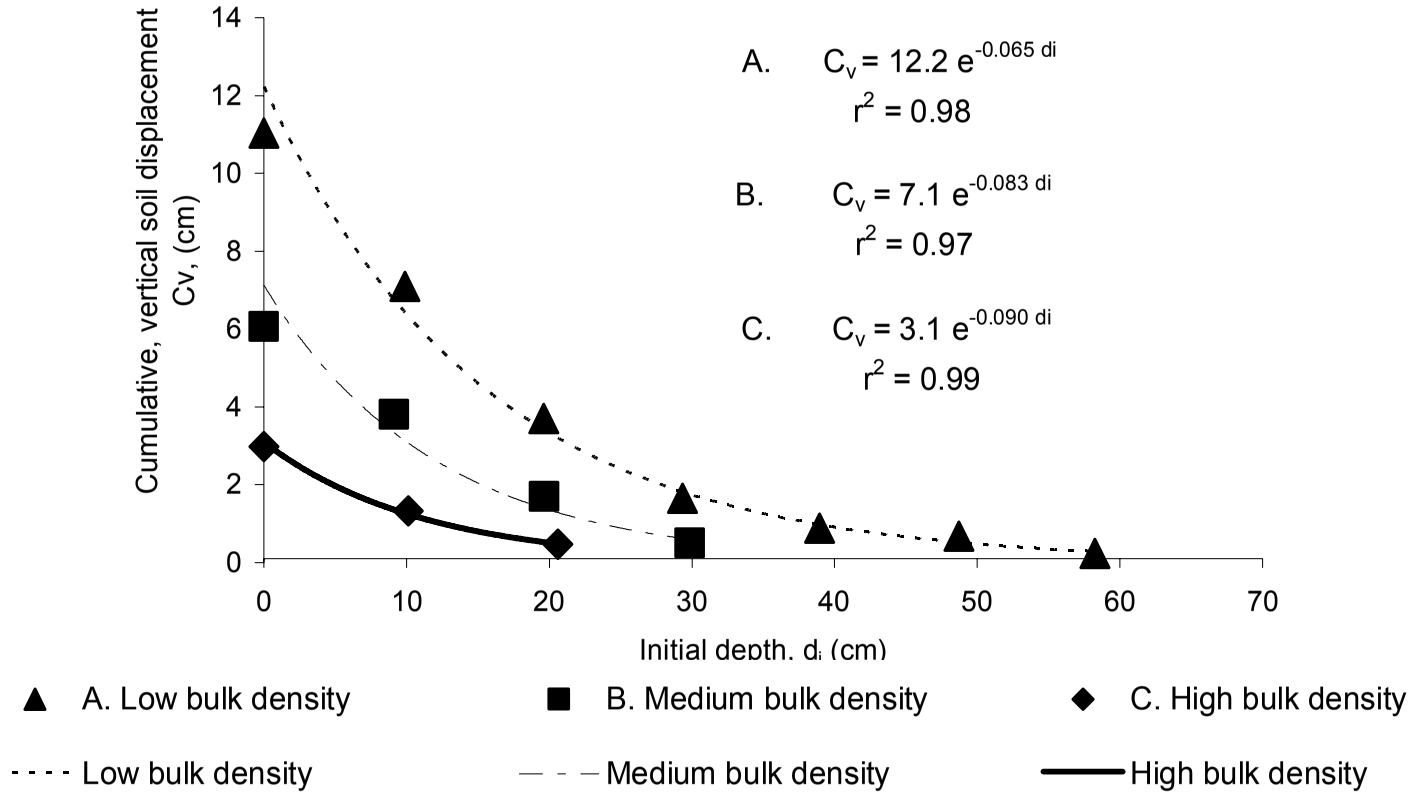


Figure 4.9 Cumulative, vertical soil displacements for soil with low moisture content (13.6%) and three bulk densities (dry basis) (1041, 1112 and 1160 kg/m^3).

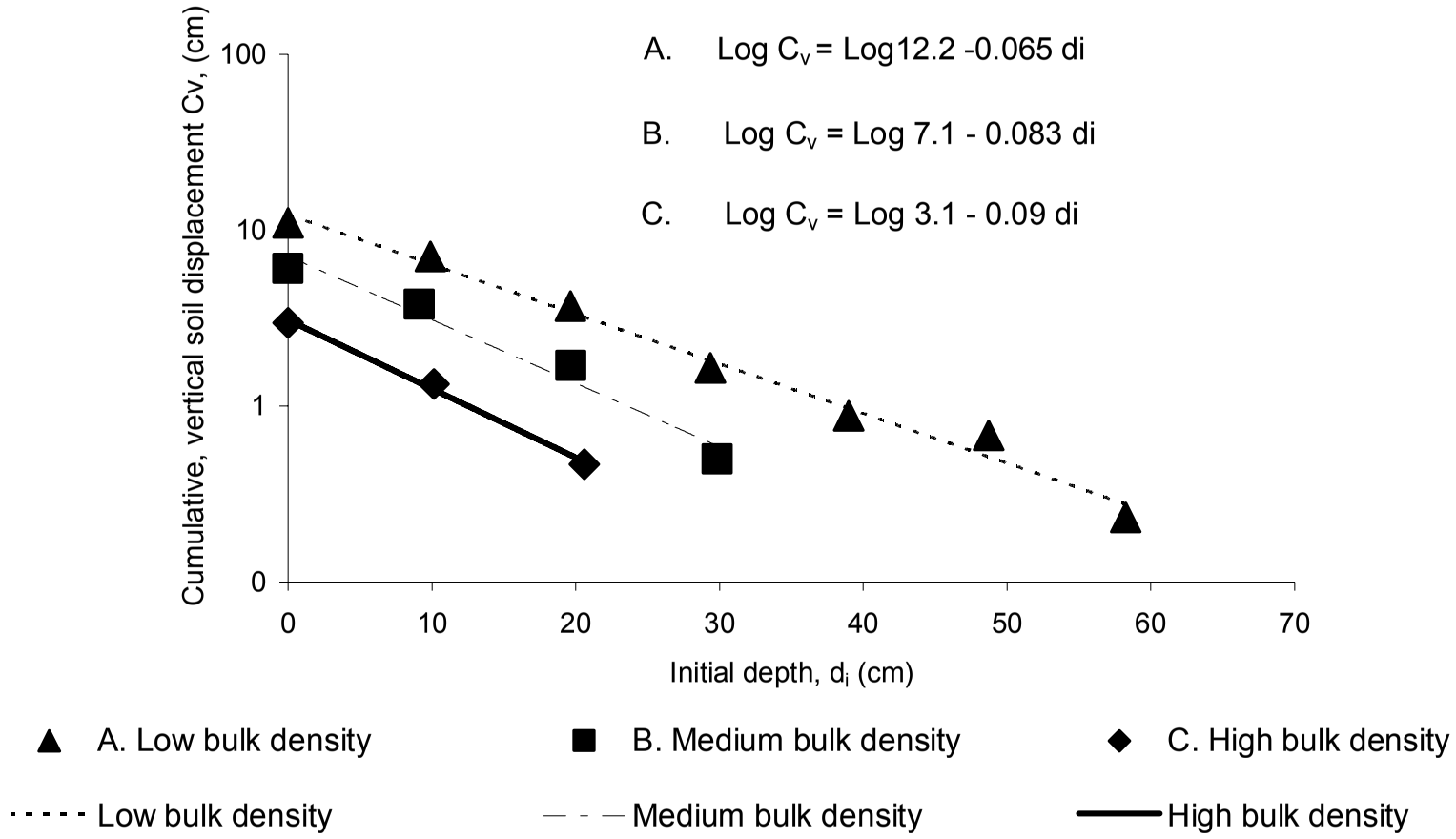


Figure 4.10 Semi-Log scale representing, Cumulative vertical soil displacements for soil with low moisture content (13.6%) and three bulk densities (dry basis) (1041, 1112 and 1160 kg/m^3).

4.1.2.2 Effect of bulk density for medium soil moisture content

Figure 4.11, based on data from Tables D28, D36 and D44 of Appendix D, shows the cumulative vertical soil displacements for soil with a moisture content of 16.7% and three bulk densities (dry basis) (960, 1068 and 1134 kg/m^3). Figure 4.12 shows a Semi-log plot of the same data when cumulative vertical displacement was plotted on the log scale.

As shown in Figure 4.11, the cumulative vertical soil displacement curves for medium and high bulk density soil columns are similar. In contrast a greater cumulative soil displacement for the low soil bulk density column was observed; i.e the column showed significantly greater compaction for the same load to a deeper depth. In summary at 17% moisture content, as the bulk density increased, the magnitude of vertical soil displacement decreased.

The analysis of variance (Table F2 of Appendix F) showed a significant difference between the vertical soil displacement for the three bulk densities at depth of 0, 100, 200, 300 and 400 mm. No significant difference was observed at depth of 500 and 600 mm.

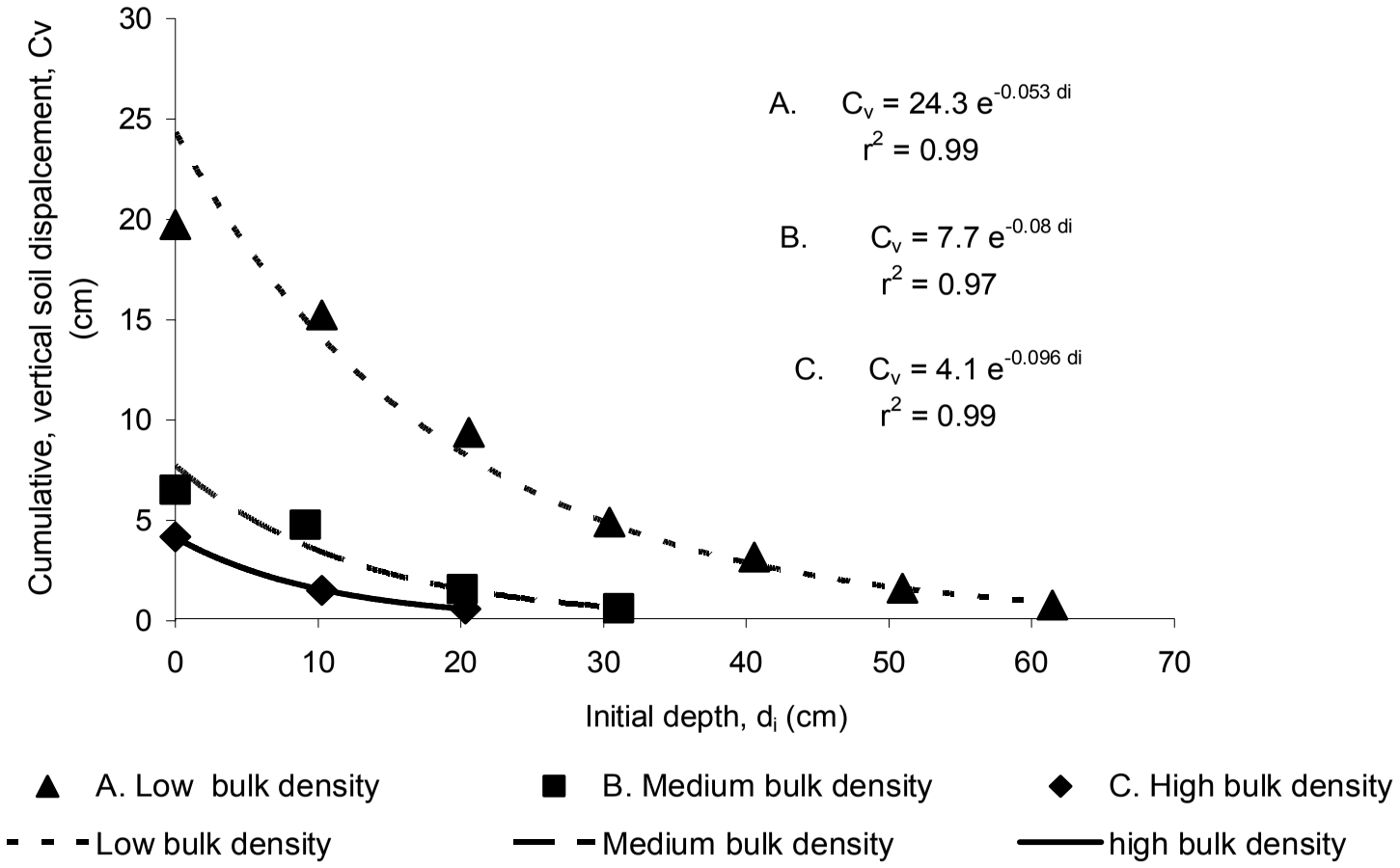


Figure 4.11 Cumulative, vertical soil displacements for soil with medium moisture content (16.7%) and three bulk densities (dry basis) (960, 1068 and 1134 kg/m^3).

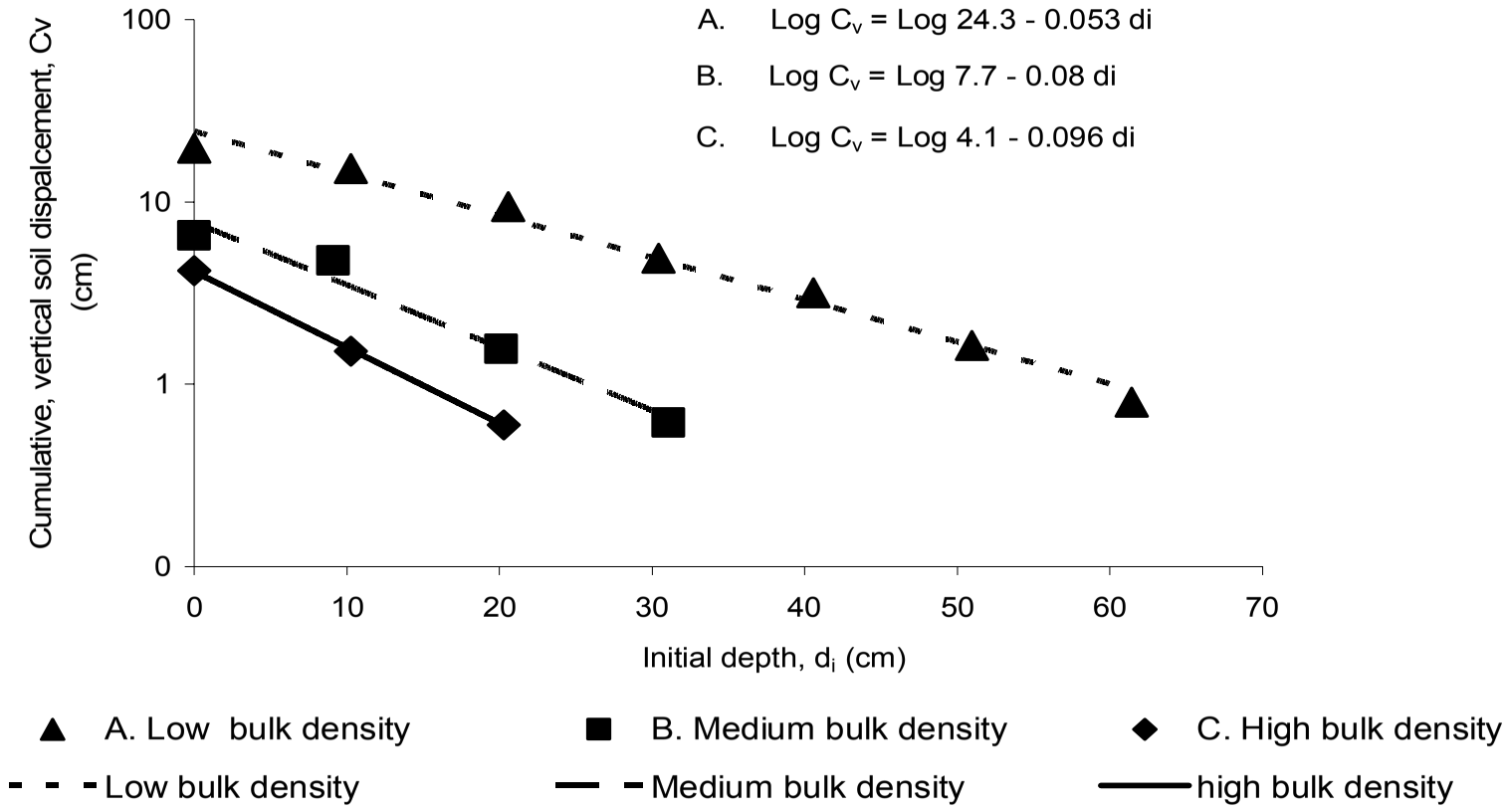


Figure 4.12 Semi-log scale representing, Cumulative vertical soil displacements for soil with medium moisture content (16.7%) and three bulk densities (dry basis) (960, 1068 and 1134

4.1.2.3 Effect of bulk density for high soil moisture content

Figure 4.13 based on data from Tables D52, D60 and D68 in Appendix D showed the cumulative, vertical soil displacement for soil with moisture content at 19.7% and three bulk densities (dry basis) (967, 1030 and 1087 kg/m^3). Figure 4.14 shows a Semi-log plot of the same data when cumulative vertical displacement was plotted on the log scale.

In Figures 4.13, a similar trend was observed as in Figure 4.9 and 4.11. The medium and high bulk density soil curves were similar with respect to decay rate and vertical soil displacement at surface (y-intercept). However, the low bulk density soil column showed increased displacement to greater depth.

The analysis of variance (Table F3 of Appendix F) showed that the difference between vertical soil displacement for the three bulk densities were highly significant at 0, 100, 200, 300, 400, 500 and 600 mm depths; however, the level of significance decreased with increased depth.

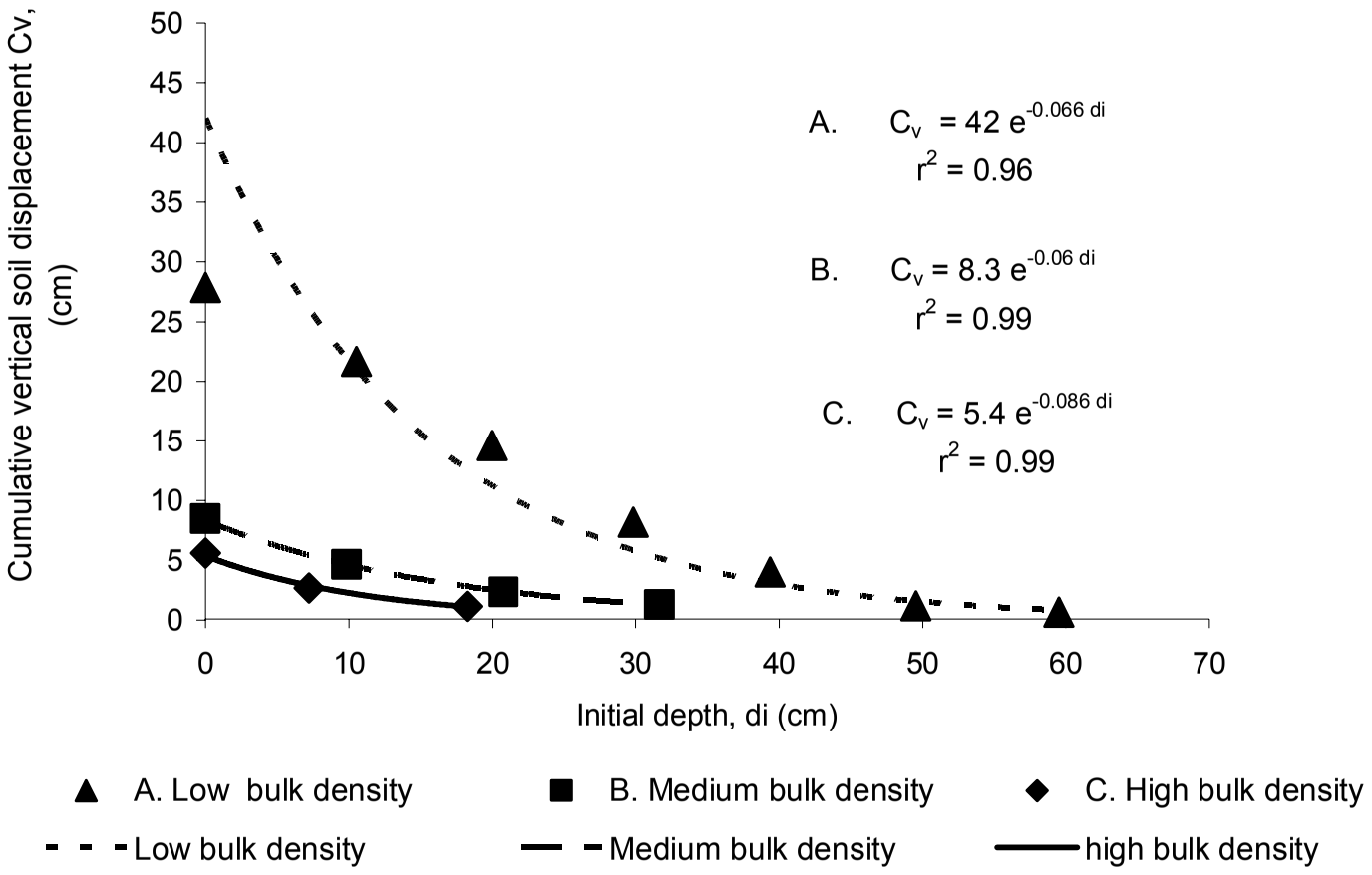


Figure 4.13 Cumulative, vertical soil displacements for soil with high moisture content (19.7%) and three bulk densities (dry basis) (967, 1030 and 1087 kg/m^3).

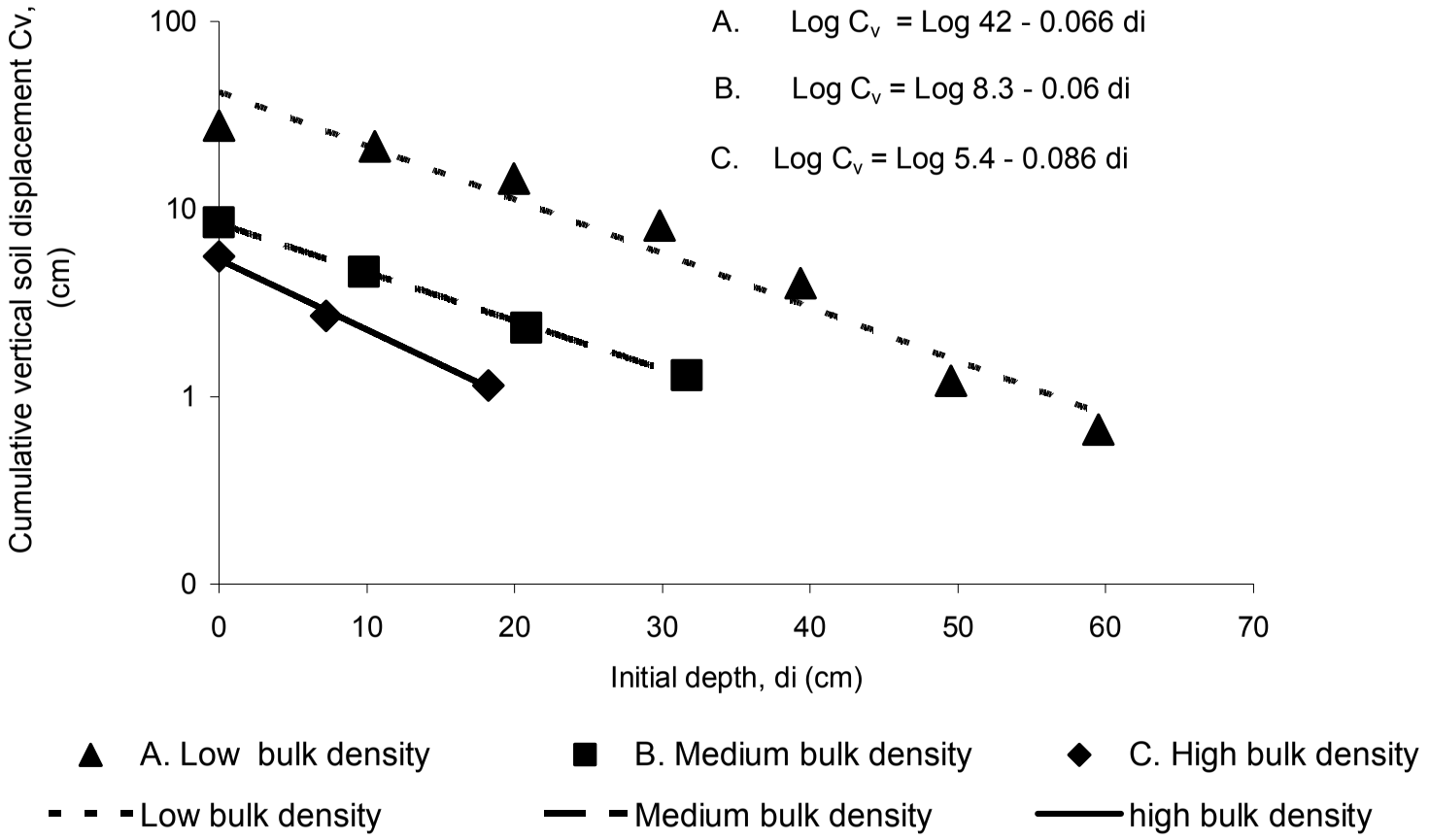


Figure 4.14 Semi-log scale representing, Cumulative vertical soil displacements for soil with high moisture content (19.7%) and three bulk densities (dry basis) (967, 1030 and 1087 kg/m^3).

When comparing Figures 4.9, 4.11 and 4.13, as the moisture content increased for the same set of bulk densities, load magnitude and loading surface, the distinction between the low bulk density soil column with the medium and high bulk density soil columns was more apparent. The observed difference in magnitude of the cumulative, vertical soil displacement between low, medium and high soil bulk densities increased as moisture content increased. As the moisture content decreased, the behavior of the medium and high bulk density soil columns became more similar, indicating that the soil resistance to an applied load must be similar above a certain level of soil density.

4.1.2.4 Effect of bulk density on soil surface vertical displacement

The effect of soil bulk density on the vertical soil displacement at the surface for each of the various moisture contents are shown in Figure 4.15

Degree of slop was higher for the high moisture content soil. The change toward lower bulk density yielded higher displacement. As shown in Figure 4.15, as the moisture content increased the magnitude of vertical soil displacement, at the surface increased. Soil with high bulk density (dry basis) (high initial compaction) showed less displacement, as the soil resistance was higher as fewer voids existed. The applied load relocated soil particles. As

moisture content decreased soil exhibited higher resistance resulting in lower vertical displacement.

As the bulk density increased, the vertical soil displacement at the surface decreased. The data cannot predict displacement for bulk densities lower than 990 kg/m^3 (dry basis) since soil with lower bulk densities is considered loose soil. The vertical soil displacement at the surface will be close to zero at bulk densities greater than 1127 kg/m^3 (dry basis). This also justifies the range of the bulk densities used in this experiment (from 990 kg/m^3 to 1127 kg/m^3)(dry basis) as there will be little or no effect on the displacement of sub-layers from an applied load of 800 N on the $6.4x10^{-3}$ m^2 surface.

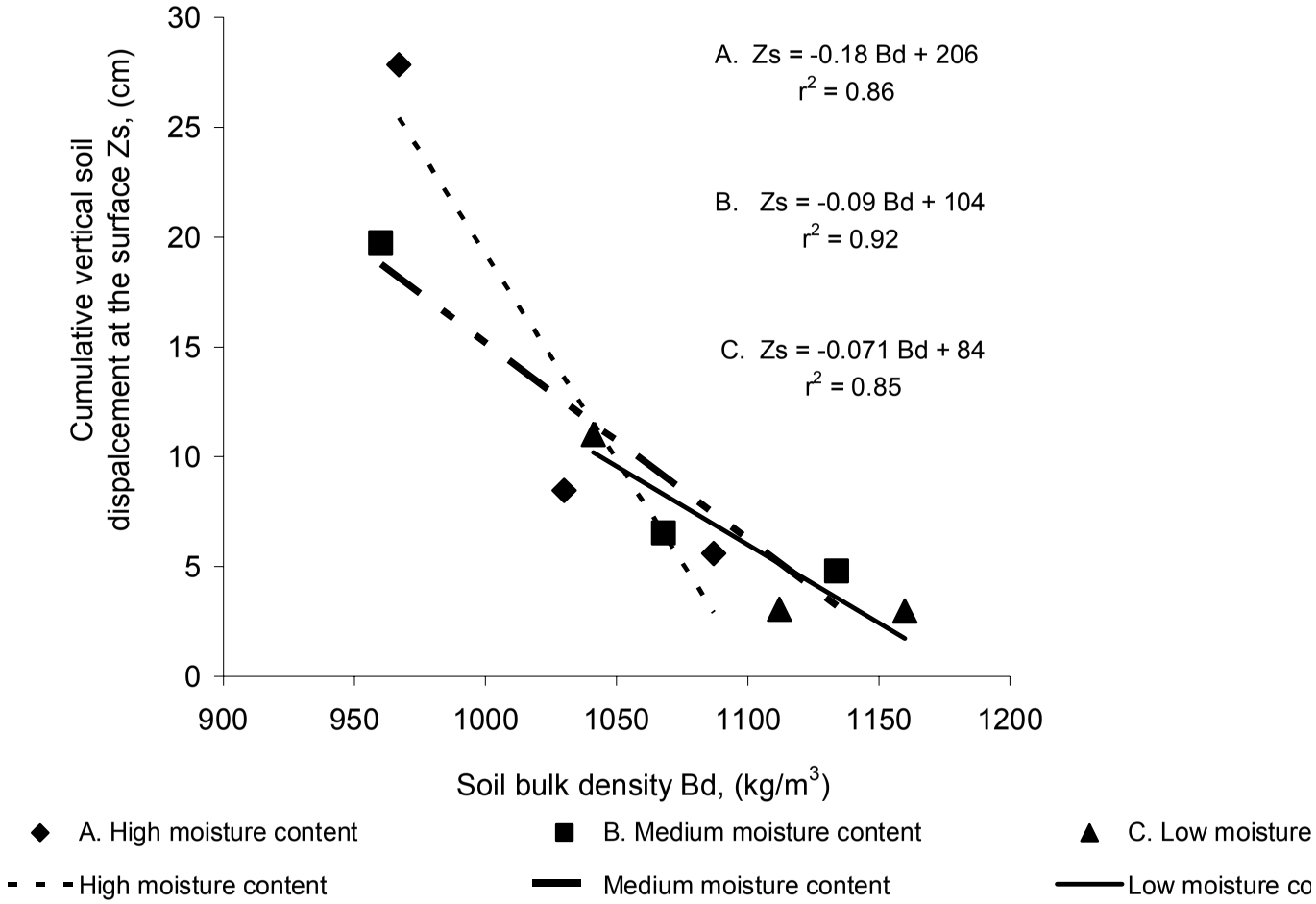


Figure 4.15 Effect of soil bulk density on cumulative, vertical soil displacement at the surface using three bulk densities (dry basis) (990, 1070, and 1127 kg/m^3) and low, medium and high soil moisture contents (13.6, 16.7 and 19.7%).

4.1.2.5 Effect of bulk density on the exponential decay term

The exponential decay rate increased with the increase in the soil bulk density based on a comparison among Figures 4.9, 4.11 and 4.13. This indicates that higher loads will be required to achieve the same surface and sub-surface displacement for higher soil densities.

The degree of slope was more for soil with high moisture content. The change in bulk density from 990 to 1127 kg/m^3 (dry basis) resulted in higher displacement than when using medium and low moisture content.

4.1.2.6 Effect of moisture content and bulk density on cumulative surface vertical soil displacement

A combined 3-D plot of cumulative surface vertical soil displacement showing the effect of moisture content and bulk density is given in Figure 4.16.

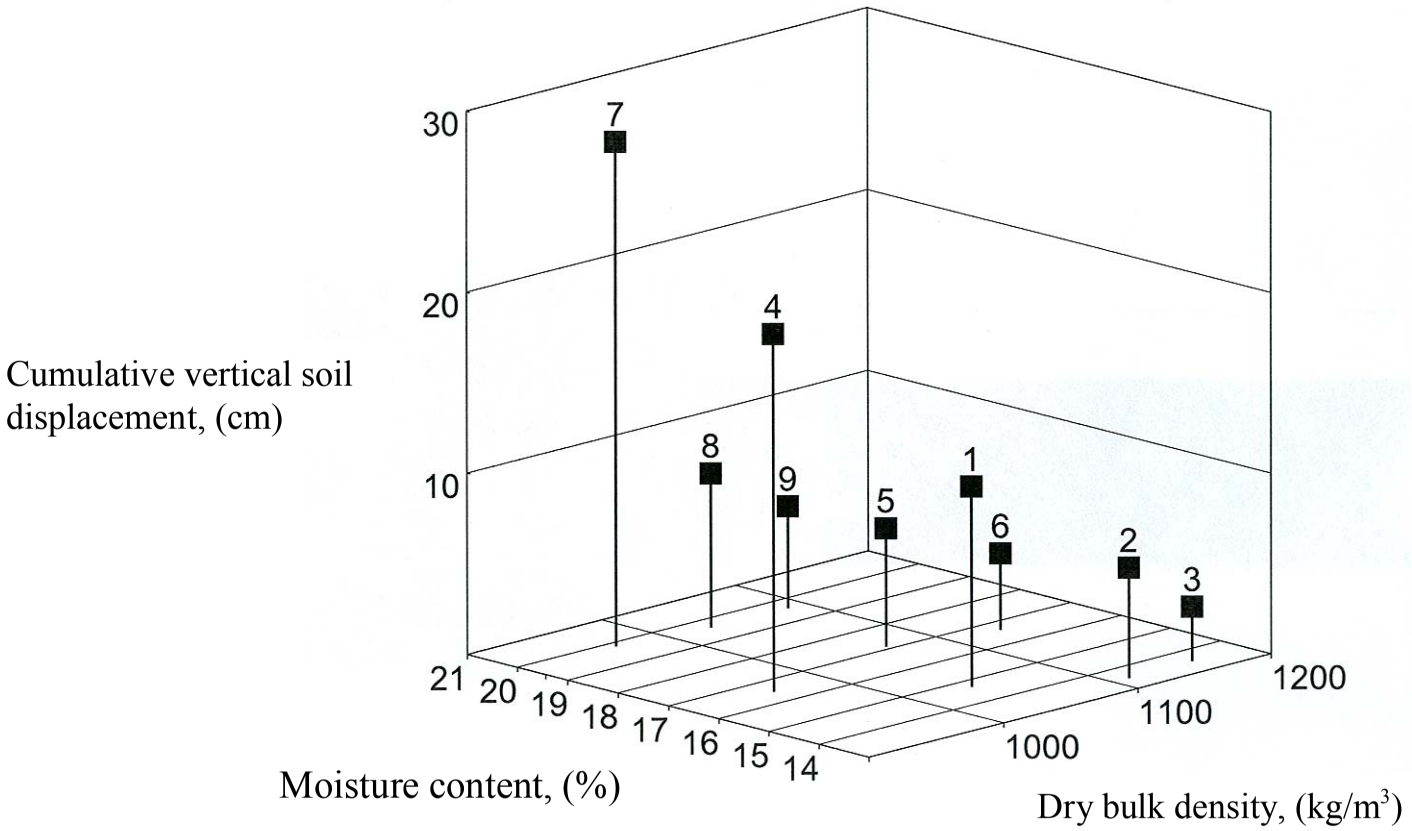


Figure 4.16 3-D plot representing cumulative vertical soil displacement for different bulk densities and moisture content

where:

1. Low dry bulk density and Low moisture content = 11 cm
2. Medium dry bulk density and low moisture content = 6.1 cm
3. High dry bulk density and low moisture content = 3 cm
4. Low dry bulk density and medium moisture content = 19.75 cm
5. Medium dry bulk density and medium moisture content = 6.5 cm
6. High dry bulk density and medium moisture content = 4.2 cm
7. Low dry bulk density and high moisture content = 27.8 cm
8. Medium dry bulk density and high moisture content = 8.5 cm
9. High dry bulk density and high moisture content = 5.6 cm

4.1.3 Effect of shape of loading interface surface

The effect of the shape of the loading surface on the soil vertical displacement is shown in Figures 4.17 and 4.18. A rectangular and elliptical shaped loading surface having the same cross sectional area were used with the soil conditions being kept constant. The aspect ratio was 1.25 for the rectangular plate, and 1.06 for the elliptical plate, although the surface area of 6.4×10^{-3} m^2 was equal for both surfaces. The y-intercept was lower with the rectangular plate in comparison to the oval plate. The applied pressure of the two loading plates was equal since the area was equal. The exponential decay rate remained nearly the same. Note that as the bulk density increased and moisture content decreased, the variation between the two loading interface surfaces diminished.

Tables F7 and F15 of Appendix F showed that there was a slight significant difference (with confidence level 95%) between the vertical soil displacements when using the two different interface surfaces.

Consistently, the rectangular surface area had less vertical soil displacement. The perimeter of the rectangular was greater than the oval plate, which had a significant effect on soil displacement as indicated in the literature review by Youssef and Ali (1982).

The analysis of variance (Appendix F) showed that there was little significant difference between the vertical soil displacement at 0, 100, 200, 300 and 400 mm depths when using high soil moisture content and low soil bulk density, but there were no significant differences when using any other combinations.

The correlation among the various soil conditions due to moisture content for the two plates is similar and has been reported in a preceding section. The plate interface surface geometry is most distinguishable for high moisture content. As moisture content decreased and bulk density increased, the differences in the surface deflection and decay rate between the loading interface plates diminished. Generally, these differences were not considered significant. The smaller aspect rate of width/length of the rectangular plate and of minor/major axis of the oval plate may be the contributing factor, also the different perimeter affecting soil shear at the edge of the plate may be the critical parameter.

The vertical soil displacement of the top layer is the cumulative effect of the displacements of the sub-layers. The vertical displacement of the sixth layer was only the absolute displacement of this layer. This is attributed to the deflection at each layer following an exponentially decaying curve to a depth of 600 mm. The complete data set for these tests using the combination of three moisture contents and three bulk densities are given in Appendix D.

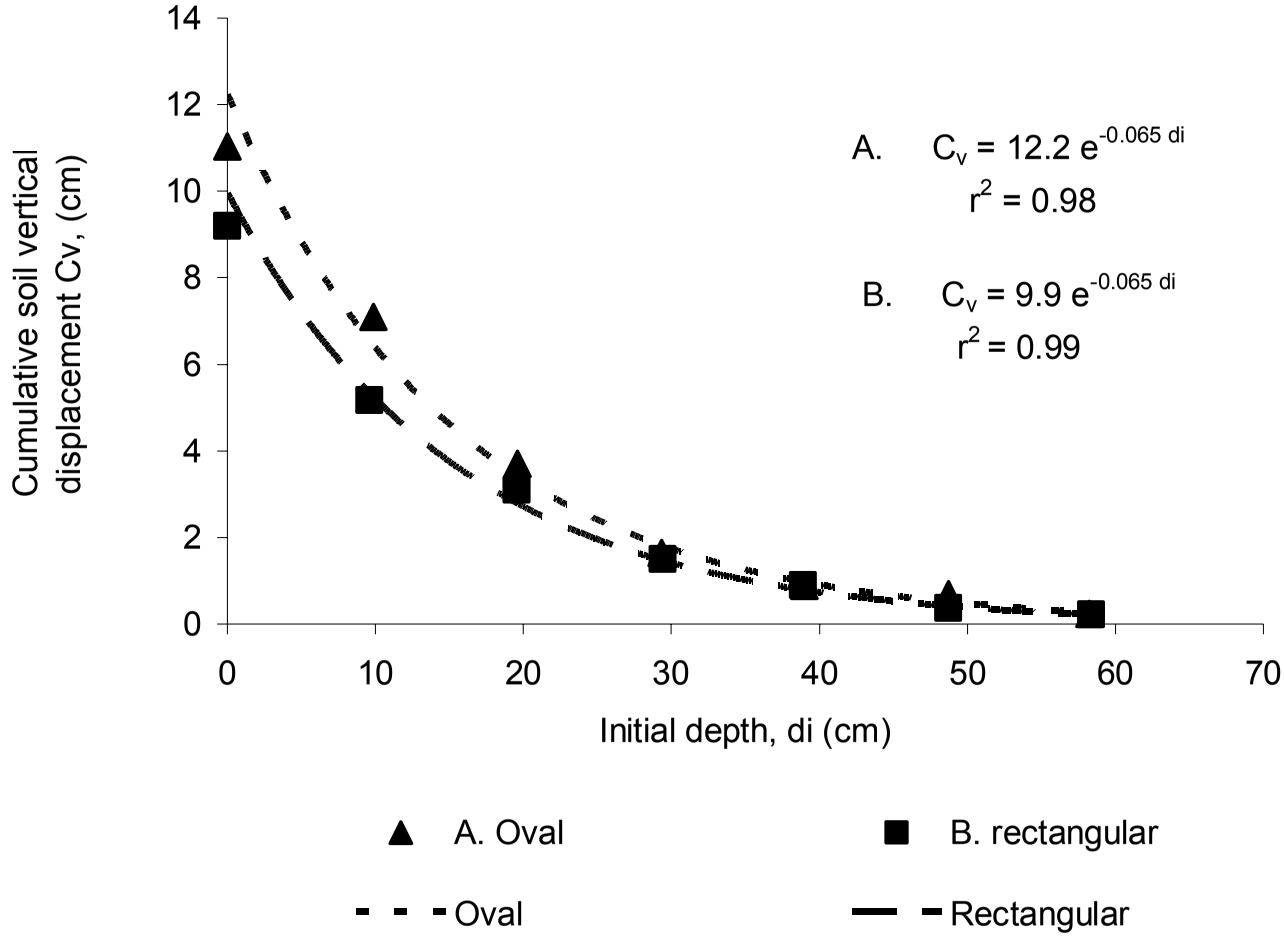


Figure 4.17 Cumulative vertical soil displacement for soil with low moisture content (13.6%) and low bulk density dry basis) (967 kg/m3) with two shapes of loading surfaces.

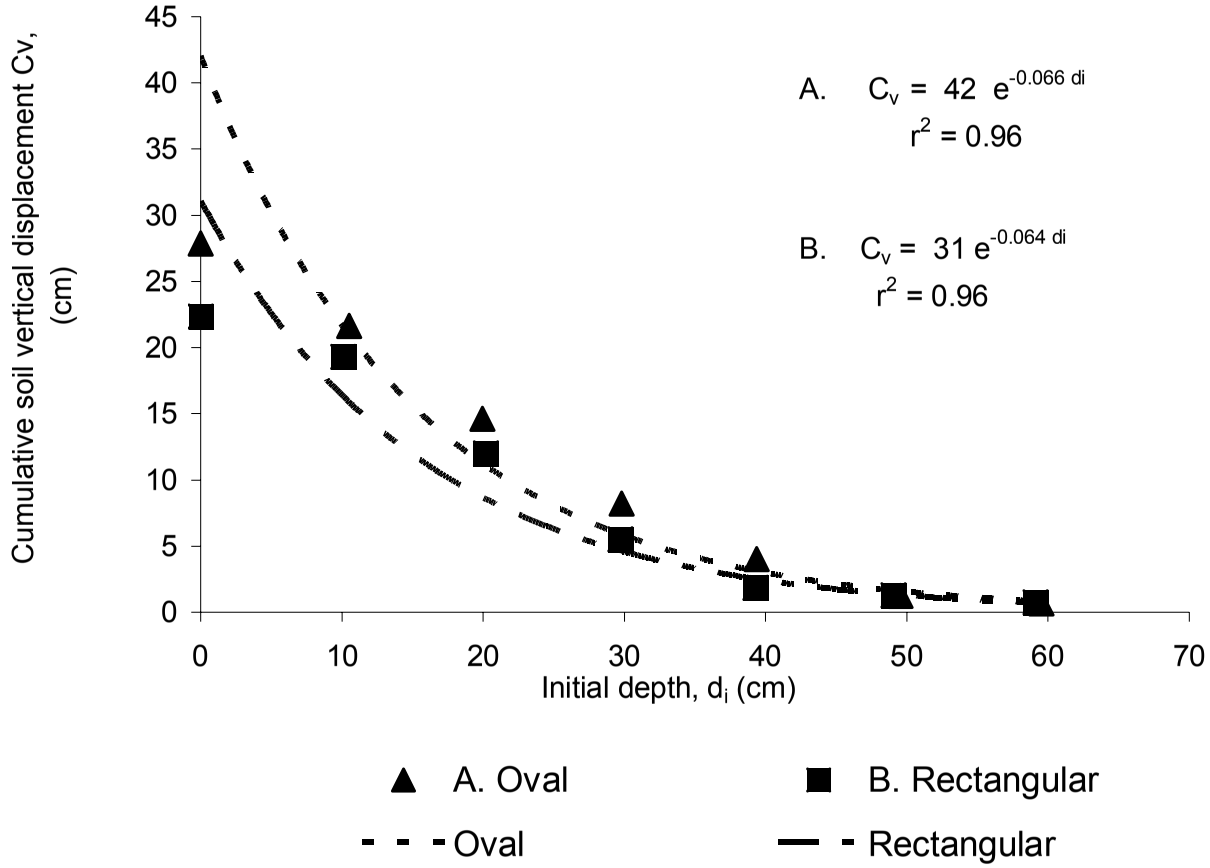


Figure 4.18 Cumulative, vertical soil displacement for soil with high moisture content (19.8%) and low bulk density (dry basis) (967 kg/m^3) with two shapes of loading surfaces (Oval and Rectangular)

4.2 Vertically transferred pressure within the soil profile

The pressure distribution within the soil profile was also measured for the same combinations of parameters, as reported for the vertical soil displacement. The sensors were placed at depths of 0, 50, 100 and 150 mm. The pressures under the centerline of the loading surface at the new locations, where the layers moved with respect to the depth of the layer before the load was applied, were also plotted.

The data also showed an exponential decay with depth, the best curve fitted to these data was the exponential one. The equation has the form:

$$P_{c=} F_d e^{-Bb\ df}$$

Where P_c = Pressure on the sensor at depth df, kPa

F_d = Constant depends on soil surface displacement, kPa

Bb = Exponential decay constant, m^{-1}

df = Depth of sensor, m

The effect of moisture content and bulk density showed no relationship with the transferred pressure as there was no significant difference between the magnitudes of the pressure at the same depth for all the comparisons made.

There was no mathematical relationship determined between the constants and soil moisture content, since the value of the constant (F_d) depended on the vertical displacement of the soil surface.

4.2.1 Effect of moisture content

First the effects of moisture content on the pressure distribution profile were studied by changing the soil moisture content and keeping the other variable constant (bulk density). Note that the effect of shape was not studied.

4.2.1.1 Effect of moisture content for low soil bulk density

Figure 4.19 shows the effect of different soil moisture contents with low bulk density (dry basis) (990 kg/m^3) on the pressure transmitted through the soil profile. The experimental data appears in Tables D4, D28 and D52 of Appendix D. Figure 4.20 shows a Semi-log plot when transferred pressure was plotted on the log scale.

The pressure used in all the experiments was 125 kPa, as a load of 800 N was applied to the 6.4 x 10^{-3} m^2 loading surface. The resistance of the soil for the three moisture contents was the same at the end of the experiment (125 kPa). However, the pressure at the centerline of the loading surface had the highest magnitude. Hence, the pressure measured by the first sensor (on top of the soil surface) was greater than 125 kPa. The pressure at the first sensor ranged from 200 to 250 kPa, for the three moisture contents.

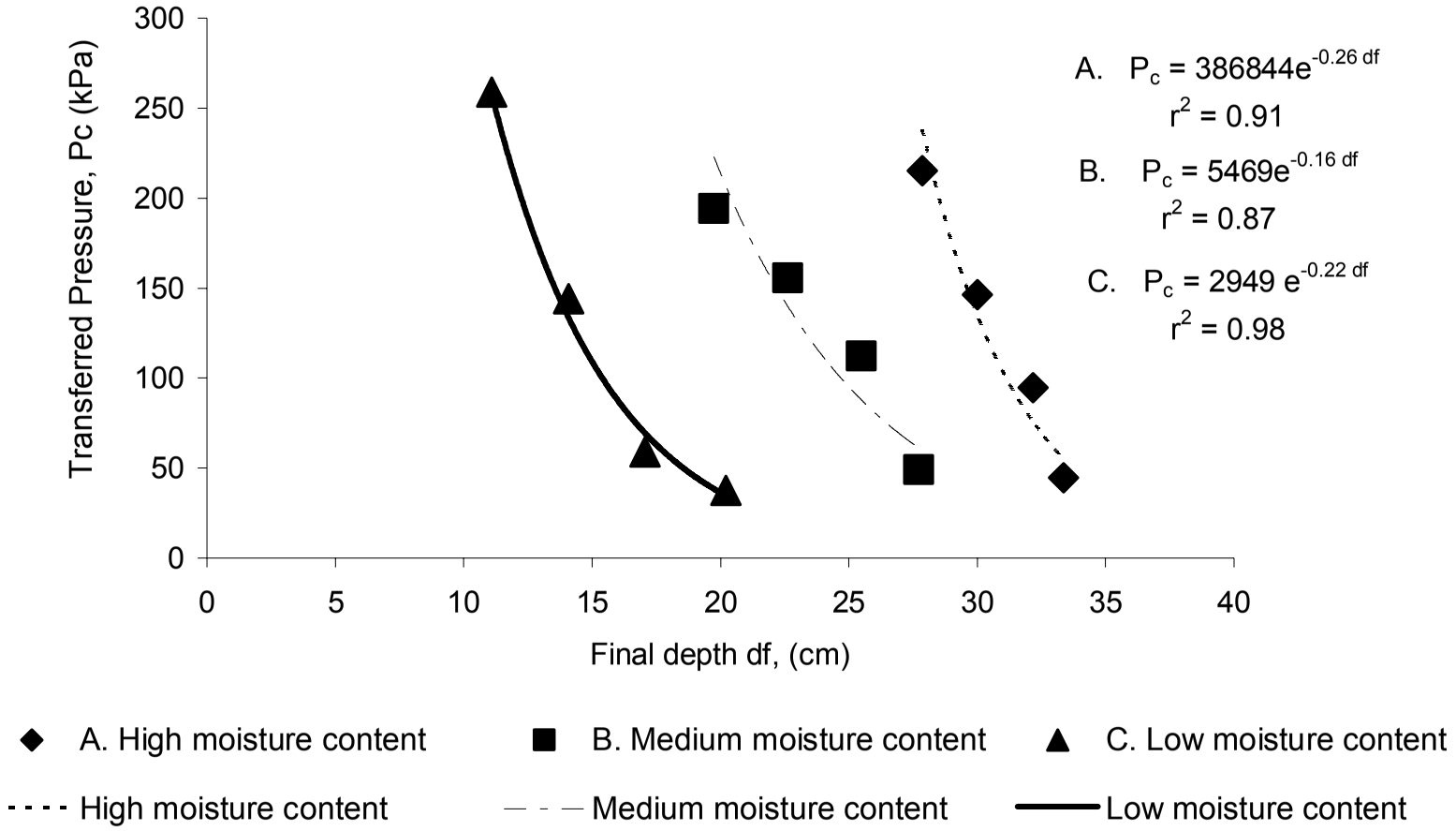


Figure 4.19 Transferred pressure through the soil profile for soil with low bulk density (dry basis) (990kg/m^3) and three moisture contents (13.7, 16.7 and 19.8%)

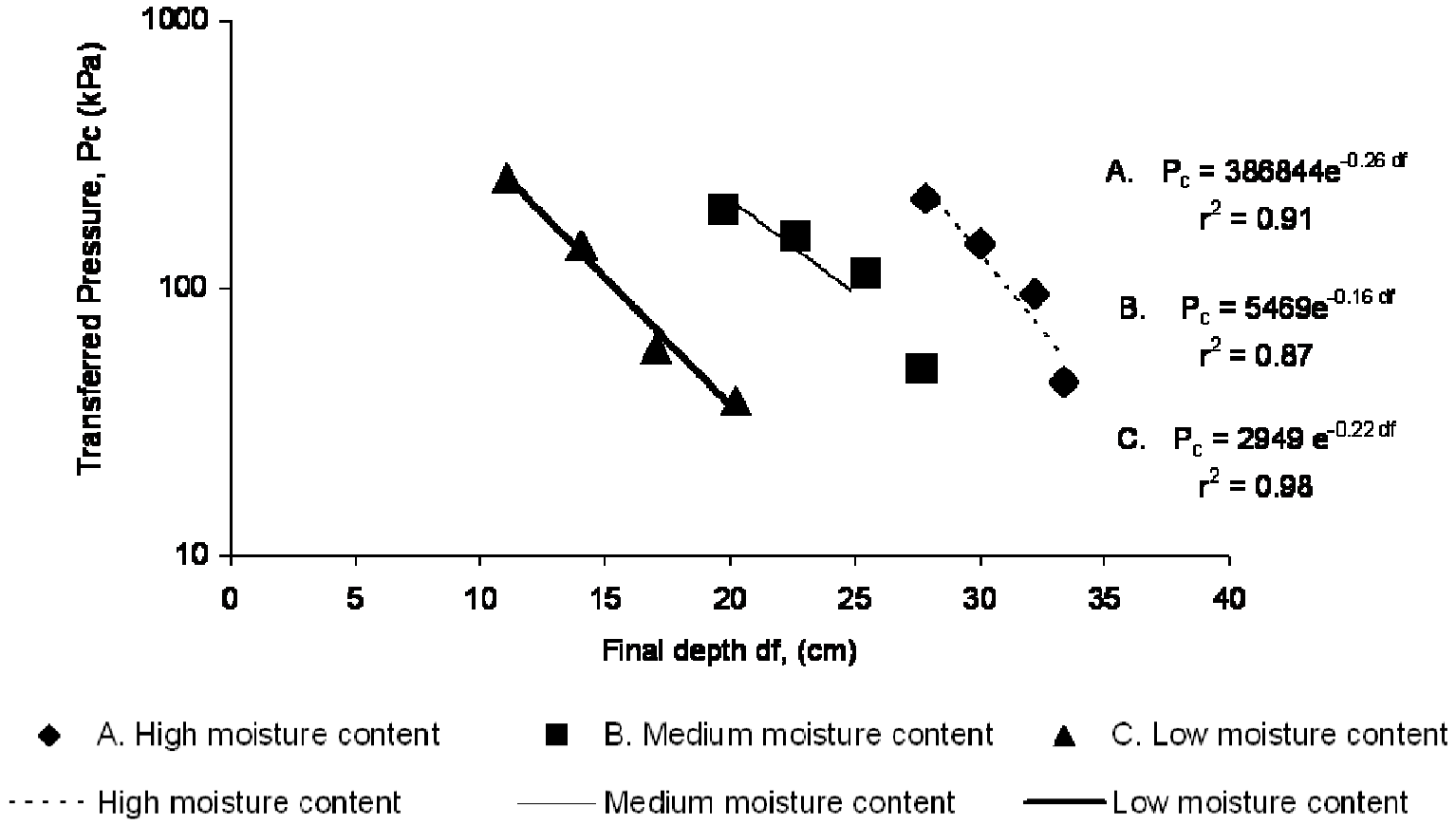


Figure 4.20 Semi-Log scale representing transferred pressure through soil profile for soil with low bulk density (dry basis) (990 kg/m^3) and three moisture contents (13.7, 16.7 and 19.8%)

For the pressure distributed with depth, the fourth sensor which was originally placed at a depth of 150 mm moved to its new location after the load was applied. The final position of the sensor was at a depth of 100, 70 and 50 mm below the initial location for low, medium and high moisture contents, respectively. The soil with higher moisture content had higher displacement than the soil with lower moisture content as indicated previously (section 4.1.1). It is to note that the pressure on the fourth sensor was nearly the same with an average magnitude of 45 kPa regardless of its depth.

For soil with medium and high moisture content, data from the first three sensors appeared to have a well defined trend, however, the fourth point appeared outside the trend. The fourth sensor indicated a more rapidly attenuation of pressure with the magnitude approaching zero. This attenuation in pressure justifies the sensors placement to only a depth of 150 mm as deeper placement was beyond the sensitivity of the sensor and pressure measurements would have been inaccurate.

An analysis of variance (Table F16 of Appendix F) showed little significance in pressure at the surface and no significance at all other depths, with 95% level of confidence.

4.2.1.2 Effect of moisture content at medium soil bulk density.

Figure 4.21 shows the effect of different soil moisture contents for medium bulk density (dry basis) (1070 kg/m^3) soil on the pressure transferred through soil. This is based on the Tables D12, D36 and D60 in Appendix D. Figure 4.22 shows a Semi-log plot of the same data when cumulative vertical displacement was plotted on the log scale.

An analysis of variance (Table F17 of Appendix F) showed no significant difference between the pressures transmitted at any of the depth for the variation in moisture content.

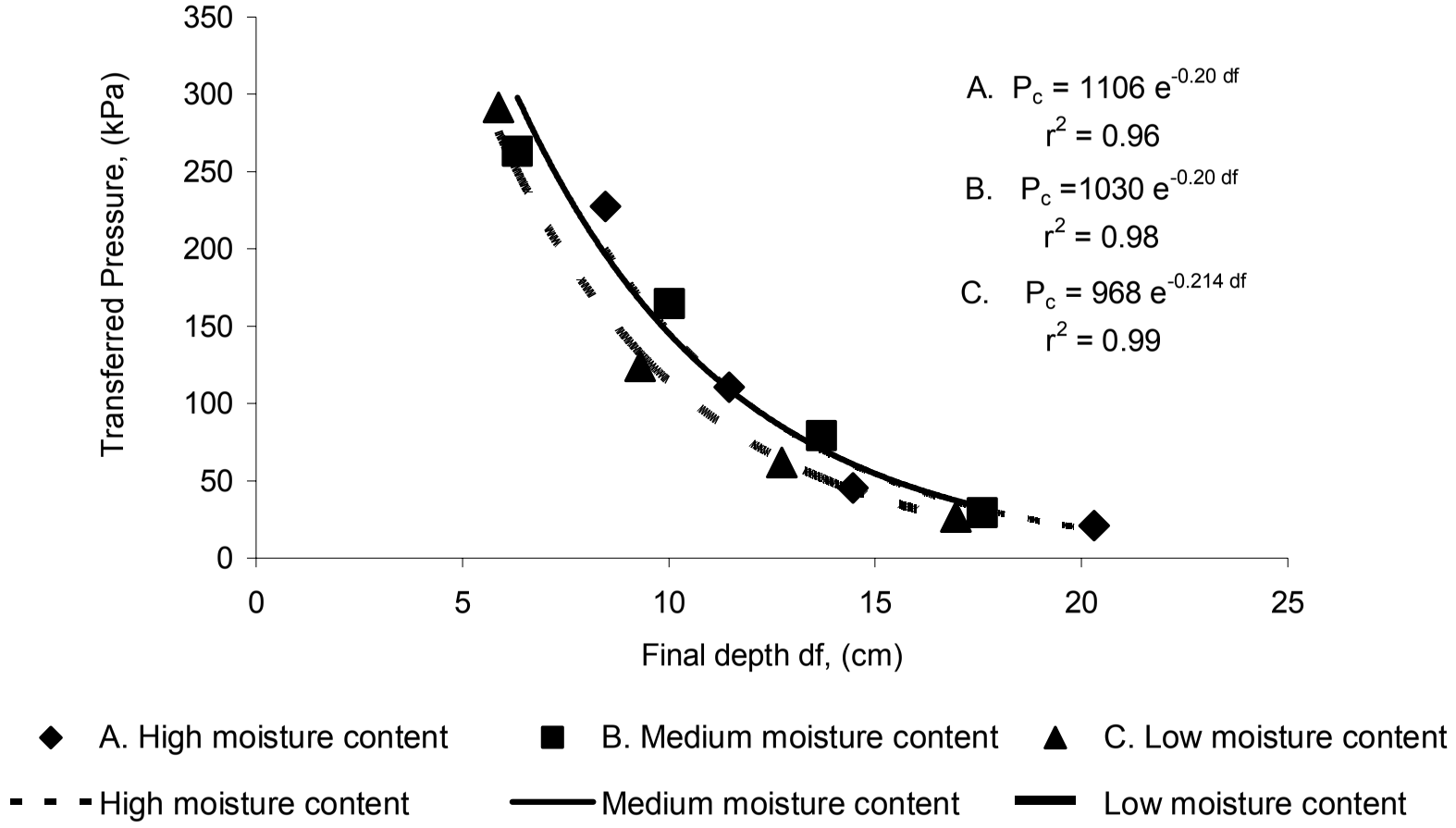


Figure 4.21 Transferred pressure through the soil profile for soil with medium bulk density (dry basis) (1070 kg/m^3) and three moisture contents (13.5, 17.1 and 19.6%)

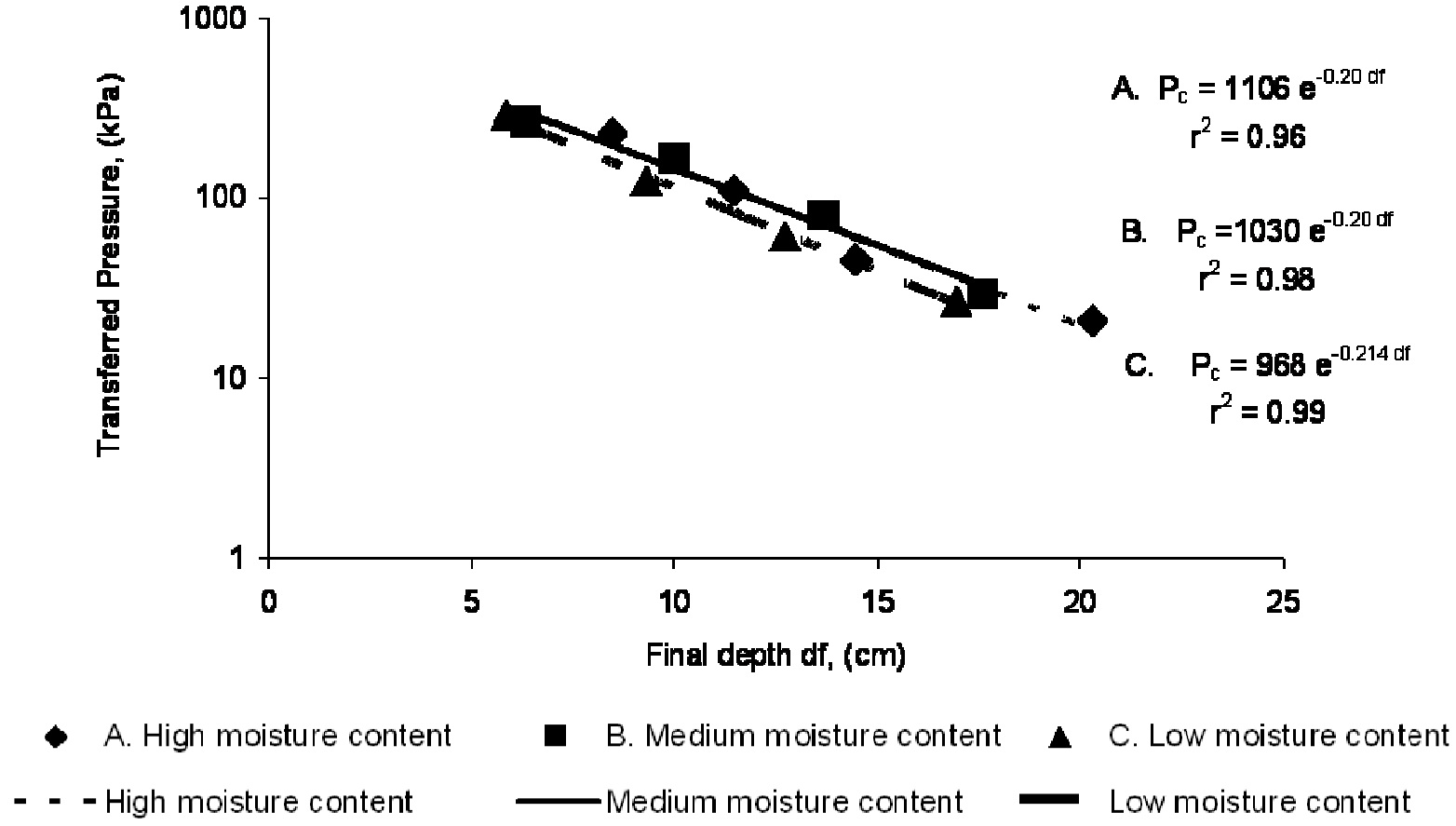


Figure 4.22 Semi-Log scale representing transferred pressure through soil profile for soil with medium bulk density (dry basis) (1070 kg/m^3) and three moisture contents (13.5, 17.1 and 19.6%)

4.2.1.2 Effect of moisture content for high soil bulk density.

Figure 4.23 shows the effect of different soil moisture contents on high bulk density (dry basis) (1127 kg/m^3) soil on the pressure transferred through the soil. Data appear in Tables D20, D44 and D68 of Appendix D.

Soil with a higher bulk densities (medium and high) and the same combinations of moisture contents, appeared to follow a single curve. The effect of the soil moisture content was indistinguishable. The displacement of the layers was comparable in magnitude as indicted in section 5.1.2.2.

An analysis of variance (Table F18 of Appendix F) showed no significant difference between the pressures transmitted at any of the depth for the variation in moisture content.

Figure 4.10 shows a Semi-log plot of the same data when cumulative vertical displacement was plotted on the log scale.

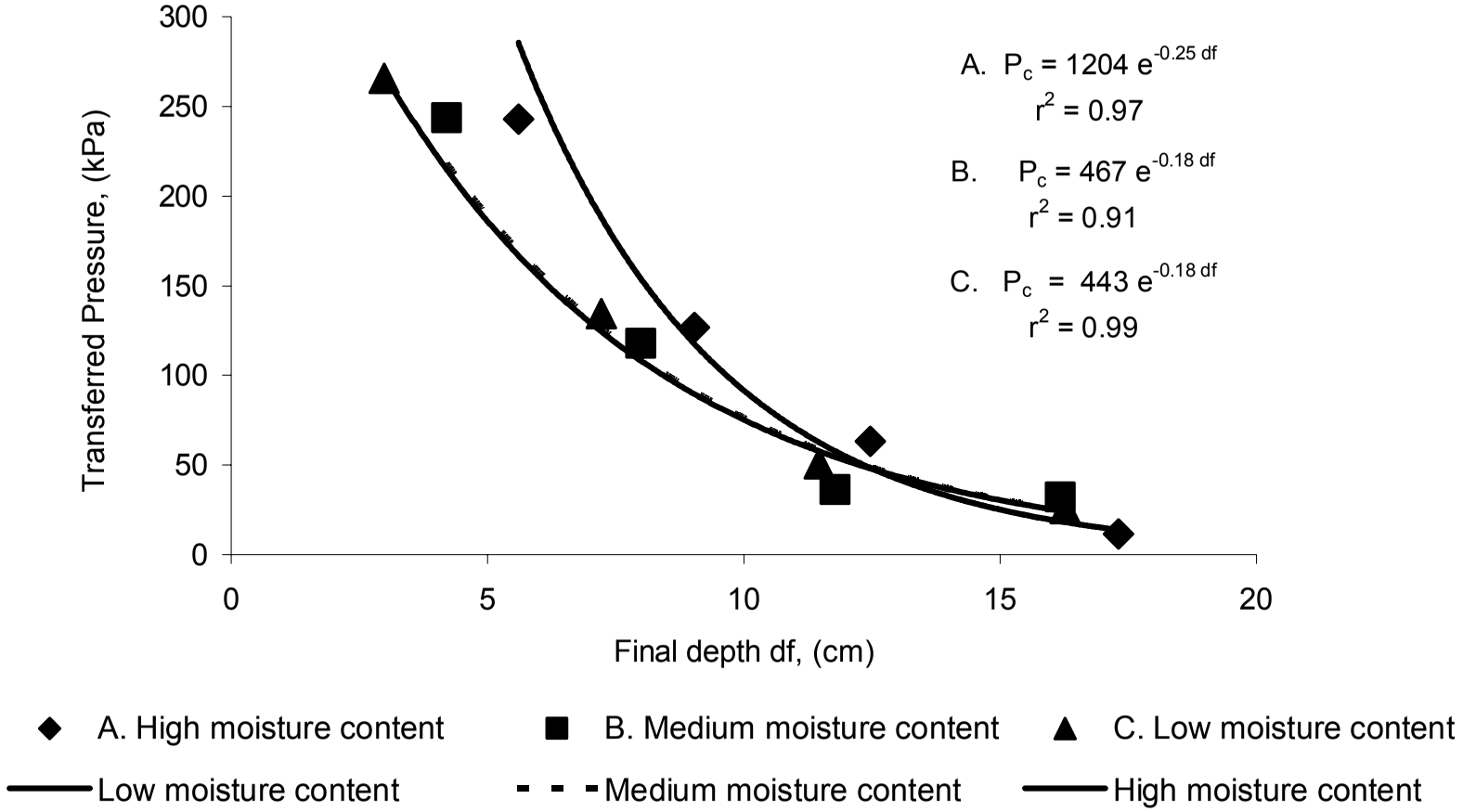


Figure 4.23 Transferred pressure through soil profile for soil with high bulk density (dry basis) (1127 kg/m^3) and three moisture contents (13.5, 17 and 20%)

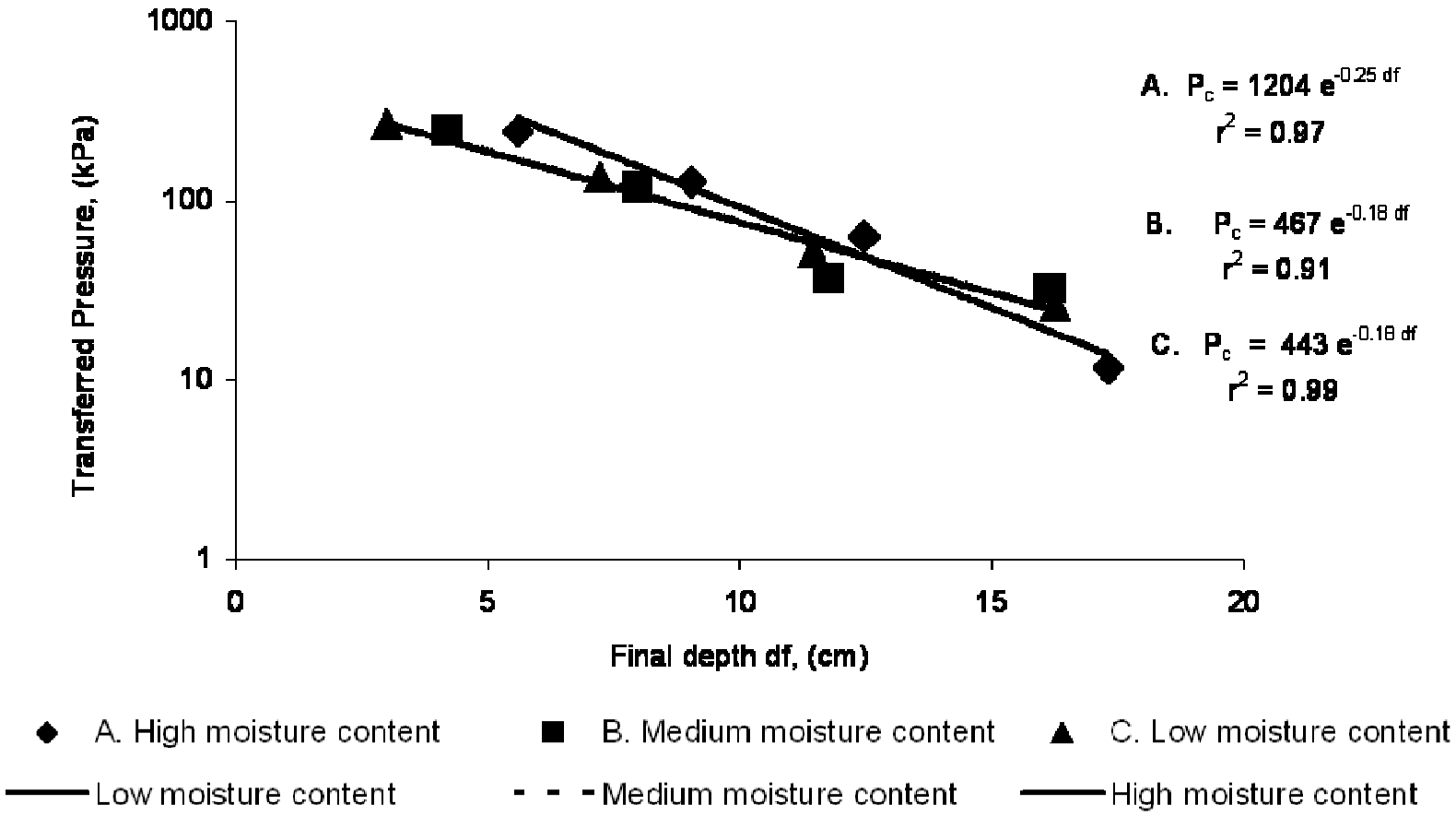


Figure 4.24 Semi-Log scale representing transferred pressure through soil profile for soil with high bulk density (dry basis) (1127 kg/m^3) and three moisture contents (13.5, 17 and 20%)

4.2.2 Effect of bulk density

4.2.2.1 Effect of bulk density for low soil moisture content

In Figure 4.25 the effect of different bulk densities at low moisture content (14%) on the pressure distribution through soil profile are shown. The data are given in Tables D12, D4 and D20 of Appendix D. Figure 4.26 shows a Semi-log plot of the same data when cumulative vertical displacement was plotted on the log scale.

For the tests at low moisture level (Figures 4.25 and 4.25) the pressure on the first sensor was more than 125 kPa. The fourth sensor which was placed at a depth of 150 mm before the load was applied, moved to its new location after applying the load to depths of 130, 110 and 90 mm below the initial surface for high, medium and low bulk density soils, respectively.

The displacement of the soil with low bulk density had more displacement than the soil with higher bulk density as indicated previously (section 4.1.2). The soil above it was compressed and more compacted, so its bulk density increased. However, the pressures on the sensors were almost the same for the fourth sensor with an average magnitude of 35 kPa; even if its depth was different.

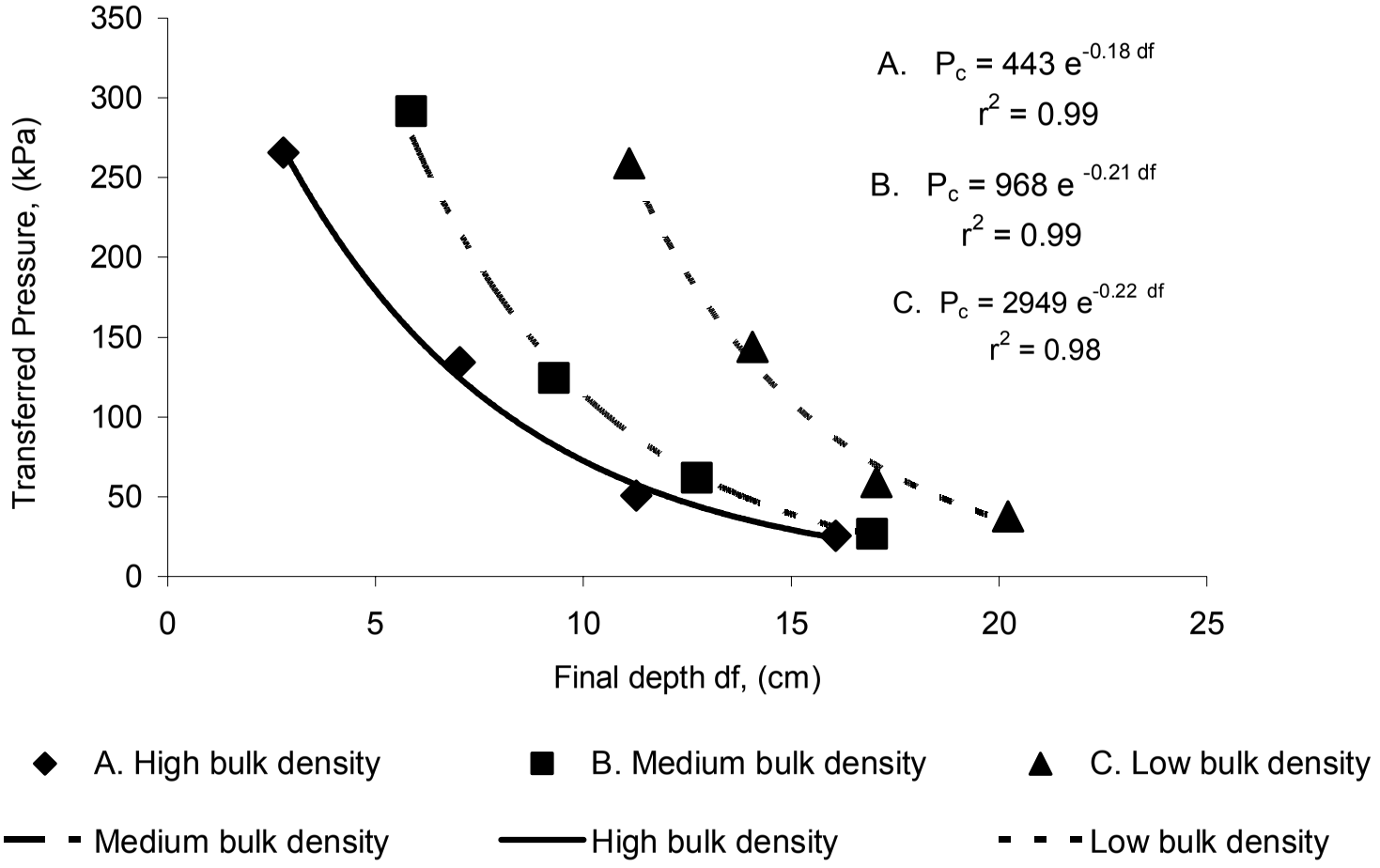


Figure 4.25 Transferred pressure through soil profile for soil with low moisture contents (14%) and three bulk densities (dry basis) (1041, 1112 and 1160 kg/m^3)

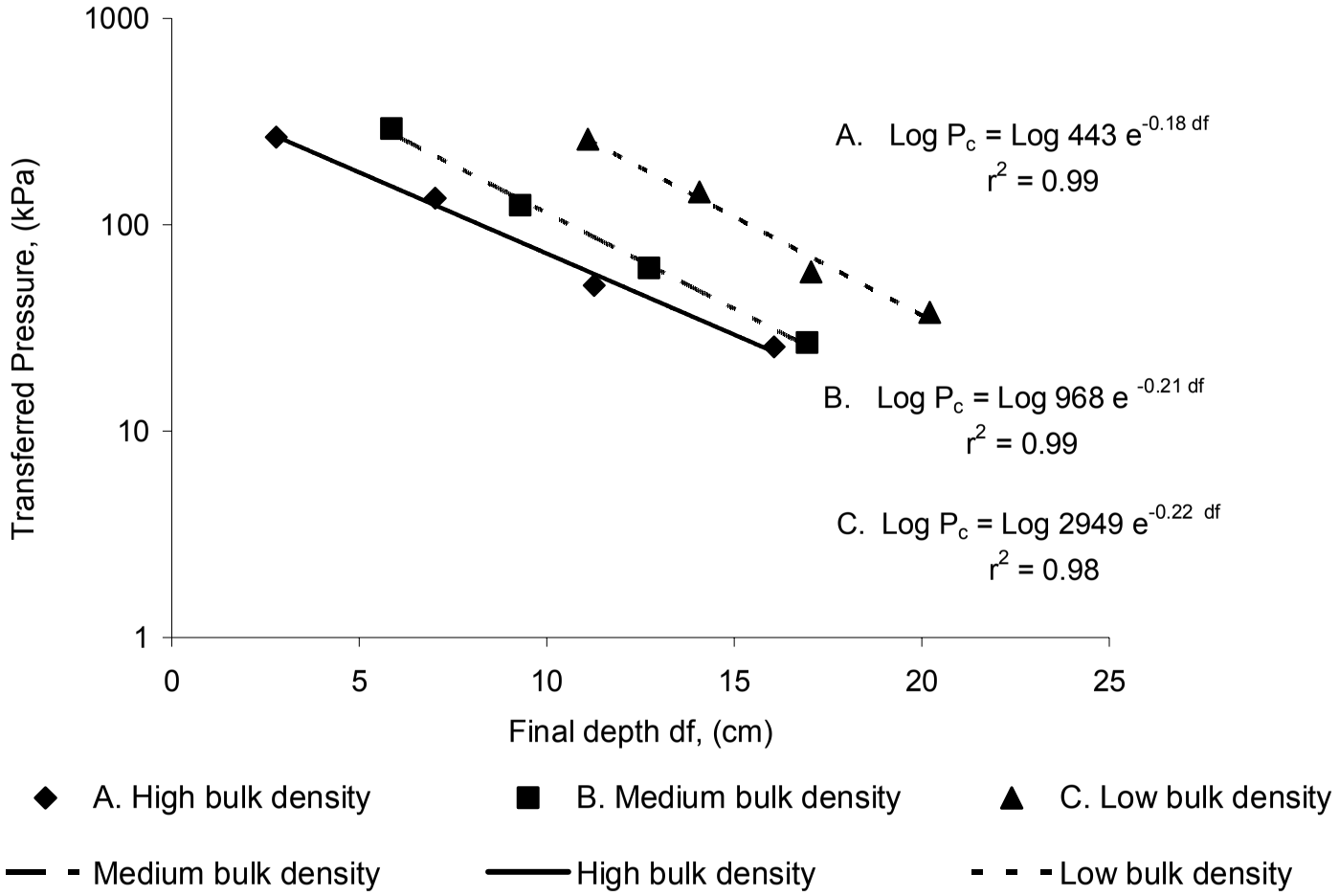


Figure 4.26 Semi-Log scale representing transferred pressure through soil profile for soil with low moisture content(14%) and three bulk densities (dry basis) (1041, 1127 and 1160 kg/m^3)

An analysis of variance (Table F19 of Appendix F) showed that there was no significant difference in pressure distribution at any depth.

4.2.2.2 Effect of bulk density for medium soil moisture content

Figure 4.28 shows a Semi-log plot of the same data when cumulative vertical displacement was plotted on the log scale.

The medium and high bulk density soils were closely related. Hence, the soil moisture did not affect pressure transfer with bulk density higher than 1250 kg/m^3 (dry basis).

An analysis of variance (Tables F 20 of Appendix F) showed that there was significant difference in pressure distribution at 100 and 150 mm depths.

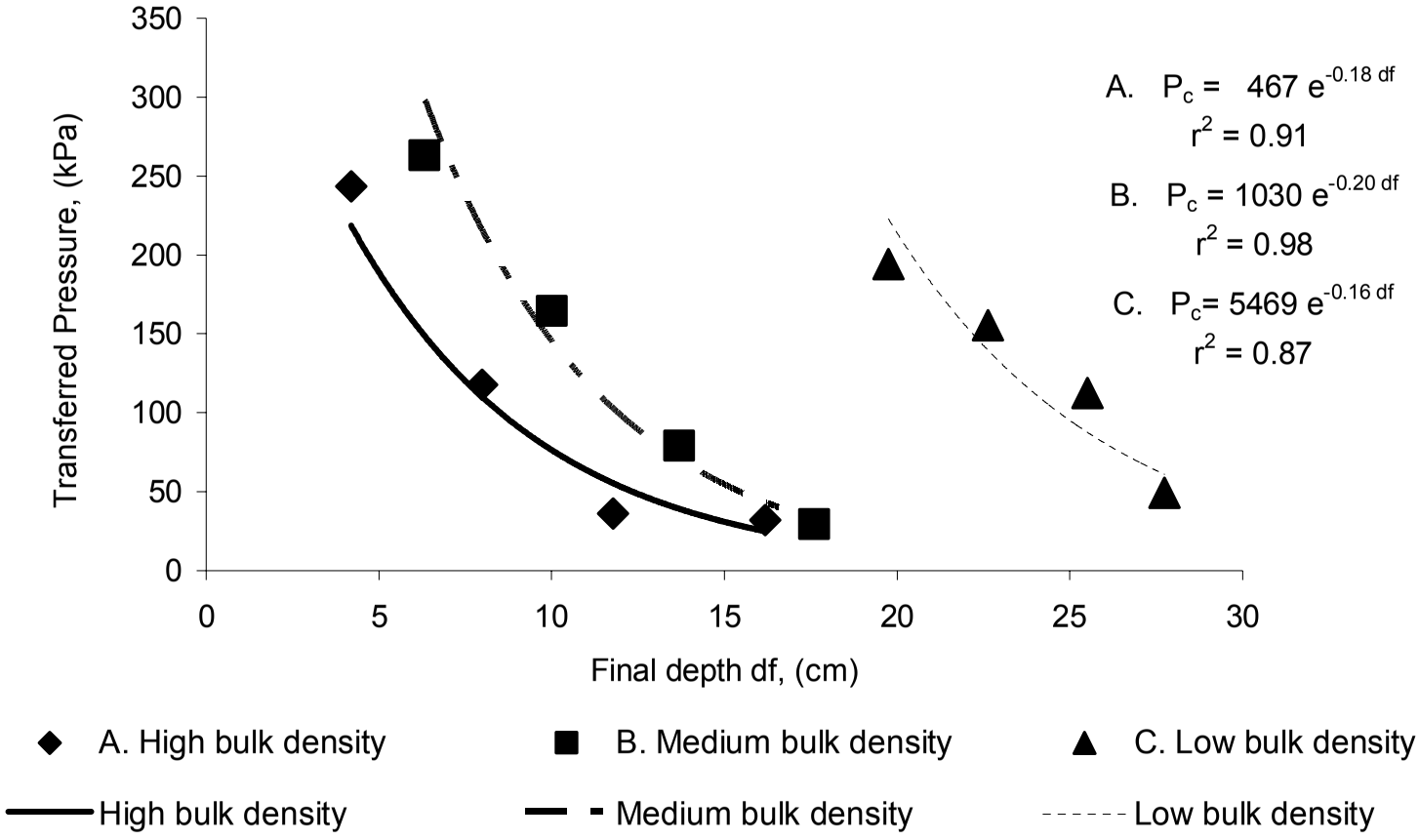


Figure 4.27 Transferred pressure through the soil profile for soil with medium moisture contents (16.8%) and three bulk densities (dry basis) (960, 1068 and 1134 kg/m^3)

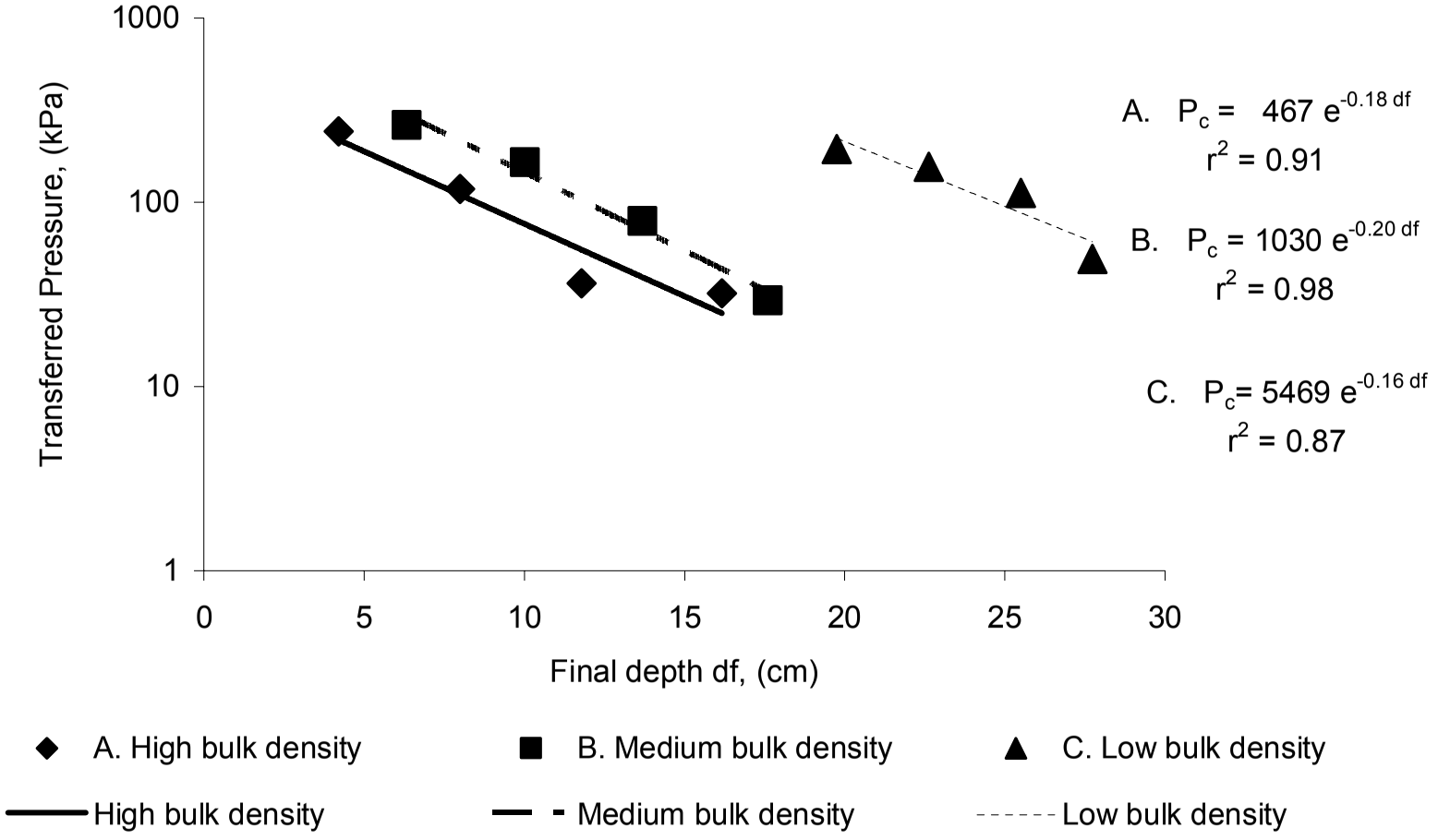


Figure 4.28 Transferred pressure through the soil profile for soil with medium moisture contents (16.8%) and three bulk densities (dry basis) (960, 1068 and 1134 kg/m^3)

4.2.2.3 Effect of bulk density for high soil moisture content

In Figure 4.29 the effect of different bulk densities at high soil moisture content (20%) on the pressure transferred through the soil are shown. Data were presented in Tables D52, D60 and D68 of Appendix D. Figure 4.30 shows a Semi-log plot of the same data when cumulative vertical displacement was plotted on the log scale.

The magnitude of the pressure at all depths had no significant difference for the three bulk densities with an average exponential decay of 0.24.

The analysis of variance (Table F21 of Appendix F showed) that there was significant difference in pressure distribution only at 50, 100, and 150 mm depths.

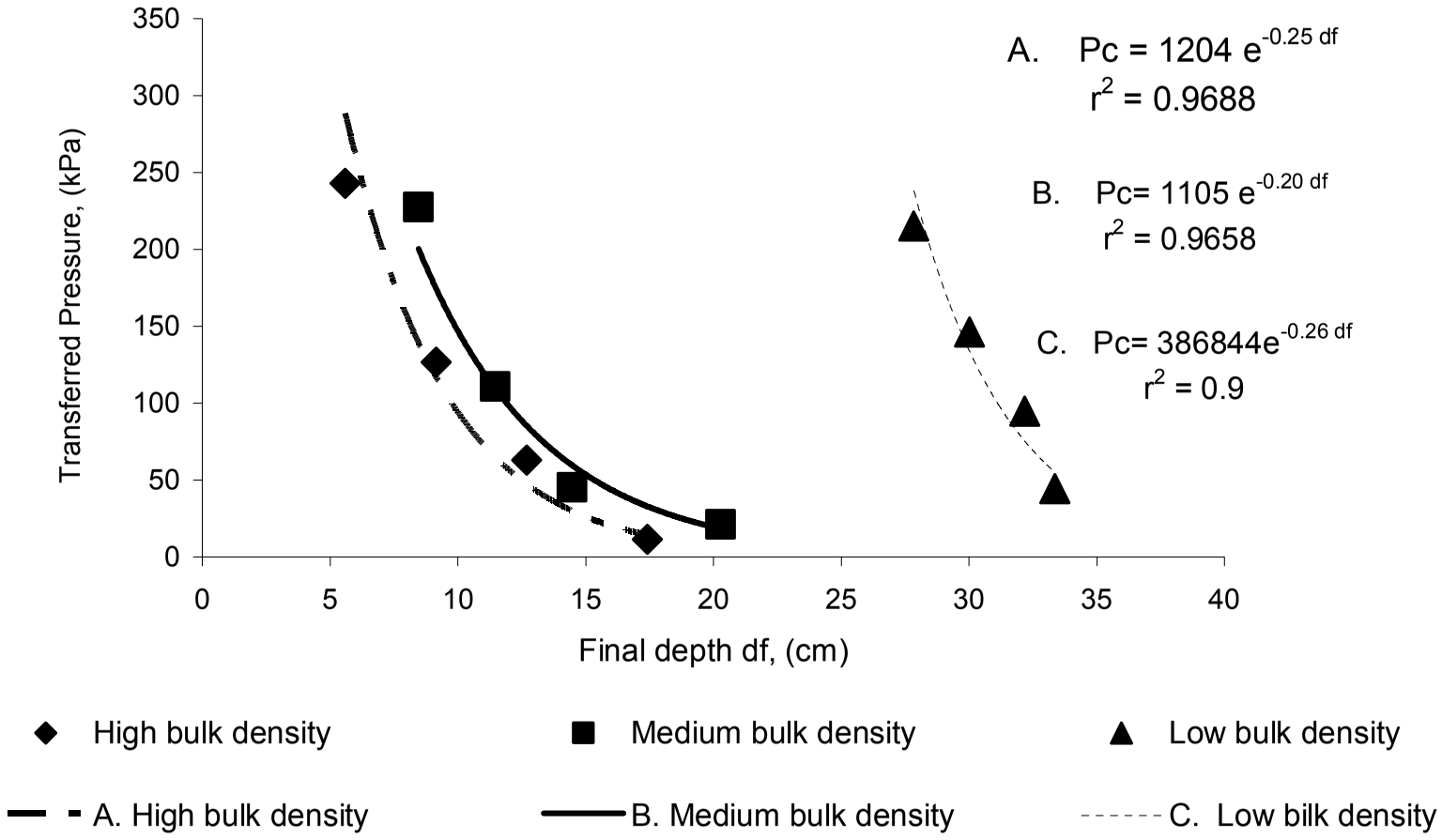


Figure 4.29 Transferred pressure through the soil profile for soil with high moisture contents (20%) and three bulk densities (dry basis) (967, 1030 and 1087 kg/m^3)

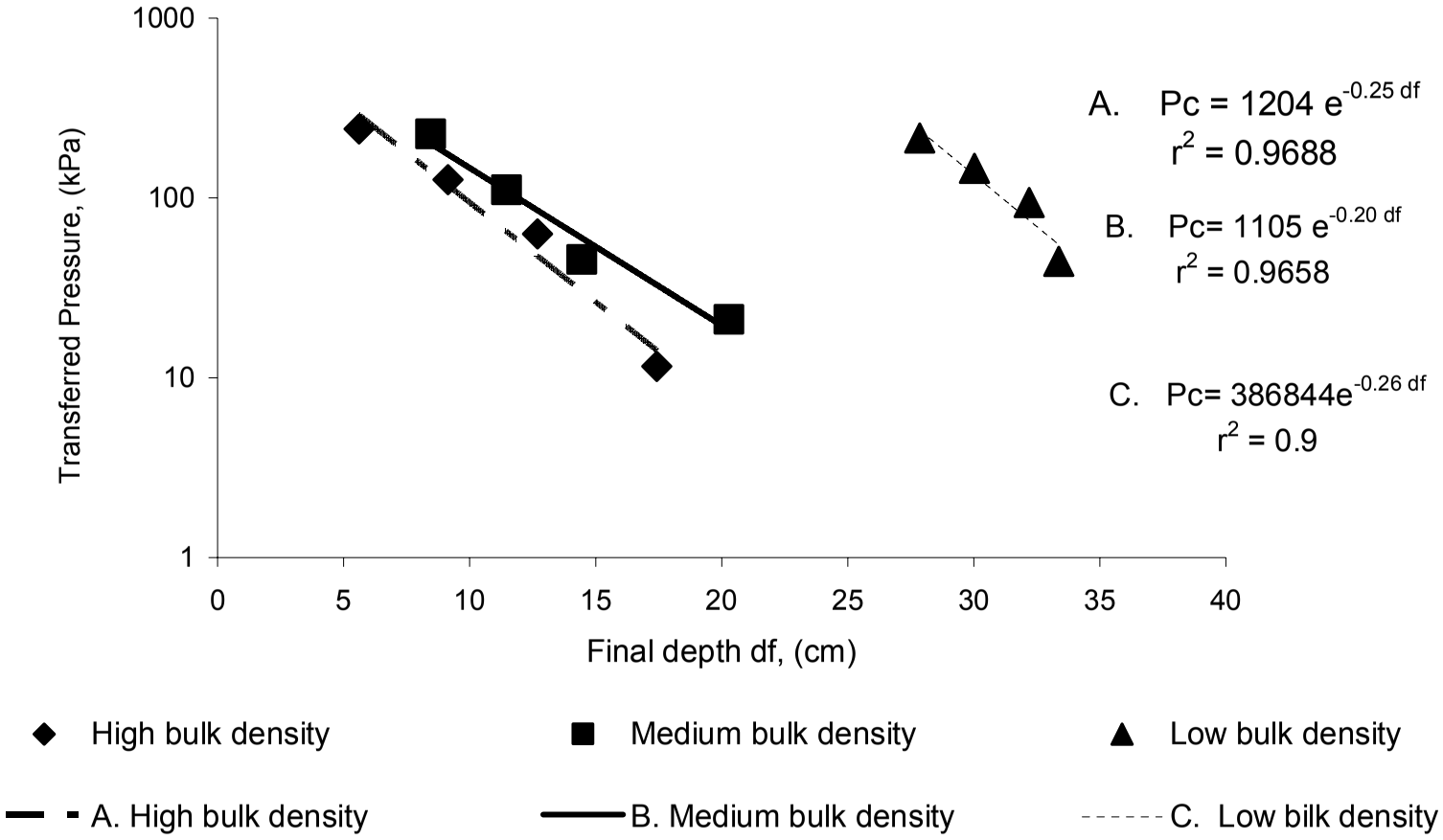


Figure 4.30 Semi-Log scale representing transferred pressure through soil profile for soil with high moisture content(20%) and three bulk densities (dry basis) (967, 1030 and 1087 kg/m^3)

4.3 Summary

It was observed that the soil resistance to a vertically applied load decreased with an increase of soil moisture content and increased with an increase in the initial bulk density of the soil. The soil resistance to a vertically applied load was not significantly affected by the loading surface shape. However, with a rectangular shaped loading surface, the resistance of the soil increased in comparison to the oval plate as the oval plate was observed to cause greater vertical soil displacement than the rectangular plate.

Soil pressure at depth of 0, 50, 100, and 150 mm decayed exponentially from 200 kPa to 40 kPa. The difference in pressure measurement was not significant when using different combinations of soil moisture content and bulk density.

The vertical soil displacement and relative pressure transferred through the soil decayed exponentially from the surface to a set depth at comparable rates.

The soil moisture affected the cumulative, displacement to a lesser degree than the initial soil compaction.

Further study is needed to measure soil pressure and final bulk density of the soil.

The F-test on the tests for a given condition showed no statistical difference to a 95% confidence level. The results of the surface deflection showed that by increasing soil moisture content the vertical soil displacement increased and by increasing the soil bulk density the vertical soil displacement decreased. The observed trends, as reported herein, agreed with physical properties of soil accepted theories for example, as the shape of the loading plate changed the vertical soil displacement changed in agreement with Youssef and Ali (1982) and Soehne (1958).

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In this section the conclusions based on results obtained from the vertical soil displacement and pressure transferred at various depths is illustrated.

5.2 Soil vertical displacement

Soil vertical displacement at the surface and sub-surface was affected by the change in moisture content, bulk density and shape of loading surface.

5.2.1 Effect of soil moisture content

As the soil moisture increased from 14% to 20%, the magnitude of the cumulative, vertical soil displacement increased.

The experimental showed an exponential relationship between cumulative vertical displacement and depth.

There was no significant difference in the exponential decay term resulting from changes in soil moisture content, bulk density and loading surface.

5.2.2 Effect of soil bulk density

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As the soil initial bulk density increased from 990 to 1127 kg/m^3 (dry basis), the magnitude of the cumulative, vertical soil displacement decreased. The vertical soil displacement was affected primarily by soil bulk density or the soil column initial compaction level. As the soil bulk density increased, the magnitude of the cumulative, soil vertical displacement decreased for the same loading conditions. Due to packing (compacting), the soil particles come closer together, which increases the soil internal friction which causes more resistance to an applied load. Again, the data plotted on the graph followed an exponential curve.

Similar to moisture content, there was no significant difference in the exponential decay term showing the same slope for three density levels.

5.2.3 Effect of shape of loading surface

The loading interface of different geometric shapes with the same surface area 6.4 x 10^{-3} m^2 had minimal influence on the vertical soil displacement. The shape of the loading plate affected the soil deflection near the surface (with the greatest sensitivity noted for low compaction levels).

There was little change in the vertical displacement when using two different shapes but it was noted that the oval shaped had more vertical displacement than the rectangular one. It was believed that the soil had to exert more shear to react against the rectangular loading surface since it had larger perimeter.

There was no significant effect of changing the shape of loading surface on the constants (A_c) and (B) of the exponential relation.

The constant (B) did not have significant change, since the depth of the hard pan was 700 mm (base of the container). The constant (B) had higher value when using high bulk density soil since the vertical displacement ceases at lower depths.

5.3 Pressure distribution

The pressure distributed within sub-soil was measured by sensors which were displaced as soil was compacted. The final bulk density of the soil would have increased. Thus, the sensors were measuring the pressure for the final bulk density.

5.3.1 Effect of soil moisture content

The transferred pressure through soil also followed an exponential curve with an average exponential decay term of 0.19 for the three moisture levels used.

The transferred pressure at the surface, for all moisture levels was the same and there was no significant difference for the experimental value.

5.3.2 Effect of soil bulk density

The transferred pressure at depth did not show significant change for different initial compaction levels. The resistance of the soil under the loading surface for different bulk densities were the same since the soil was compressed by the same magnitude of load (800 N).

The final soil bulk density level of the soil was not measured. The distance between the surface and the fourth sensor was ranging form 120 mm to 50 mm.

The effect of the bulk density on the surface could not be distinguished. There was no significant difference among the pressure distribution at the surface using different bulk densities since the ranges of bulk density used were narrow.

The pressure at the first sensor was higher than the pressure applied, which may be contributed to:

- There could be a side effect of shear forces at the sides of the container which increased the pressure at the sensors.

- The level of compaction of the soil column under the loading plate, at the time of the reading, was not uniformly equal. This was evident from the shape of the deflection of soil layers that looked like a parabola.

5.4 Recommendations

1. When measuring the soil vertical displacement for soil with maximum strength, the displacement occurred up to a depth of 200 mm only, which gave 3 data points. It is recommended to have layers marked at lower depths.

2. The soil internal frication, cohesion and void ratio would be the main parameter adding to the main effect of the different values observed for the vertical displacement. Further experiments are needed to relate the angle of internal friction, cohesion and void ratio of soil with the constant (A_c).

3. The number of tests could be increased to extend the ranges of moisture contents and bulk densities to provide better insight on the surface soil displacement. Using three combinations of a set of variables is insufficient to predict the behavior of soil displacement at different ranges of the selected variables.

4. Several other shapes of the loading surface with the same surface area could be included to verify results.

5. Additional sensors and/or other types of pressure sensors could be used with different sensitivities depending on the depth of the sensor placement.

6. Soil bin tests could be conducted to compare the laboratory results.

7. The effect of the rate of loading, soil type and soil resistance to penetration (as measured in cone index) could be included in future experiments.

8. Tests may be conducted to measure pressure distribution while soil behaves elastically, where no volume change takes place, i.e the bulk density remains constant before and after loading.

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APPENDIX A

The Datalogger and sensors specifications are presented.

A.1 Campbell Datalogger

Figure A1 Campbell Scientific 21X Micrologger (Campbell Scientific Inc., Logan, UT)

The 21 X Datalogger has 16 single ended analog inputs (8 double ended). It has 19328 storage locations, a keypad interface, a software interface for programming, and an LCD display. Short programs can be entered using the number pad as shown in Figure A1. However, it is recommended to use Edlog for longer programs. Edlog is a DOS application used to write programs for the Campbell Scientific Datalogger. Appendix E shows the program written in Edlog to collect data from the sensors.

A.2 Thin Film Sensor

The physical properties, typical performance, standard force ranges and the excitation circuit presented hereby are from Tekscan Inc., South Boston, MA.

Figure A2. FlexiForce® sensor

Physical Properties

Thickness 0.008" (0.127 mm)
Length 8.000" (203 mm) End of connector to tip of sensor
Width 0.55" (14 mm)
Active sensing area 0.375" (9.53 mm) Diameter
Connector male square pin

Typical Performance

Accuracy: < ±5% (Line drawn from 0 to 50% load)
Repeatability: < ±2.5% of Full Scale (Conditioned Sensor, 80% of Full Force Applied)
Hysteresis: < 4.5 % of Full Scale (Conditioned Sensor, 80% of Full Force Applied)
Rise Time: < 20 µsec (Impact load - recorded on Oscilloscope)
Operating Temperature: 15°F - 140°F (-9°C - 60°C)*

- Force reading change per degree of temperature change = ±0.2% / °F (0.36%/°C)
  * For loads less than 10 lb., the operating temperature can be increased to 165° F (74° C)

Standard Force Ranges

As tested with the circuit shown in Figure A3, the standard force range is 0 to 444 N. In order to measure forces above 444 N, a lower drive voltage could be applied and the resistance of the feedback resistor could be reduced.

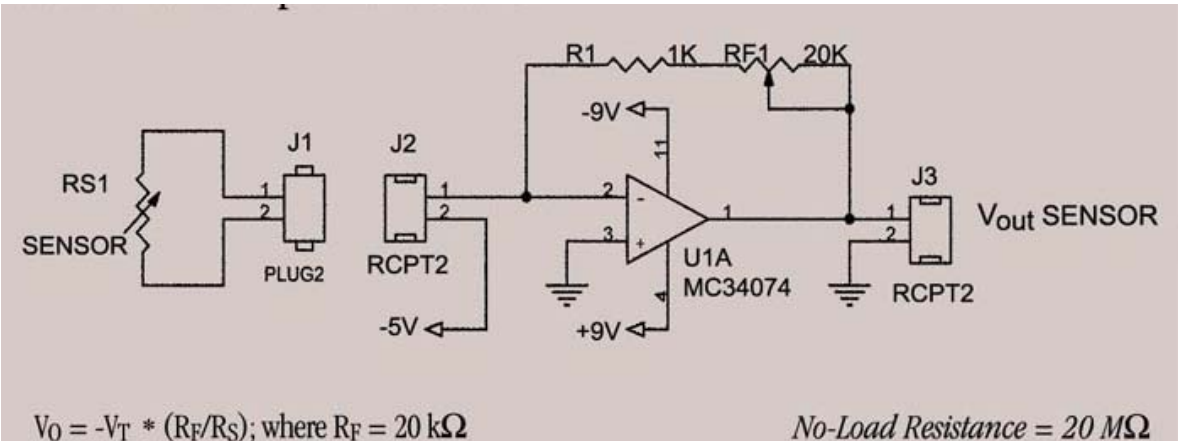


Figure A3 FlexiForce sample Excitation circuit

APPENDIX B

The schematic shows the connection of sensors, excitation circuit and datalogger.

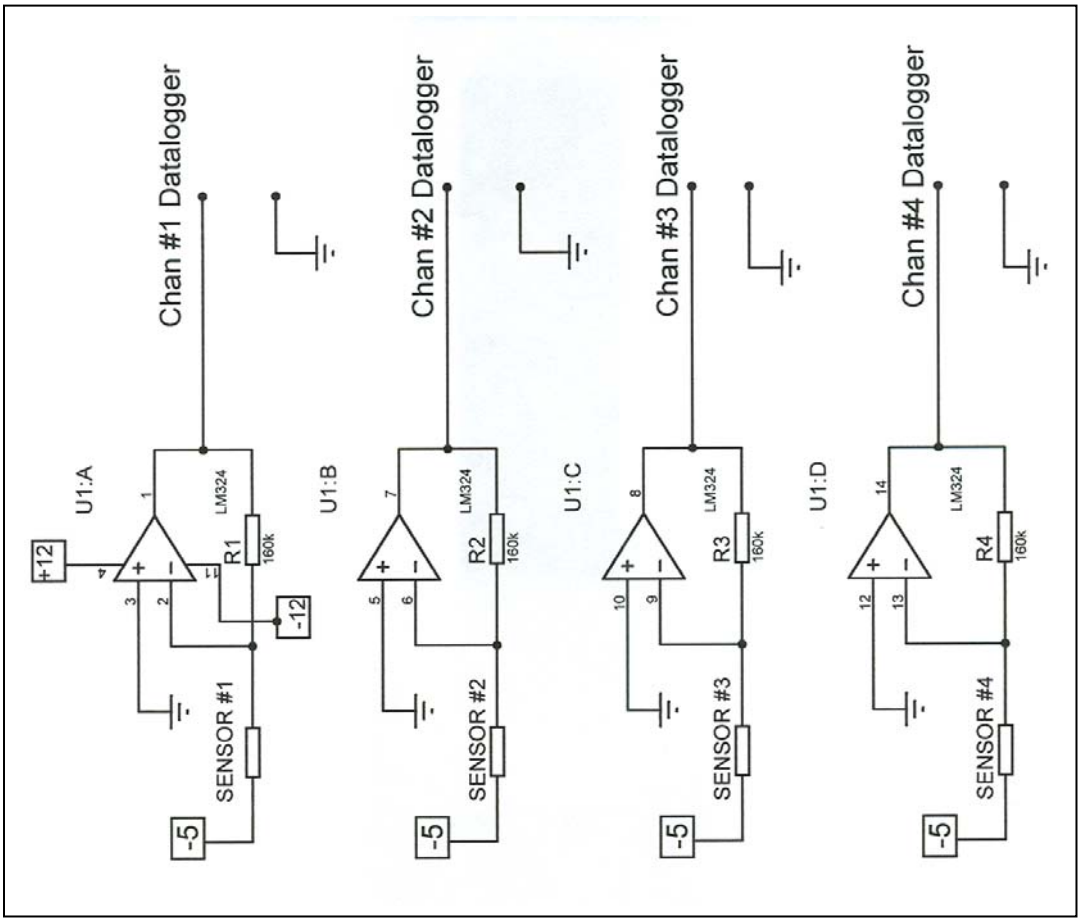


Figure B1 FlexiForce excitation circuit

APPENDIX C

The calibration curves and equations for the sensors are included. When calibrating a known force (N) was applied and the output voltage (mV) was recorded for each sensor.

The output voltage (millivolt) from the datalogger was converted to an applied force in (Newton) for each sensor that is placed within the soil during the test, for each trial.

Table C1. Calibration tables for the four sensors before experiments with low moisture content

Sensor 1		Sensor 2		Senosr 3		Sensor 4	
Force, (N)	Voltage, (mV)	Force, (N)	Voltage, (mV)	Force, (N)	Voltage, (mV)	Force, (N)	Voltage, (mV)
0.00	14.00	0.00	-12.00	0.00	20.00	0.00	-20.00
41.25	716.00	31.25	840.00	21.25	795.00	27.50	1100.00
70.00	1216.00	51.25	1354.00	56.25	2055.00	50.00	2340.00
97.50	1787.00	90.00	2340.00	81.25	2880.00	70.00	3170.00
135.00	2374.00	120.00	3150.00	100.00	3500.00	106.20	4300.00
172.00	3017.00	150.00	4000.00	134.00	4600.00	134.00	5100.00
207.00	3742.00	187.50	5000.00	160.00	5470.00	133.00	5050.00
230.00	4160.00	185.00	4960.00	157.00	5465.00	112.50	4350.00
256.00	4633.00	152.00	4101.00	146.20	4939.00	73.00	3260.00
272.00	4950.00	127.00	3512.00	110.00	3888.00	65.00	2926.00
266.00	4990.00	98.75	2820.00	75.00	2835.00	33.75	1560.00
200.00	3960.00	56.25	1744.00	50.00	1945.00	0.00	25.00
175.00	3361.00	30.00	1083.00	22.00	900.00		
157.00	3090.00	0.00	18.00	0.00	2.00		
137.00	2735.00						
90.00	1861.00						
62.50	1355.00						
31.25	431.00						
0.00	14.00						
F (N) = 0.054 V (mV) - 0.55		F (N) = 0.038 V (mV) - 2.86		F (N) = 0.029 V (mV) - 3.3		F (N) = 0.026 V (mV) - 4.76	

Table C2. Forces applied on each sensor inside the soil for soil with low moisture content and three bulk densities

	Sensor 1		Sensor 2		Sensor 3		Sensor 4	
	0 cm depth		5 cm depth		10 cm depth		15 cm depth	
	Voltage, (mV)	Force, (N)	Voltage, (mV)	Force, (N)	Voltage, (mV)	Force, (N)	Voltage, (mV)	Force, (N)
Low Density								
Trial 1	2250.00	120.95	1787.00	65.05	884.00	22.34	746.00	14.64
Trial 2	2017.00	108.37	1922.00	70.18	1303.00	34.49	862.00	17.65
Trial 3	2270.00	122.03	1658.00	60.14	919.00	23.35	906.00	18.80
Medium Density								
Trial 1	2053.00	110.31	1403.00	50.45	1098.00	28.54	750.00	14.74
Trial 2	2790.00	150.11	1456.00	52.47	963.00	24.63	522.00	8.81
Trial 3	2514.00	135.21	1798.00	65.46	1166.00	30.51	674.00	12.76
High Density								
Trial 1	2249.00	120.90	1787.00	65.05	884.00	22.34	746.00	14.64
Trial 2	2333.00	125.43	1753.00	63.75	1017.00	26.19	670.00	12.66
Trial 3	2124.00	114.15	1485.00	53.57	818.00	20.42	466.00	7.36

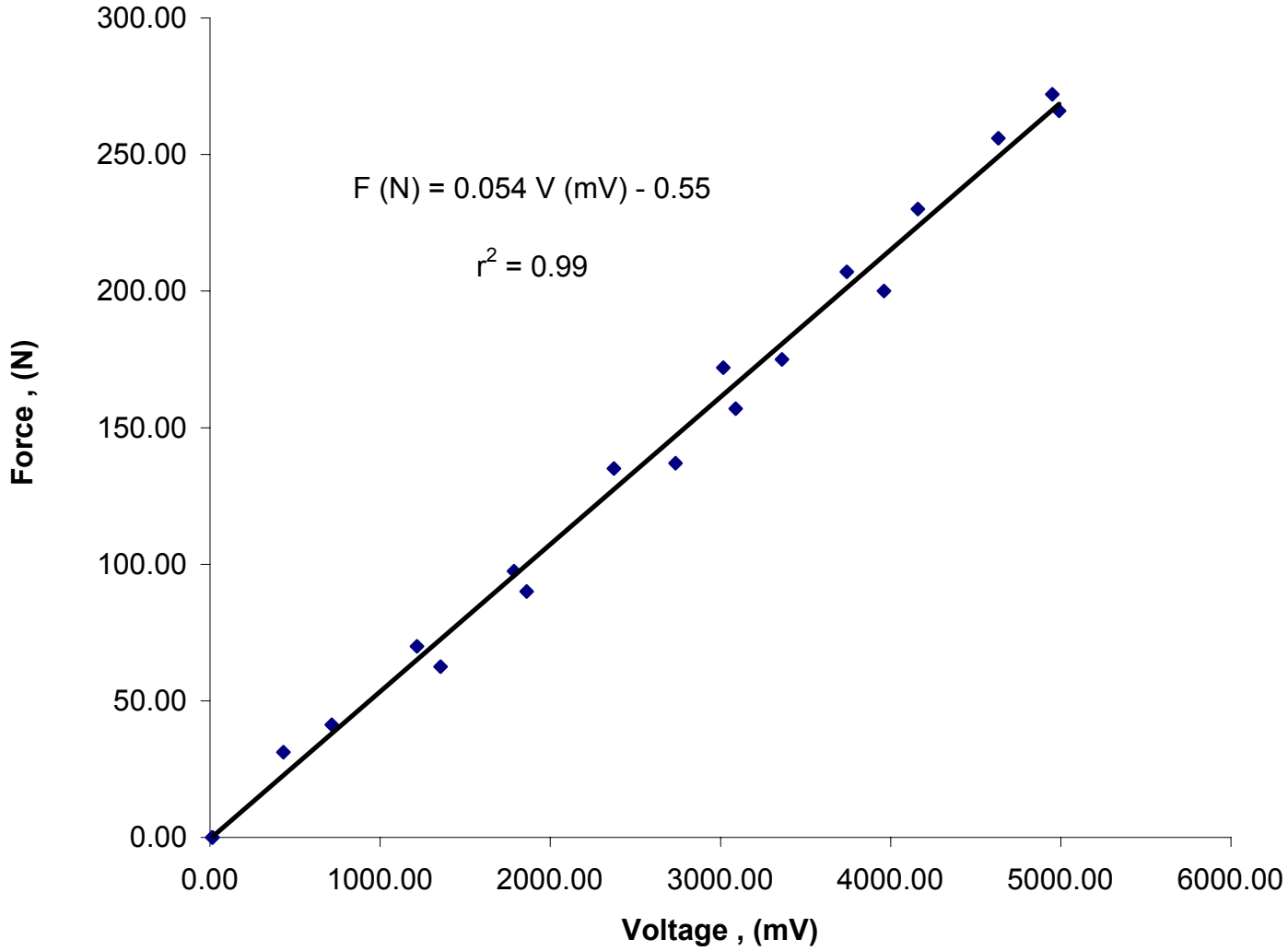


Figure C1. Calibration curve for sensor 1 before experiments with low moisture content

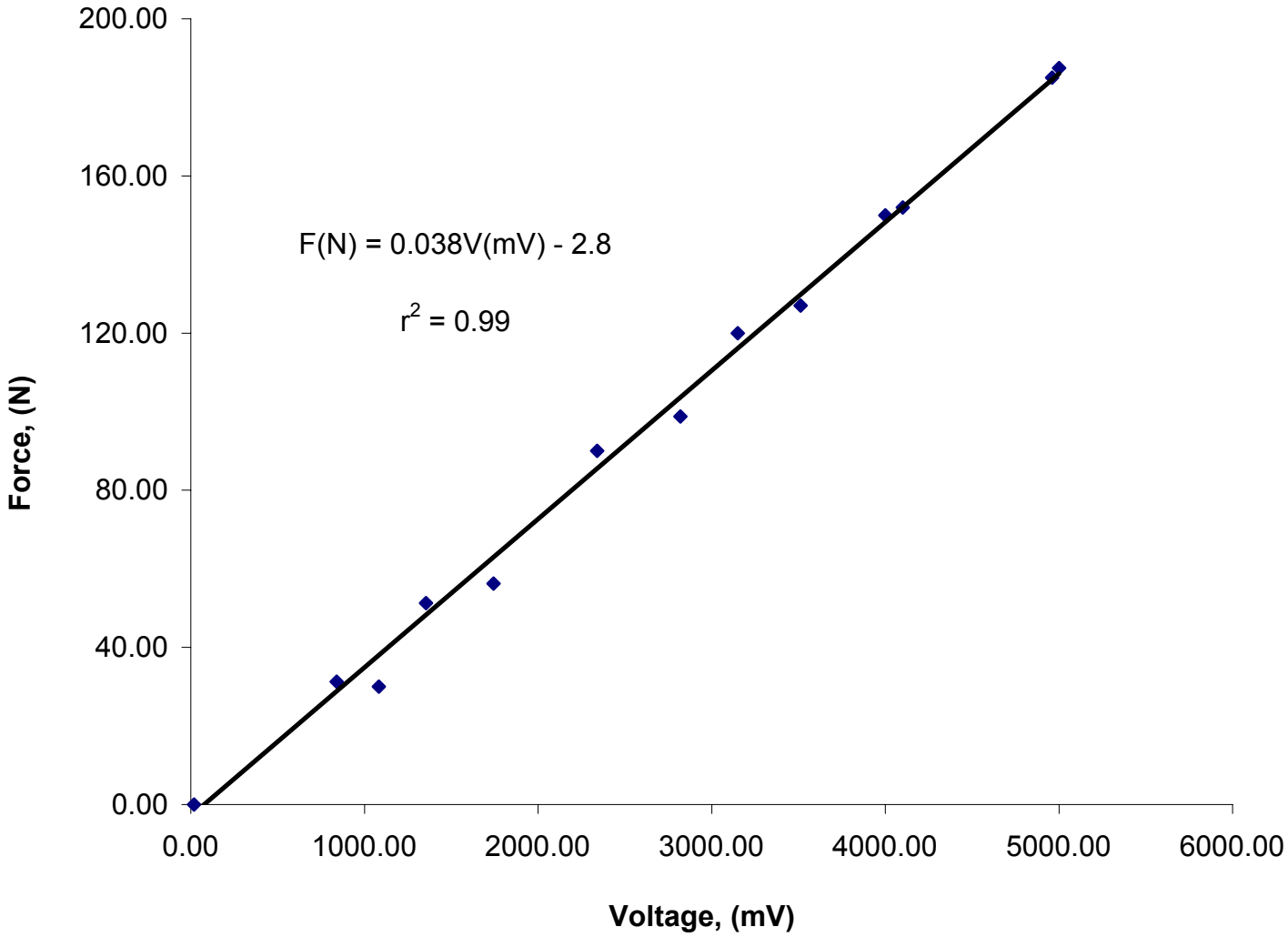


Figure C2. Calibration curve for sensor 2 before experiments with low moisture content

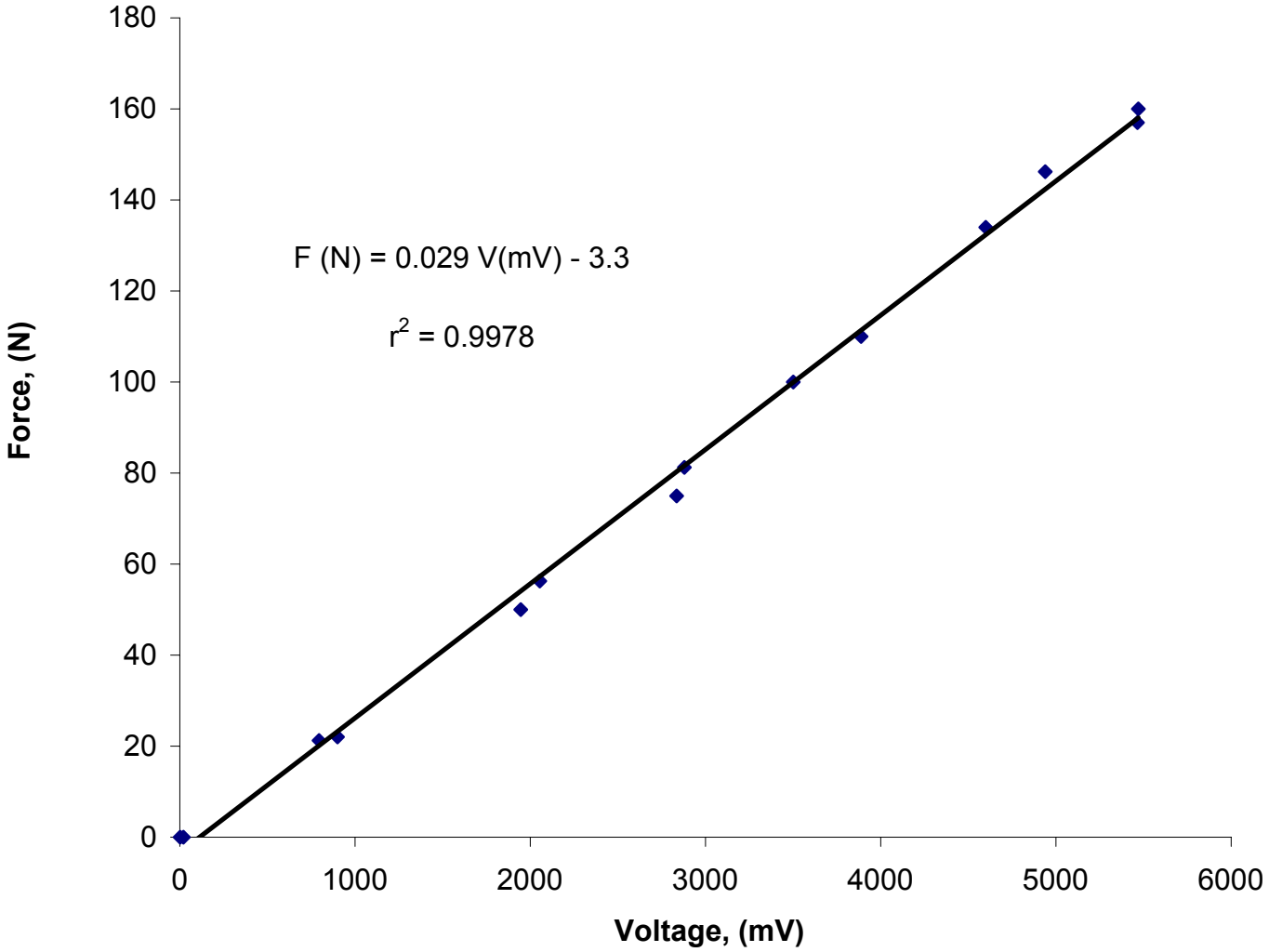


Figure C3. Calibration curve for sensor 3 before experiments with low moisture content

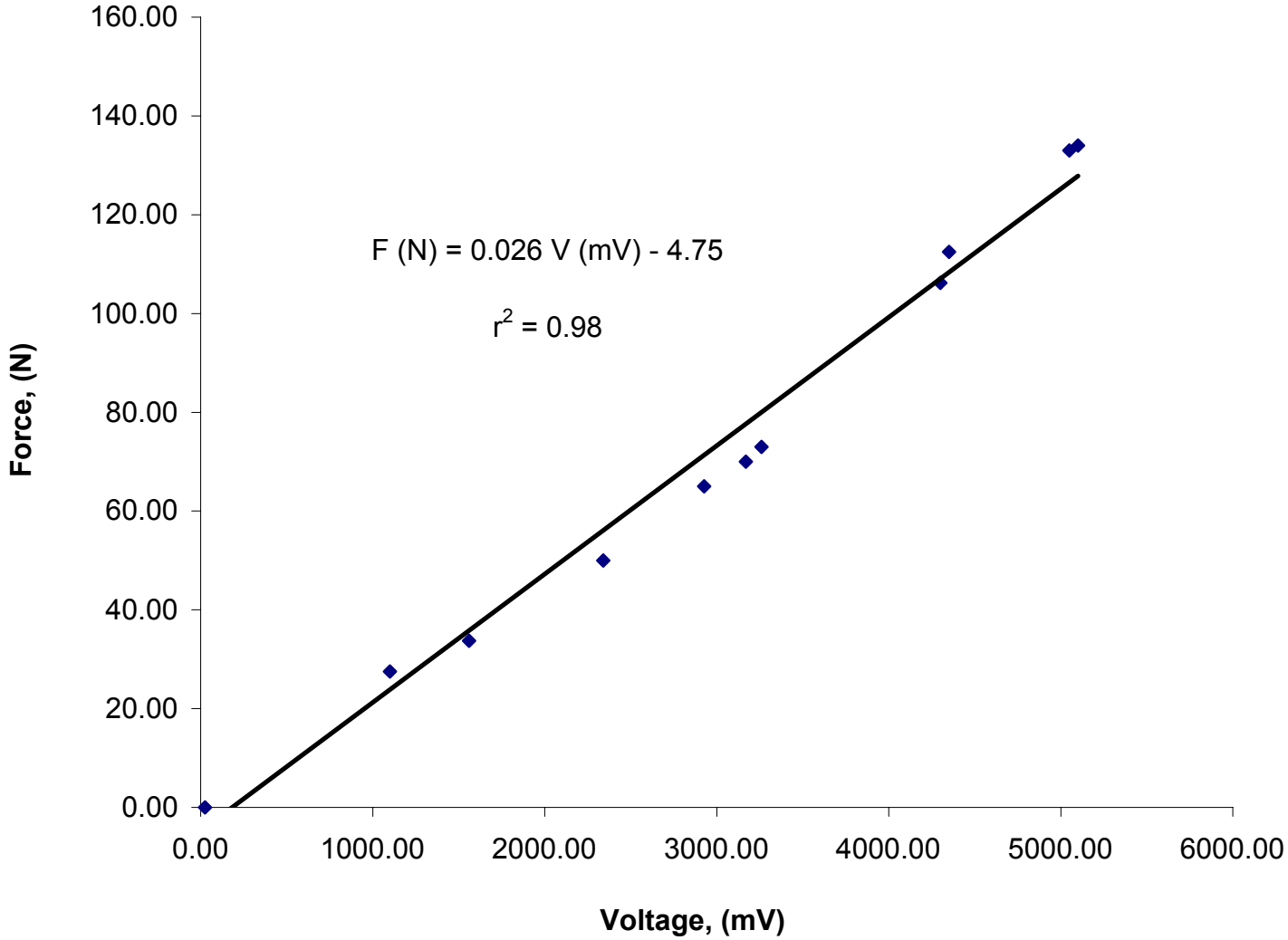


Figure C4. Calibration curve for sensor 4 before experiments with low moisture content

Table C3. Calibration tables for the four sensors before experiments with medium moisture content

Sensor 1	
Force, (N)	Voltage, (mV)
0	0
44	620
108	1818
152.5	2515
202.5	3375
246.2	4020
245	4018
193	3282
166	2793
97	1704
53.7	909
0	0
F (N) = 0.06 V (mV) - 0.09	

Sensor 2	
Force, (N)	Voltage, (mV)
0	0
25	860
46.25	1358
65	1804
92.5	2404
127.5	3039
166.2	3619
197.5	4150
220	4500
216	4496
180	3996
158	3611
121.2	3038
75	2211
48.7	1631
27	979
0	0
F (N) = 0.05 V (mV) - 17.8	

Senosr 3	
Force, (N)	Voltage, (mV)
0	0
37	1250
68.75	2236
112.5	3555
158	4973
155	4931
105	3425
71.5	2406
39	1251
0	0
F (N) = 0.03 V (mV) - 1.3	

Sensor 4	
Force, (N)	Voltage, (mV)
0	0
26.25	1148
55	2554
88	3958
122.5	4990
120	4988
72.5	3372
50	2493
25	1300
0	0
F (N) = 0.024 V (mV) - 3.5	

Table C4. Forces applied on each sensor inside the soil for soil with medium moisture content and three bulk densities

	Sensor 1		Sensor 2		Sensor 3		Sensor 4	
	0 cm depth		5 cm depth		10 cm depth		15 cm depth	
	Voltage, (mV)	Force, (N)	Voltage, (mV)	Force, (N)	Voltage, (mV)	Force, (N)	Voltage, (mV)	Force, (N)
Low Density								
Trial 1	1450	86.91	1900	77.20	1950	57.20	1000	20.50
Trial 2	1586	95.07	1700	67.20	1750	51.20	1230	26.02
Trial 3	1359	81.45	1685	66.45	1510	44.00	988	20.21
Medium Density								
Trial 1	1650	98.91	1934	78.90	1350	39.20	620	11.38
Trial 2	2300	137.91	2100	87.20	1000	28.70	900	18.10
Trial 3	2000	119.91	1500	57.20	1350	39.20	570	10.18
High Density								
Trial 1	2000	119.91	1537	59.05	685	19.25	815	16.06
Trial 2	1723	103.29	1326	48.50	542	14.96	800	15.70
Trial 3	1790	107.31	1400	52.20	540	14.90	633	11.69

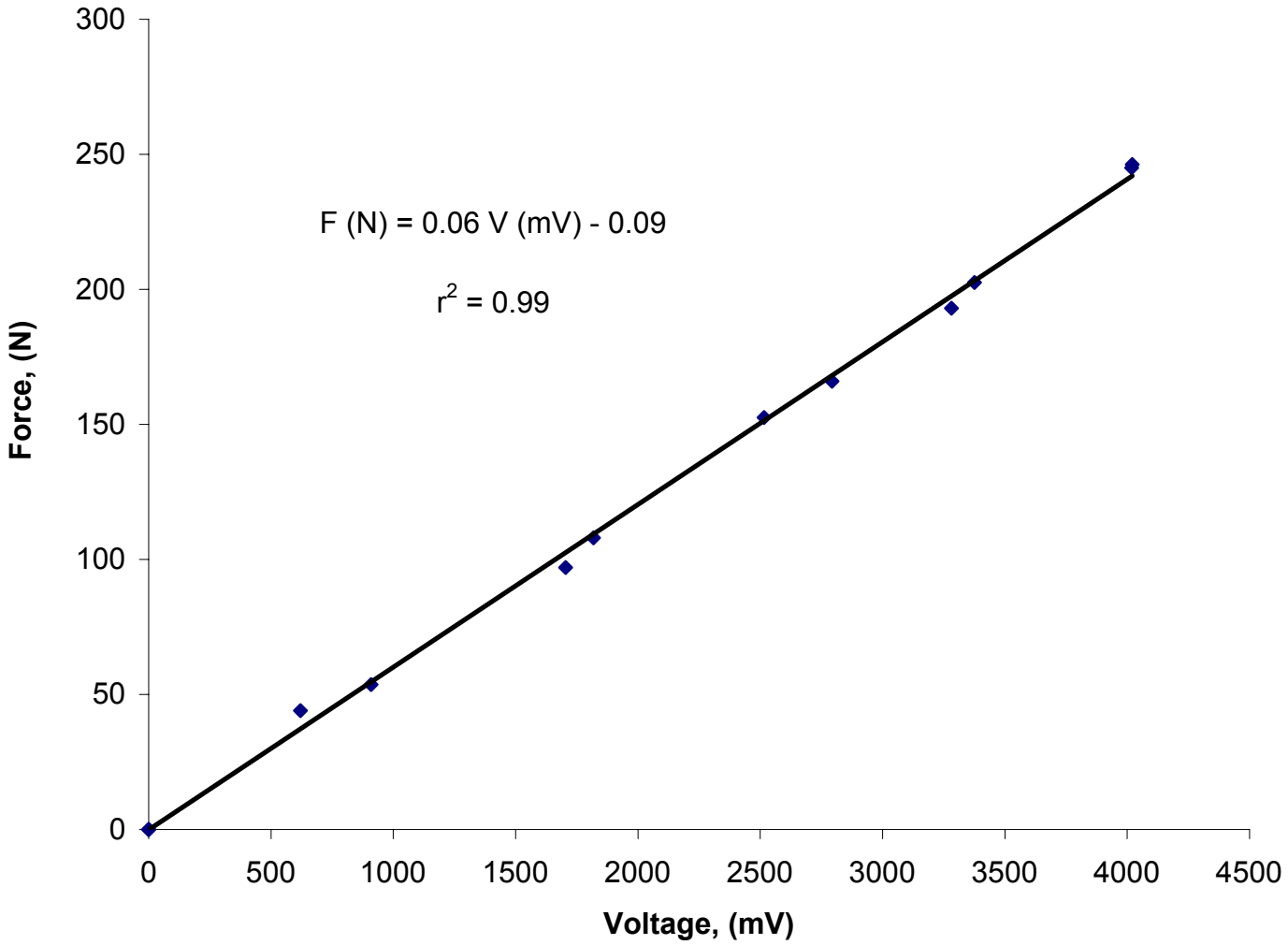


Figure C5. Calibration curve for sensor 1 before experiments with medium moisture content

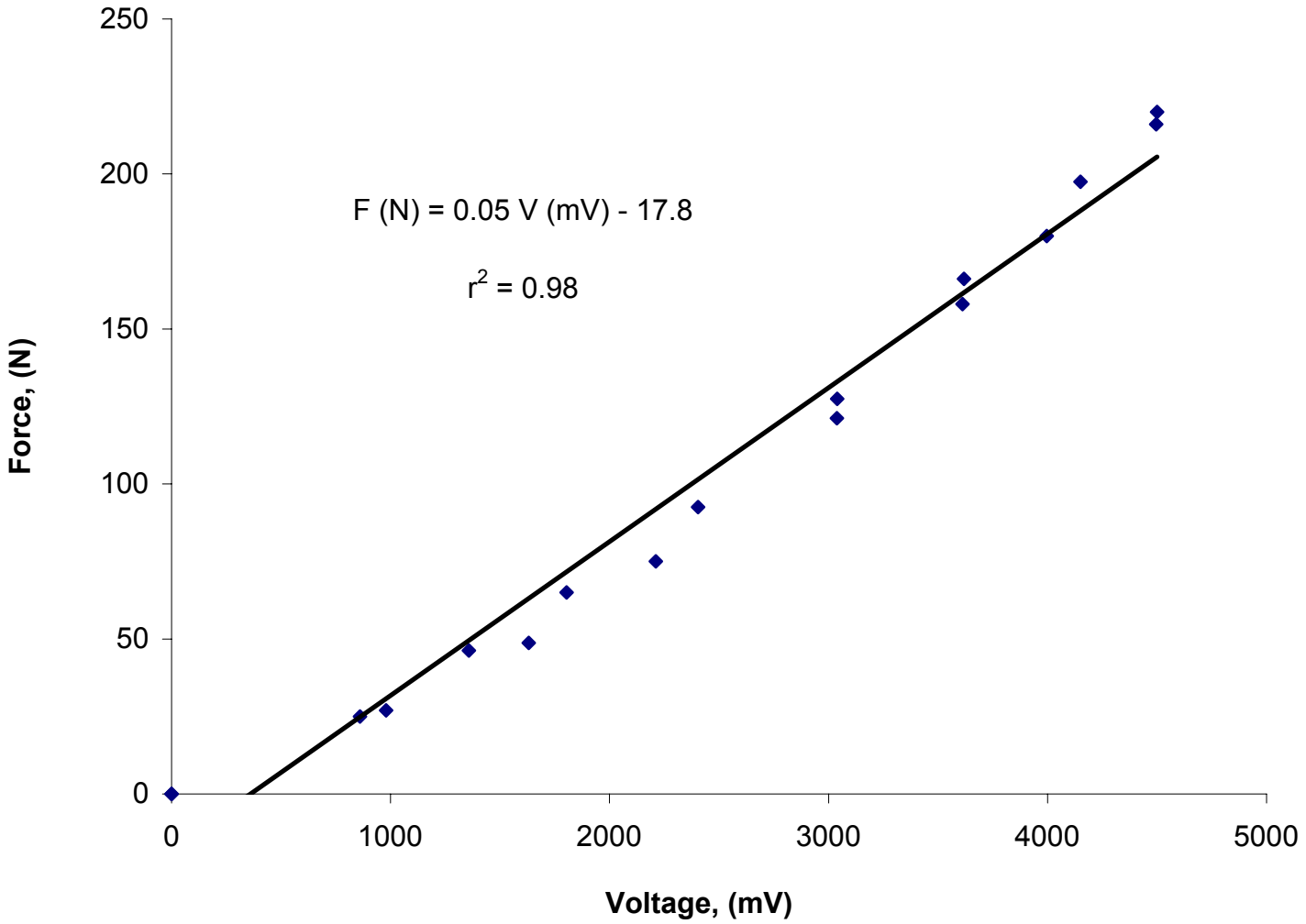


Figure C6. Calibration curve for sensor 2 before experiments with medium moisture content

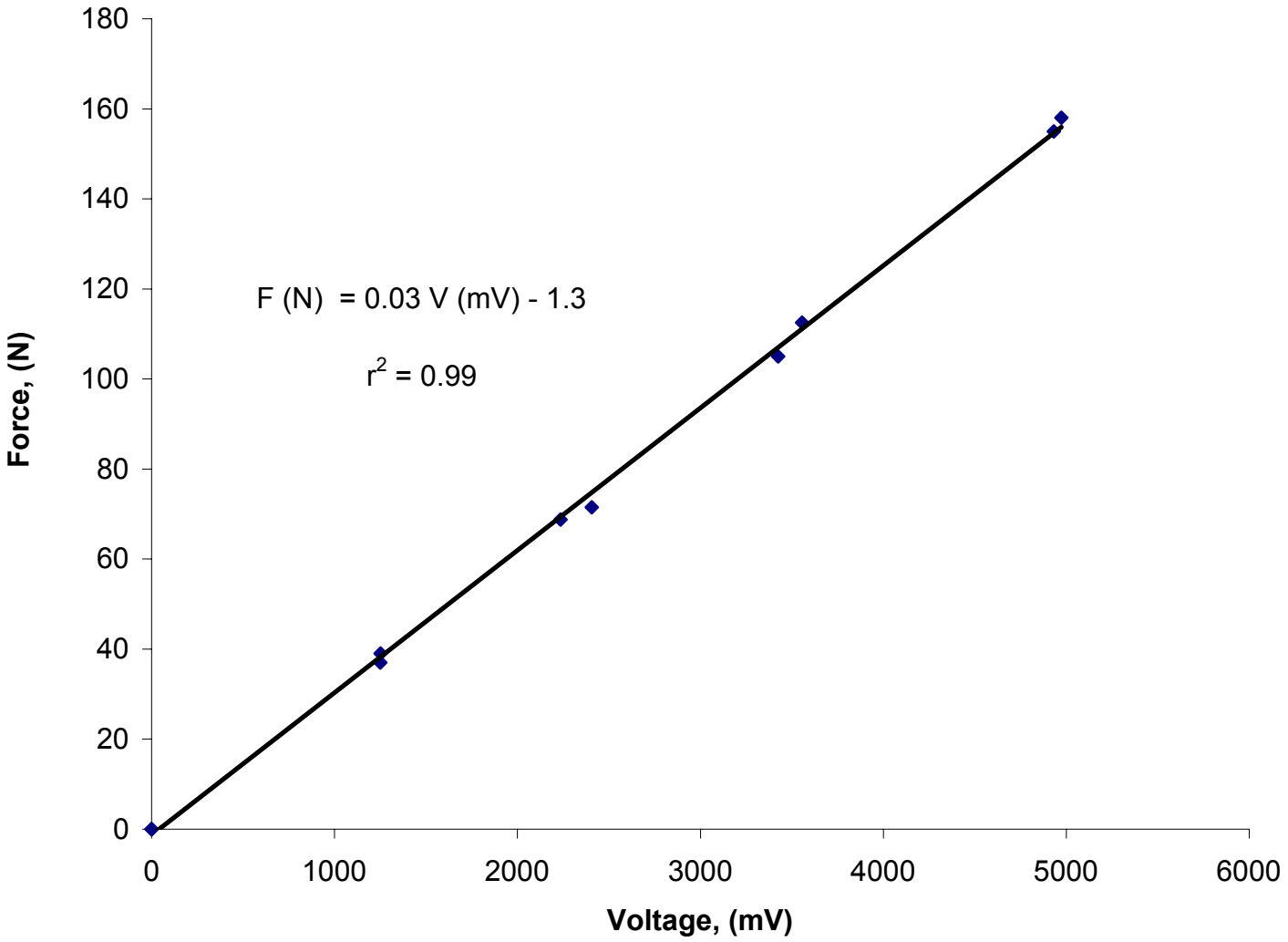


Figure C7. Calibration curve for sensor 3 before experiments with medium moisture content

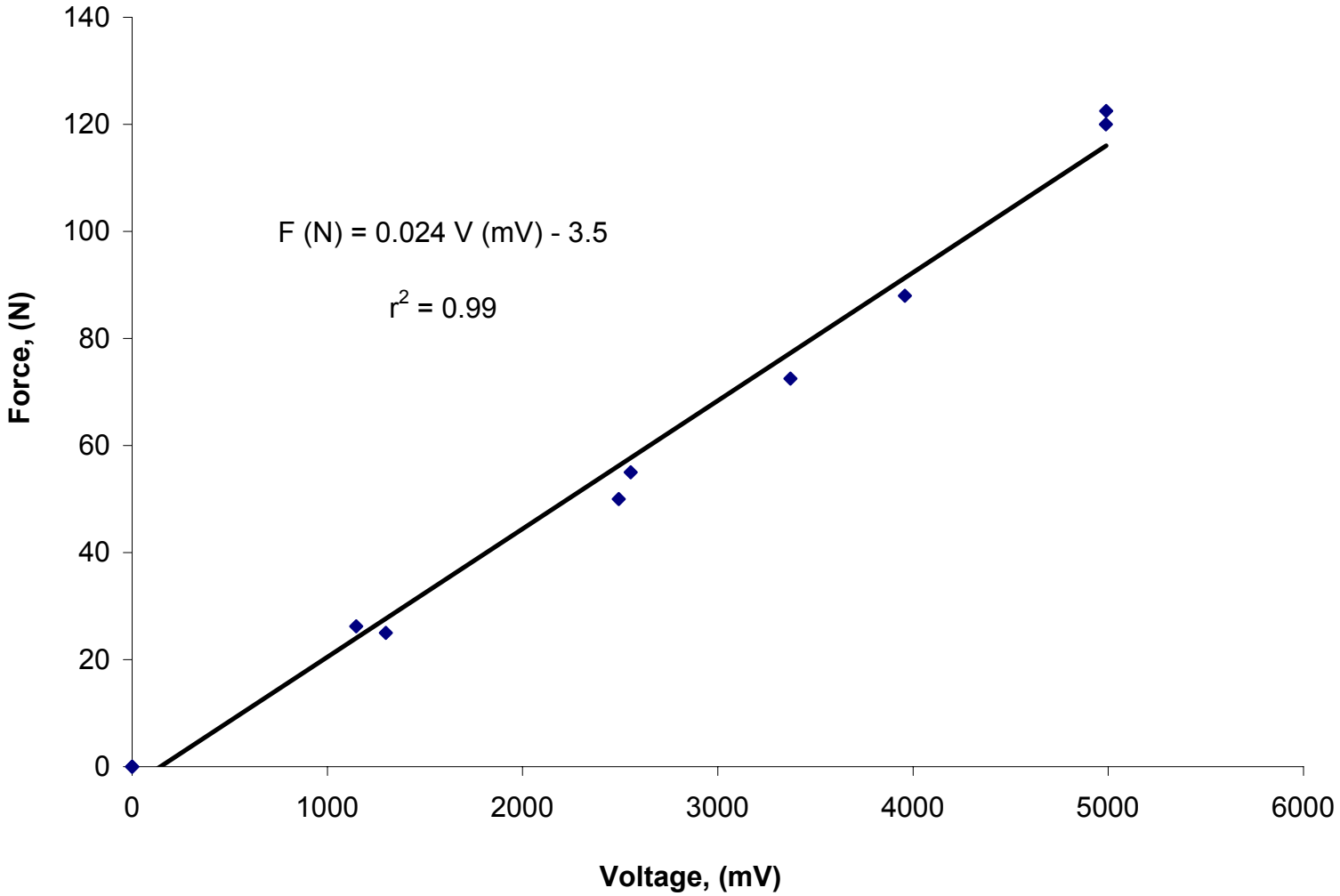


Figure C8. Calibration curve for sensor 4 before experiments with medium moisture content

Table C5. Calibration tables for the four sensors before experiments with high moisture content

Sensor 1	
Force, (N)	Voltage, (mV)
0	0
44	620
108	1818
152.5	2515
202.5	3375
245	4200
285	4980
280	4901
255	4285
210	3600
170	2850
135	2045
100	1300
35	450
F (N) = 0.06 V (mV) - 7.6	

Sensor 2	
Force, (N)	Voltage, (mV)
0	0
28	760
42	1250
72	1804
96.4	2404
100.3	3000
153.5	3750
150	4150
200	4732
198	4700
174	4200
151	3500
119	3010
78	2211
44	1300
21	800
0	0
F (N) = 0.042 V (mV) - 6.8	

Senosr 3	
Force, (N)	Voltage, (mV)
0	0
30	1295
72	2985
125	4300
168	5195
162	5120
120	4195
73	3052
25	1250
0	0
F (N) = 0.03 V (mV) - 9	

Sensor 4	
Force, (N)	Voltage, (mV)
0	0
27	1350
50	2600
75	3545
130	5200
125	4990
80	3640
45	2510
20	1200
0	0
F (N) = 0.025 V (mV) - 6.8	

Table C6. Forces applied on each sensor inside the soil for soil with high moisture content and three bulk densities

	Sensor 1		Sensor 2		Sensor 3		Sensor 4	
	0 cm depth		5 cm depth		10 cm depth		15 cm depth	
	Voltage, (mV)	Force, (N)	Voltage, (mV)	Force, (N)	Voltage, (mV)	Force, (N)	Voltage, (mV)	Force, (N)
Low Density								
Trial 1	1700	94.40	1700	64.60	1850	46.50	1000	18.20
Trial 2	1810	101.00	1689	64.14	1730	42.90	1250	24.45
Trial 3	1732	96.32	1820	69.64	1600	39.00	980	17.70
Medium Density								
Trial 1	1850	103.40	1300	47.80	880	17.40	800	13.20
Trial 2	2000	112.40	1400	52.00	1100	24.00	650	9.45
Trial 3	1670	92.60	1360	50.32	970	20.10	510	5.95
High Density								
Trial 1	1930	108.20	1475	55.15	1284	29.52	430	3.95
Trial 2	2110	119.00	1590	59.98	1102	24.06	460	4.70
Trial 3	1830	102.20	1510	56.62	1352	31.56	555	7.08

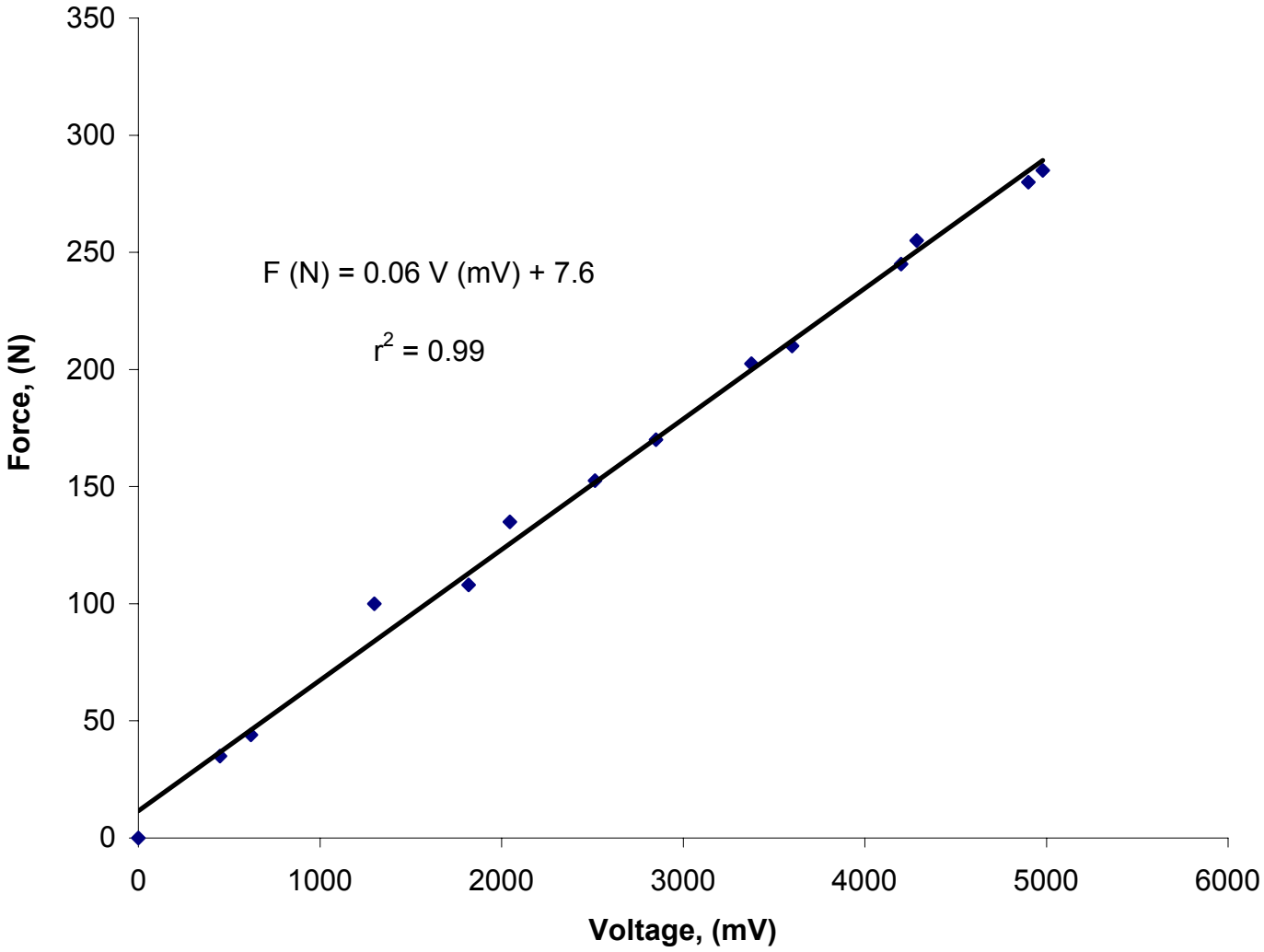


Figure C9. Calibration curve for sensor 1 before experiments with high moisture content

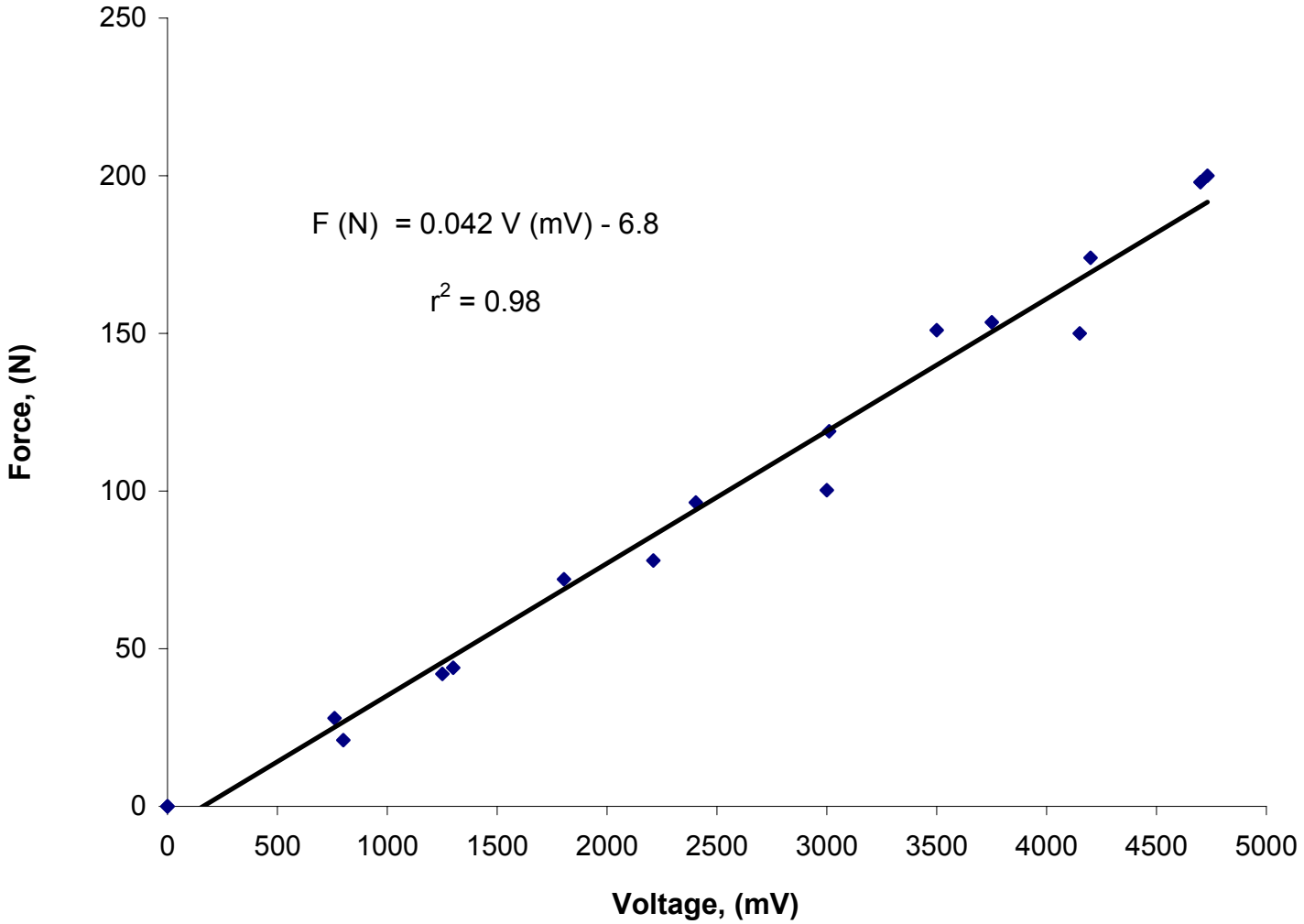


Figure C10. Calibration curve for sensor 2 before experiments with high moisture content

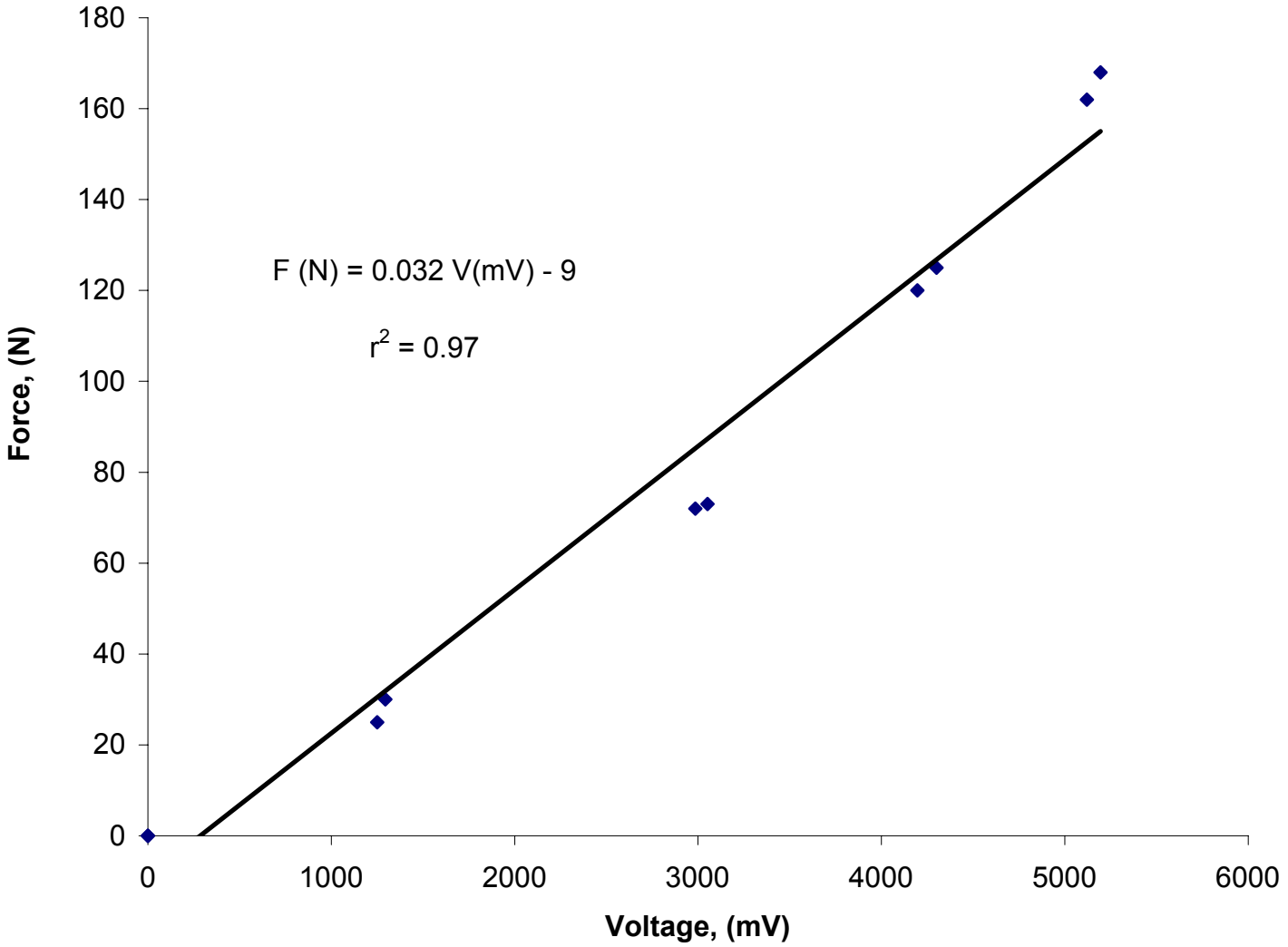


Figure C11. Calibration curve for sensor 3 before experiments with high moisture content

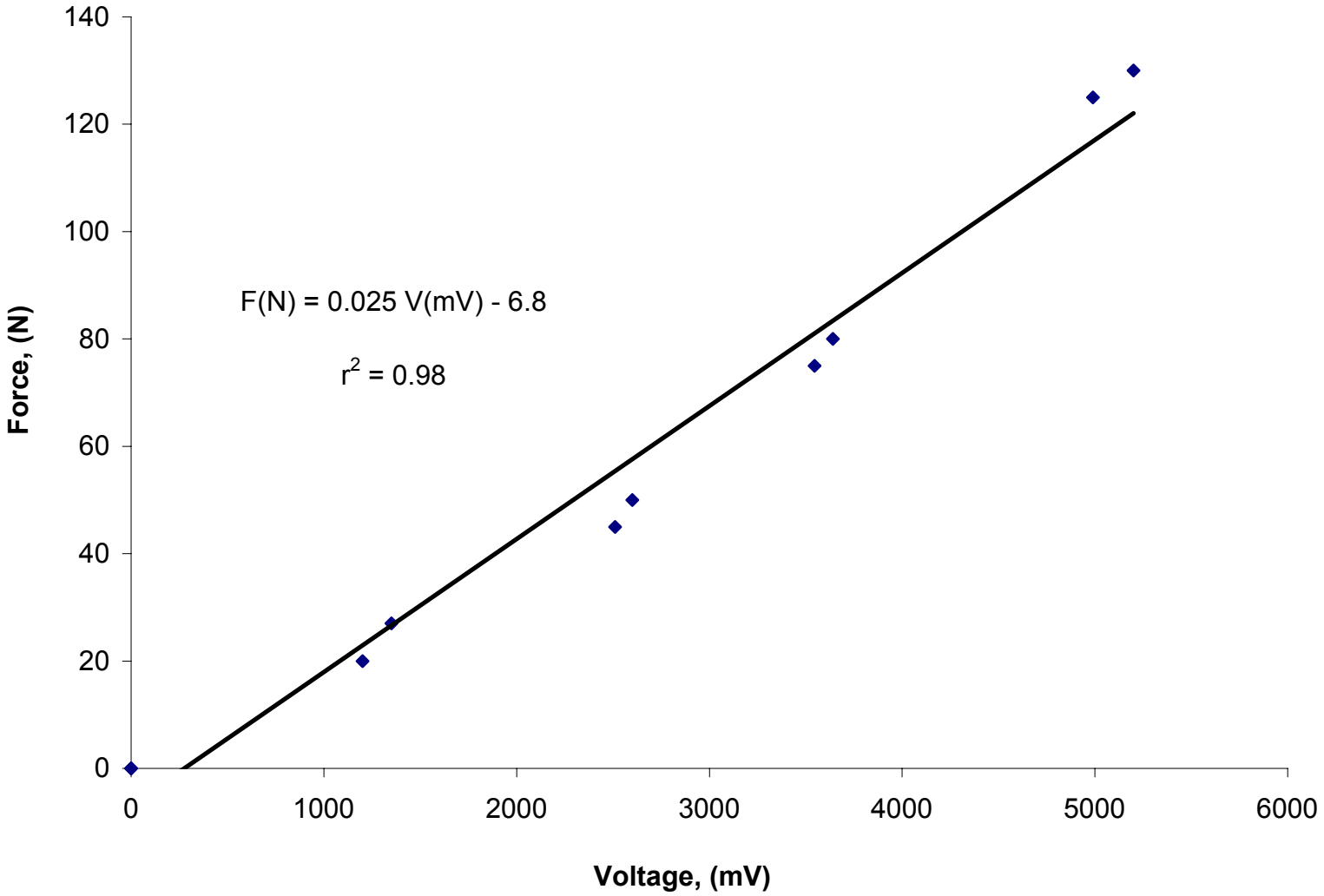


Figure C12. Calibration curve for sensor 4 before experiments with high moisture content

APPENDIX D

Data for each trial showing the vertical soil displacement (at depth 0 mm to 600 mm), pressure transferred (at depth 0 mm to 150 mm), average soil moisture content of each trial and initial bulk density of soil column. The average data and curves of the three trials are also included.

Table D1. Trial 1 for soil vertical displacement and pressure distribution using soil with low moisture content, low bulk density and an oval shaped contact surface

Vertical displacement and bulk density calculations										
Layer	Soil Mass, (kg)	Depth of layer before packing, (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	67.65	67.65	0.00
7th	9.20	66.00	66.70	67.10	9.30	1227.34	67.40	58.35	58.65	0.30
6th	9.20	57.05	57.20	57.60	9.50	1201.50	58.00	48.85	49.25	0.40
5th	9.20	47.05	47.70	47.90	9.70	1176.73	48.80	39.15	40.05	0.90
4th	9.20	37.50	37.90	38.10	9.80	1164.72	39.75	29.35	31.00	1.65
3rd	9.20	27.30	28.10	28.30	9.80	1164.72	32.00	19.55	23.25	3.70
2nd	9.20	17.80	18.50	18.70	9.60	1188.98	25.50	9.95	16.75	6.80
Surface	9.20	7.90	8.55	8.75	9.95	1147.16	19.75	0.00	11.00	11.00
		Wet bulk density of soil column, (kg/m^3)				1181.59				
		Dry bulk density of soil column, (kg/m^3)				1039.07				

Pressure distribution calaculation						Moisture content calaculation				
Depth of sensor before load, (cm)	Depth of sensor after load, (cm)	Depth of sensor after load, (cm)	Output force, (N)	Area of the sensor, (cm^2)	Pressure, (kPa)	Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content,
						3.70	97.90	86.50	13.77	
						3.70	145.00	128.30	13.40	13.72
						3.70	126.00	111.00	13.98	
0.00	11.00	0.00	120.95	4.52	267.49					
4.98	13.88	2.88	65.05	4.52	143.87					
9.95	16.75	5.75	22.34	4.52	49.41					
14.75	20.00	9.00	14.64	4.52	32.38					
19.55	23.25									

Table D2. Trial 2 for soil vertical displacement and pressure distribution using soil with low moisture content, low bulk density and an oval shaped contact surface

Vertical displacement and bulk density calculation										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement , (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	68.10	68.10	0.00
7^{th}	9.20	66.10	66.60	67.00	9.40	1214.28	67.40	58.70	59.10	0.40
6^{th}	9.20	56.70	56.90	57.30	9.70	1176.73	58.60	49.00	50.30	1.30
5^{th}	9.20	46.80	47.20	47.40	9.90	1152.95	48.80	39.10	40.50	1.40
4^{th}	9.20	37.00	37.80	38.00	9.40	1214.28	40.30	29.70	32.00	2.30
3^{rd}	9.20	27.70	27.90	28.10	9.90	1152.95	32.60	19.80	24.30	4.50
2^{nd}	9.20	17.55	17.80	18.00	10.10	1130.12	26.00	9.70	17.70	8.00
Surface	9.20	7.50	8.10	8.30	9.70	1176.73	20.25	0.00	11.95	11.95
		Wet bulk density of soil column, (kg/m^3)				1174.01				
		Dry bulk density of soil column, (kg/m^3)				1032.61				

Pressure distribution calaculation						Moisture content calaculation				
Depth of sensor before load, (cm)	Depth of sensor after load, (cm)	Depth of sensor after load, (cm)	Output force, (N)	Area of the sensor, (cm^2)	Pressure, (kPa)	Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
						3.70	110.00	97.00	13.93	
						3.70	170.00	150.00	13.67	13.69
						3.70	130.00	115.00	13.48	
0.00	12.15	0.00	108.37	4.52	239.67					
4.85	15.03	2.88	70.18	4.52	155.21					
9.70	17.90	5.75	34.49	4.52	76.28					
14.75	21.20	9.05	17.65	4.52	39.03					
19.80	24.50									

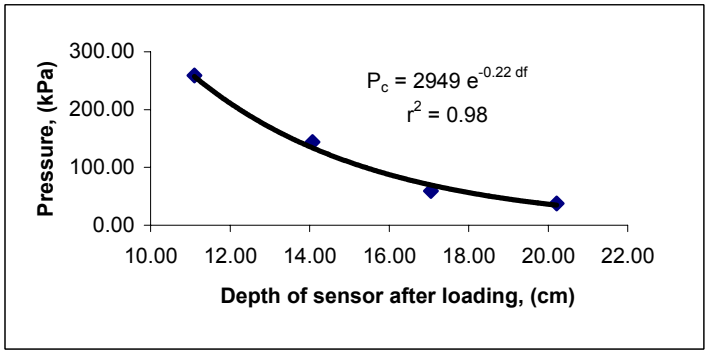
Table D3. Trial 3 for soil vertical displacement and pressure distribution using soil with low moisture content, low bulk density and an oval shaped contact surface

Vertical displacement and bulk density calculation										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	66.80	66.80	0.00
7^{th}	9.20	66.20	66.90	67.30	9.10	1254.31	67.30	57.70	57.70	0.00
6^{th}	9.20	56.90	57.55	57.95	9.35	1220.78	58.30	48.35	48.70	0.35
5^{th}	9.20	47.50	48.05	48.25	9.70	1176.73	48.60	38.65	39.00	0.35
4^{th}	9.20	37.80	38.40	38.60	9.65	1182.82	39.60	29.00	30.00	1.00
3^{rd}	9.20	28.55	28.90	29.10	9.50	1201.50	32.00	19.50	22.40	2.90
2^{nd}	9.20	19.00	19.40	19.60	9.50	1201.50	26.10	10.00	16.50	6.50
Surface	9.20	8.90	9.40	9.60	10.00	1141.43	19.75	0.00	10.15	10.15
		Wet bulk density of soil column, (kg/m^3)				1197.01				
		Dry bulk density of soil column, (kg/m^3)				1052.41				

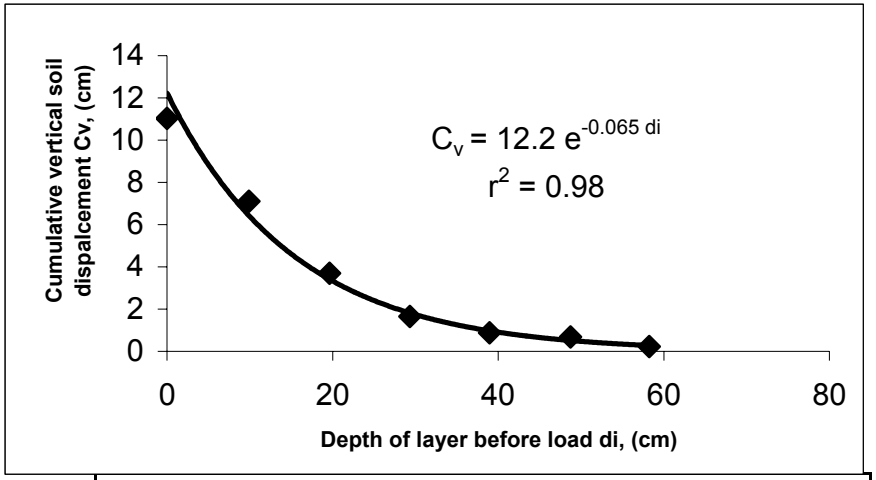
Pressure distribution calaculation						Moisture content calaculation				
Depth of sensor before load, (cm)	Depth of sensor after load, (cm)	Depth of sensor after load, (cm)	Output force, (N)	Area of the sensor, (cm^2)	Pressure, (kPa)	Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
						3.70	155.28	137.11	13.62	
						3.70	147.66	130.10	13.89	13.74
						3.70	116.84	103.20	13.71	
0.00	10.15	0.00	122.03	4.52	269.88					
5.00	13.33	3.18	60.14	4.52	133.01					
10.00	16.50	6.35	23.35	4.52	51.64					
14.75	19.45	9.30	18.8	4.52	41.58					
19.50	22.40									

Table D4. Average of trials 1, 2, and 3 for vertical displacement, pressure distribution, bulk density and moisture content using soil with low moisture content, low bulk density and an oval shaped contact surface

Pressure distribution	
Depth of sensor after load, (cm)	**Pressure, (kPa)**
11.10	259.02
14.08	144.03
17.05	59.11
20.22	37.66



Vertical displacement			
Layer	**Depth before Load, (cm)**	**Depth after load, (cm)**	**Vertical Displacement, (cm)**
Base	67.52	67.52	0.00
7th	58.25	58.48	0.23
6th	48.73	49.42	0.68
5th	38.97	39.85	0.88
4th	29.35	31.00	1.65
3rd	19.62	23.32	3.70
2nd	9.88	16.98	7.10
Surface	0.00	11.03	11.03



Bulk density of soil column, (kg/m^3)			
Trial 1	**Trial 2**	**Trial 3**	**Average**
1181.59	1174.01	1197.01	1184.20
1039.07	1032.61	1052.41	1041.36

Moisture content of soil column, (%)			
Trial 1	**Trial 2**	**Trial 3**	**Average**
13.72	13.69	13.74	13.72

Table D5. Trial 1 for soil vertical displacement using soil with low moisture content, low bulk density and a rectangular shaped contact surface

Vertical displacement and bulk density calculations										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.4	76.40			76.40	67.60	67.60	0.00
7^{th}	9.20	66.00	66.7	67.10	9.30	1227.34	67.40	58.30	58.60	0.30
6^{th}	9.20	57.00	57.2	57.60	9.50	1201.50	58.00	48.80	49.20	0.40
5^{th}	9.20	47.10	47.6	47.80	9.80	1164.72	48.50	39.00	39.70	0.70
4^{th}	9.20	37.60	38	38.20	9.60	1188.98	39.60	29.40	30.80	1.40
3^{rd}	9.20	27.30	28.2	28.40	9.80	1164.72	31.50	19.60	22.70	3.10
2^{nd}	9.20	17.80	18.3	18.50	9.90	1152.95	24.00	9.70	15.20	5.50
Surface	9.20	7.80	8.6	8.80	9.70	1176.73	18.00	0.00	9.20	9.20
		Bulk density of soil column, (kg/m^3)				1182.42				
						1043.02				

Moisture content calaculation				
Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
3.70	126.38	112.20	13.07	13.36
3.70	170.57	151.10	13.21	
3.70	178.18	157.00	13.82	

Table D6. Trial 2 for soil vertical displacement using soil with low moisture content, low bulk density and a rectangular shaped contact surface

Vertical displacement and bulk density calculation										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	67.10	67.10	0.00
7^{th}	9.20	66.00	66.80	67.20	9.20	1240.68	67.40	57.90	58.10	0.20
6^{th}	9.20	56.80	57.10	57.50	9.70	1176.73	57.90	48.20	48.60	0.40
5^{th}	9.20	47.30	47.50	47.70	9.80	1164.72	48.60	38.40	39.30	0.90
4^{th}	9.20	37.70	38.10	38.30	9.40	1214.28	39.60	29.00	30.30	1.30
3^{rd}	9.20	27.80	28.30	28.50	9.80	1164.72	31.20	19.20	21.90	2.70
2^{nd}	9.20	18.30	18.80	19.00	9.50	1201.50	23.50	9.70	14.20	4.50
Surface	9.20	8.20	9.10	9.30	9.70	1176.73	17.80	0.00	8.50	8.50
		Bulk density of soil column, (kg/m^3)				1191.34				
						1048.03				

Moisture content calaculation				
Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
3.70	167.84	148.00	13.75	
3.70	145.34	128.30	13.68	13.67
3.70	111.64	98.72	13.60	

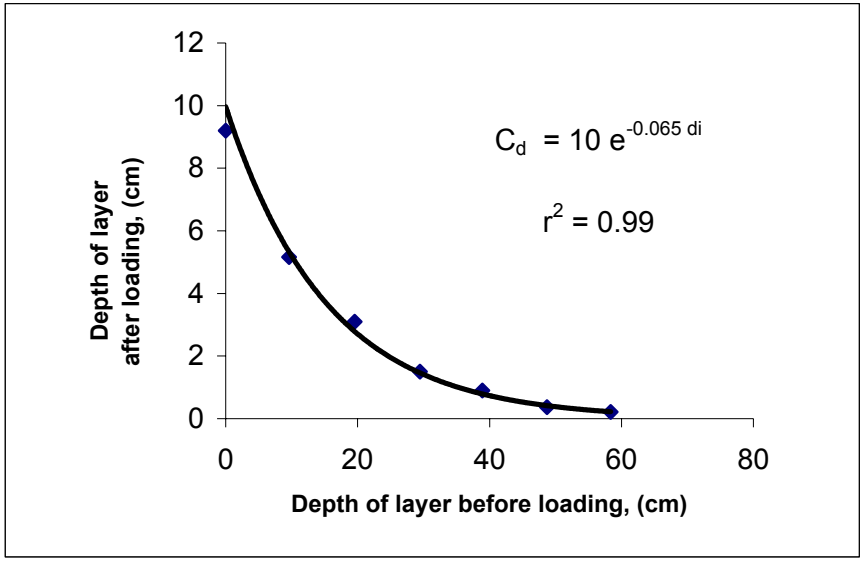
Table D7. Trial 3 for soil vertical displacement using soil with low moisture content, low bulk density and a rectangular shaped contact surface

Vertical displacement and bulk density calculation										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	68.30	68.30	0.00
7^{th}	9.20	66.20	66.65	67.05	9.35	1220.78	67.20	58.95	59.10	0.15
6^{th}	9.20	56.70	56.80	57.20	9.85	1158.81	57.50	49.10	49.40	0.30
5^{th}	9.20	46.70	47.20	47.40	9.80	1164.72	48.50	39.30	40.40	1.10
4^{th}	9.20	36.70	37.80	38.00	9.40	1214.28	39.80	29.90	31.70	1.80
3^{rd}	9.20	27.60	27.80	28.00	10.00	1141.43	31.50	19.90	23.40	3.50
2^{nd}	9.20	17.10	17.30	17.50	10.50	1087.07	23.00	9.40	14.90	5.50
Surface	9.20	7.30	7.90	8.10	9.40	1214.28	18.00	0.00	9.90	9.90
		Bulk density of soil column, (kg/m^3)				1171.62				
						1031.91				

Moisture content calaculation				
Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
3.70	128.49	114.01	13.13	13.54
3.70	113.48	99.69	14.37	
3.70	175.22	155.32	13.12	

Table D8. Average of trials 1, 2, and 3 for vertical displacement, bulk density and moisture content using soil with low moisture content, low bulk density and a rectangular shaped contact surface

Vertical displacement			
Layer	**Depth before Load, (cm)**	**Depth after load, (cm)**	**Vertical Displacement, (cm)**
Base	67.67	67.67	0.00
7th	58.38	58.60	0.22
6th	48.70	49.07	0.37
5th	38.90	39.80	0.90
4th	29.43	30.93	1.50
3rd	19.57	22.67	3.10
2nd	9.60	14.77	5.17
Surface	0.00	9.20	9.20



Bulk density of soil column, (kg/m^3)			
Trial 1	**Trial 2**	**Trial 3**	**Average**
1182.42	1191.34	1171.62	1181.79
1043.02	1048.03	1031.91	1040.99

Moisture content of soil column, (%)			
Trial 1	**Trial 2**	**Trial 3**	**Average**
13.36	13.67	13.54	13.53

Table D9. Trial 1 for soil vertical displacement and pressure distribution using soil with low moisture content, medium bulk density and an oval shaped contact surface

Vertical displacement and bulk density calculations										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	69.60	69.60	0.00
7^{th}	10.00	66.05	66.40	66.60	9.80	1266.00	66.80	59.80	60.00	0.20
6^{th}	10.00	56.10	56.50	56.70	9.90	1253.21	56.80	49.90	50.00	0.10
5^{th}	10.00	46.40	46.55	46.75	9.95	1246.91	47.40	39.95	40.60	0.65
4^{th}	10.00	36.30	36.90	36.90	9.85	1259.57	37.50	30.10	30.70	0.60
3^{rd}	10.00	26.30	26.80	26.80	10.10	1228.40	28.20	20.00	21.40	1.40
2^{nd}	10.00	16.10	16.80	16.80	10.00	1240.68	21.00	10.00	14.20	4.20
Surface	10.00	6.05	6.80	6.80	10.00	1240.68	13.00	0.00	6.20	6.20
		Wet bulk density of soil column, (kg/m^3)				1247.92				
		Dry bulk density of soil column, (kg/m^3)				1096.05				

Pressure distribution calaculation						Moisture content calaculation				
Depth of sensor before load, (cm)	Depth of sensor after load, (cm)	Depth of sensor after load, (cm)	Output force, (N)	Area of the sensor, (cm^2)	Pressure, (kPa)	Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
						3.70	157.00	138.30	13.89	
						3.70	168.30	148.20	13.91	13.86
						3.70	87.66	77.50	13.77	
0.00	6.00	0.00	110.31	4.52	243.96					
5.00	10.00	4.00	50.45	4.52	111.58					
10.00	14.00	8.00	28.54	4.52	63.12					
15.00	17.60	11.60	14.74	4.52	32.60					
20.00	21.20									

Table D10. Trial 2 for soil vertical displacement and pressure distribution using soil with low moisture content, low medium density and an oval shaped contact surface

Vertical displacement and bulk density calculation										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	69.00	69.00	0.00
7^{th}	10.00	65.50	66.10	66.30	10.10	1228.40	66.50	58.90	59.10	0.20
6^{th}	10.00	56.30	56.60	56.80	9.50	1305.98	56.80	49.40	49.40	0.00
5^{th}	10.00	46.50	47.20	47.40	9.40	1319.87	47.20	40.00	39.80	-0.20
4^{th}	10.00	36.40	36.90	36.90	10.50	1181.60	37.60	29.50	30.20	0.70
3^{rd}	10.00	26.20	27.10	27.10	9.80	1266.00	28.90	19.70	21.50	1.80
2^{nd}	10.00	16.10	16.50	16.50	10.60	1170.45	19.80	9.10	12.40	3.30
Surface	10.00	6.05	7.40	7.40	9.10	1363.38	13.20	0.00	5.80	5.80
		Wet bulk density of soil column, (kg/m^3)				1262.24				
		Dry bulk density of soil column, (kg/m^3)				1112.94				

Pressure distribution calaculation						Moisture content calaculation				
Depth of sensor before load, (cm)	Depth of sensor after load, (cm)	Depth of sensor after load, (cm)	Output force, (N)	Area of the sensor, (cm^2)	Pressure, (kPa)	Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
						3.70	68.23	60.55	13.51	
						3.70	97.15	86.20	13.27	13.42
						3.70	67.58	60.00	13.46	
0.00	5.60	0.00	150.11	4.52	331.98					
4.55	8.90	3.30	52.47	4.52	116.04					
9.10	12.20	6.60	24.63	4.52	54.47					
14.40	16.75	11.15	8.81	4.52	19.48					
19.70	21.30									

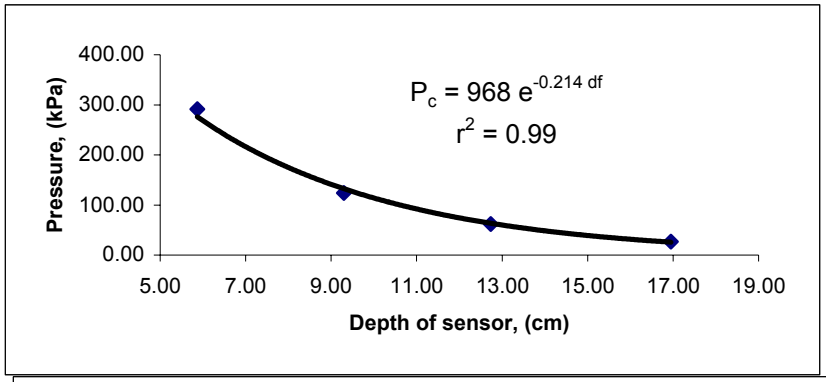
Table D11. Trial 3 for soil vertical displacement and pressure distribution using soil with low moisture content medium bulk density and an oval shaped contact surface

Vertical displacement and bulk density calculation										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	68.60	68.60	0.00
7^{th}	10.00	66.30	66.60	66.80	9.60	1292.37	66.80	59.00	59.00	0.00
6^{th}	10.00	56.00	56.40	56.60	10.20	1216.35	56.50	48.80	48.70	-0.10
5^{th}	10.00	46.60	46.90	47.10	9.50	1305.98	47.30	39.30	39.50	0.20
4^{th}	10.00	37.30	37.80	37.80	9.30	1334.06	38.00	30.00	30.20	0.20
3^{rd}	10.00	26.70	27.10	27.10	10.70	1159.51	29.00	19.30	21.20	1.90
2^{nd}	10.00	15.80	16.10	16.10	11.00	1127.89	20.00	8.30	12.20	3.90
Surface	10.00	7.30	7.80	7.80	8.30	1494.79	14.00	0.00	6.20	6.20
		Wet bulk density of soil column, (kg/m^3)				1275.85				
		Dry bulk density of soil column, (kg/m^3)				1127.16				

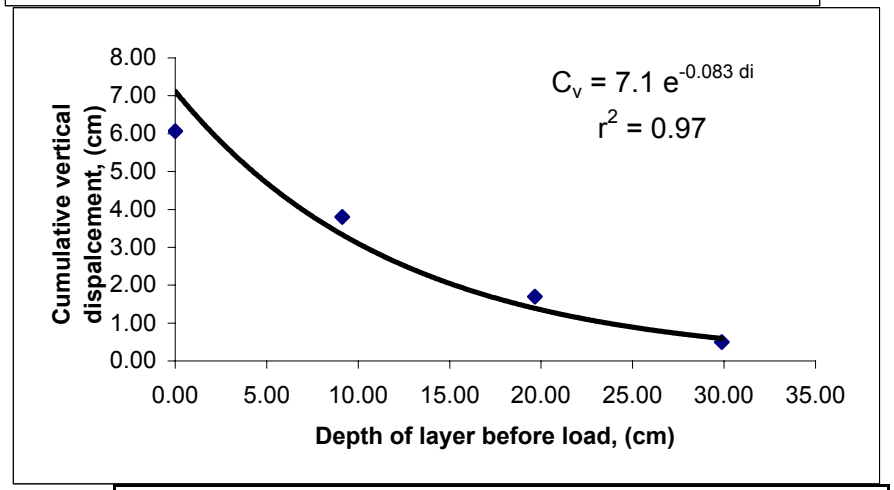
Pressure distribution calaculation						Moisture content calaculation				
Depth of sensor before load, (cm)	Depth of sensor after load, (cm)	Depth of sensor after load, (cm)	Output force, (N)	Area of the sensor, (cm^2)	Pressure, (kPa)	Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
						3.70	154.80	137.40	13.01	
						3.70	144.71	128.27	13.20	13.19
						3.70	128.40	113.70	13.36	
0.00	6.00	0.00	135.21	4.52	299.03					
4.15	9.00	3.00	65.46	4.52	144.77					
8.30	12.00	6.00	30.51	4.52	67.48					
13.80	16.50	10.50	12.76	4.52	28.22					
19.30	21.00									

Table D12. Average of trials 1, 2, and 3 for vertical displacement, pressure distribution, bulk density and moisture content using soil with low moisture content, medium bulk density and an oval shaped contact surface

Pressure distribution	
Depth of sensor after load, (cm)	**Pressure, (kPa)**
5.87	291.66
9.30	124.13
12.73	61.69
16.95	26.77



Vertical displacement			
Layer	**Depth before Load, (cm)**	**Depth after load, (cm)**	**Vertical Displacement, (cm)**
Base	69.07	69.07	0.00
7th	59.23	59.37	0.13
6th	49.37	49.37	0.00
5th	39.75	39.97	0.22
4th	29.87	30.37	0.50
3rd	19.67	21.37	1.70
2nd	9.13	12.93	3.80
Surface	0.00	6.07	6.07



Bulk density of soil column, (kg/m^3)			
Trial 1	**Trial 2**	**Trial 3**	**Average**
1247.92	1262.24	1275.85	1262.00
1096.05	1112.94	1127.16	1112.05

Moisture content of soil column, (%)			
Trial 1	**Trial 2**	**Trial 3**	**Average**
13.86	13.42	13.19	13.49

Table D13. Trial 1 for soil vertical displacement using soil with low moisture content, medium bulk density and a rectangular shaped contact surface

Vertical displacement and bulk density calculations										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	69.10	69.10	0.00
7^{th}	10.00	65.95	66.50	66.70	9.70	1279.05	66.90	59.40	59.60	0.20
6^{th}	10.00	56.00	56.50	56.70	10.00	1240.68	56.70	49.40	49.40	0.00
5^{th}	10.00	46.40	46.60	46.80	9.90	1253.21	47.00	39.50	39.70	0.20
4^{th}	10.00	36.40	37.00	37.00	9.80	1266.00	37.40	29.70	30.10	0.40
3^{rd}	10.00	26.50	26.90	26.90	10.10	1228.40	28.20	19.60	20.90	1.30
2^{nd}	10.00	16.00	17.20	17.20	9.70	1279.05	20.00	9.90	12.70	2.80
Surface	9.20	6.00	7.30	7.30	9.90	1152.95	13.20	0.00	5.90	5.90
		Bulk density of soil column, (kg/m^3)				1242.76				
						1099.23				

Moisture content calaculation				
Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
3.70	125.38	112.20	12.15	13.06
3.70	170.57	151.10	13.21	
3.70	178.18	157.00	13.82	

Table D14. Trial 2 for soil vertical displacement using soil with low moisture content, medium bulk density and a rectangular shaped contact surface

Vertical displacement and bulk density calculation										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	68.10	68.10	0.00
7^{th}	10.00	66.20	66.60	66.80	9.60	1292.37	66.80	58.50	58.50	0.00
6^{th}	10.00	56.30	57.00	57.20	9.60	1292.37	57.25	48.90	48.95	0.05
5^{th}	10.00	46.20	46.80	47.00	10.20	1216.35	47.10	38.70	38.80	0.10
4^{th}	10.00	37.30	37.90	37.90	9.10	1363.38	38.20	29.60	29.90	0.30
3^{rd}	10.00	26.65	27.80	27.80	10.10	1228.40	29.00	19.50	20.70	1.20
2^{nd}	10.00	17.30	18.10	18.10	9.70	1279.05	20.85	9.80	12.55	2.75
Surface	9.20	7.30	8.30	8.30	9.80	1164.72	13.80	0.00	5.50	5.50
		Bulk density of soil column, (kg/m^3)				1262.38				
						1110.53				

Moisture content calaculation				
Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
3.70	167.84	148.00	13.75	13.67
3.70	145.34	128.30	13.68	
3.70	111.64	98.72	13.60	

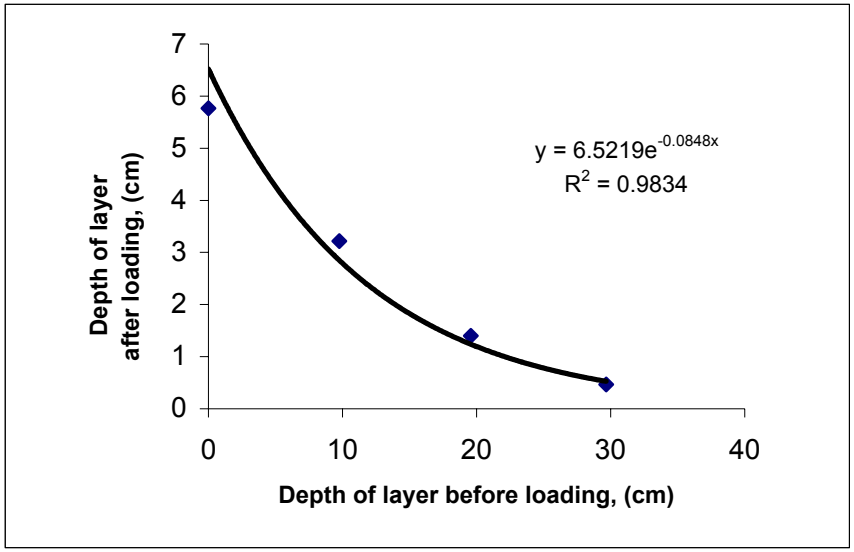
Table D15. Trial 3 for soil vertical displacement using soil with low moisture content, medium bulk density and a rectangular shaped contact surface

Vertical displacement and bulk density calculation										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	69.20	69.20	0.00
7^{th}	10.00	66.10	66.60	66.80	9.60	1292.37	66.80	59.60	59.60	0.00
6^{th}	10.00	56.10	56.50	56.70	10.10	1228.40	56.80	49.50	49.60	0.10
5^{th}	10.00	46.55	47.10	47.30	9.40	1319.87	47.60	40.10	40.40	0.30
4^{th}	10.00	36.50	36.90	36.90	10.40	1192.96	37.60	29.70	30.40	0.70
3^{rd}	10.00	26.10	26.80	26.80	10.10	1228.40	28.50	19.60	21.30	1.70
2^{nd}	10.00	16.05	16.80	16.80	10.00	1240.68	20.90	9.60	13.70	4.10
Surface	9.20	6.10	7.20	7.20	9.60	1188.98	13.10	0.00	5.90	5.90
		Bulk density of soil column, (kg/m^3)				1241.67				
						1095.67				

Moisture content calaculation				
Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
3.70	87.45	77.68	13.21	13.32
3.70	124.11	110.04	13.23	
3.70	134.88	119.24	13.54	

Table D16. Average of trials 1, 2, and 3 for vertical displacement, bulk density and moisture content using soil with low moisture content, medium bulk density and a rectangular shaped contact surface

Vertical displacement			
Layer	**Depth before Load, (cm)**	**Depth after load, (cm)**	**Vertical Displacement, (cm)**
Base	68.80	68.80	0.00
7th	59.17	59.23	0.07
6th	49.27	49.32	0.05
5th	39.43	39.63	0.20
4th	29.67	30.13	0.47
3rd	19.57	20.97	1.40
2nd	9.77	12.98	3.22
Surface	0.00	5.77	5.77



Bulk density of soil column, (kg/m^3)			
Trial 1	**Trial 2**	**Trial 3**	**Average**
1242.76	1262.38	1241.67	1248.94
1099.00	1110.00	1095.00	1101.33

Moisture content of soil column, (%)			
Trial 1	**Trial 2**	**Trial 3**	**Average**
13.06	13.32	13.32	13.24

Table D17. Trial 1 for soil vertical displacement and pressure distribution using soil with low moisture content, high bulk density and an oval shaped contact surface

Vertical displacement and bulk density calculations										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	71.10	71.10	0.00
7^{th}	10.70	64.80	66.30	66.30	10.10	1314.38	66.40	61.00	61.10	0.10
6^{th}	10.70	55.10	56.50	56.50	9.80	1354.62	56.70	51.20	51.40	0.20
5^{th}	10.70	45.30	46.30	46.30	10.20	1301.50	46.55	41.00	41.25	0.25
4^{th}	10.70	34.60	36.30	36.30	10.00	1327.53	36.60	31.00	31.30	0.30
3^{rd}	10.70	24.40	26.10	26.10	10.20	1301.50	26.50	20.80	21.20	0.40
2^{nd}	10.70	14.70	15.30	15.30	10.80	1229.19	16.80	10.00	11.50	1.50
Surface	10.70	3.80	5.30	5.30	10.00	1327.53	8.00	0.00	2.70	2.70
		Bulk density of soil column, (kg/m^3)				1308.03				
		Dry bulk density of soil column, (kg/m^3)				1153.30				

Pressure distribution calaculation						Moisture content calaculation				
Depth of sensor before load, (cm)	Depth of sensor after load, (cm)	Depth of sensor after load, (cm)	Output force, (N)	Area of the sensor, (cm^2)	Pressure, (kPa)	Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
						3.70	164.28	145.10	13.56	
						3.70	149.67	132.50	13.33	13.42
						3.70	122.70	108.68	13.35	
0.00	2.70	0.00	120.90	4.52	267.38					
5.00	7.10	4.40	65.05	4.52	143.87					
10.00	11.50	8.80	22.34	4.52	49.41					
15.40	16.35	13.65	14.64	4.52	32.38					
20.80	21.20									

Table D18. Trial 2 for soil vertical displacement and pressure distribution using soil with low moisture content, high bulk density and an oval shaped contact surface

Vertical displacement and bulk density calculation										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	70.80	70.80	0.00
7th	10.70	65.30	66.10	66.10	10.30	1288.86	66.30	60.50	60.70	0.20
6th	10.70	55.00	56.30	56.30	9.80	1354.62	56.60	50.70	51.00	0.30
5th	10.70	45.00	46.20	46.20	10.10	1314.38	46.30	40.60	40.70	0.10
4th	10.70	35.00	36.20	36.20	10.00	1327.53	36.50	30.60	30.90	0.30
3rd	10.70	25.00	26.20	26.20	10.00	1327.53	26.50	20.60	20.90	0.30
2nd	10.70	14.90	15.80	15.80	10.40	1276.47	17.30	10.20	11.70	1.50
Surface	10.70	3.80	5.60	5.60	10.20	1301.50	8.75	0.00	3.15	3.15
		Bulk density of soil column, (kg/m^3)				1312.98				
		Dry bulk density of soil column, (kg/m^3)				1158.22				

Pressure distribution calaculation						Moisture content calaculation				
Depth of sensor before load, (cm)	Depth of sensor after load, (cm)	Depth of sensor after load, (cm)	Output force, (N)	Area of the sensor, (cm^2)	Pressure, (kPa)	Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
						3.70	110.49	97.95	13.31	
						3.70	109.00	96.00	14.08	13.36
						3.70	76.84	68.60	12.70	
0.00	3.15	0.00	125.43	4.52	277.40					
5.10	7.43	4.28	63.75	4.52	140.99					
10.20	11.70	8.55	26.19	4.52	57.92					
15.40	16.30	13.15	12.66	4.52	28.00					
20.60	20.90									

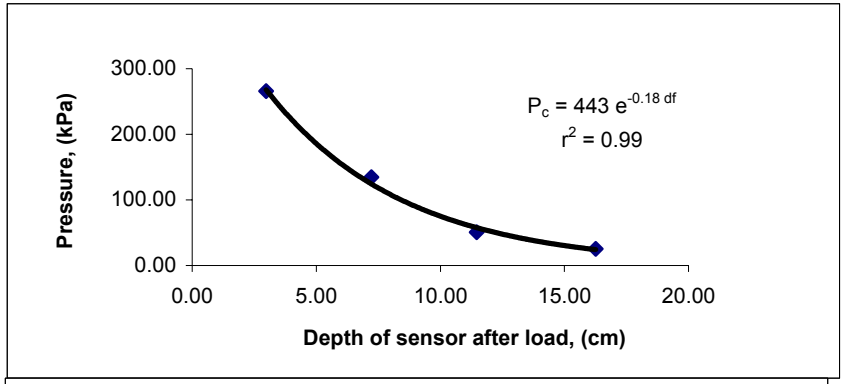
Table D19. Trial 3 for soil vertical displacement and pressure distribution using soil with low moisture content, high bulk density and an oval shaped contact surface

Vertical displacement and bulk density calculation										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	70.10	70.10	0.00
7th	10.70	65.20	66.20	66.20	10.20	1301.50	66.20	59.90	59.90	0.00
6th	10.70	56.10	57.30	57.30	8.90	1491.60	57.50	51.00	51.20	0.20
5th	10.70	46.30	47.00	47.00	10.30	1288.86	47.10	40.70	40.80	0.10
4th	10.70	35.80	36.80	36.80	10.20	1301.50	37.30	30.50	31.00	0.50
3rd	10.70	25.50	26.70	26.70	10.10	1314.38	27.40	20.40	21.10	0.70
2nd	10.70	15.10	16.50	16.50	10.20	1301.50	17.50	10.20	11.20	1.00
Surface	10.70	5.00	6.30	6.30	10.20	1301.50	9.40	0.00	3.10	3.10
		Bulk density of soil column, (kg/m^3)				1328.69				
		Dry bulk density of soil column, (kg/m^3)				1167.95				

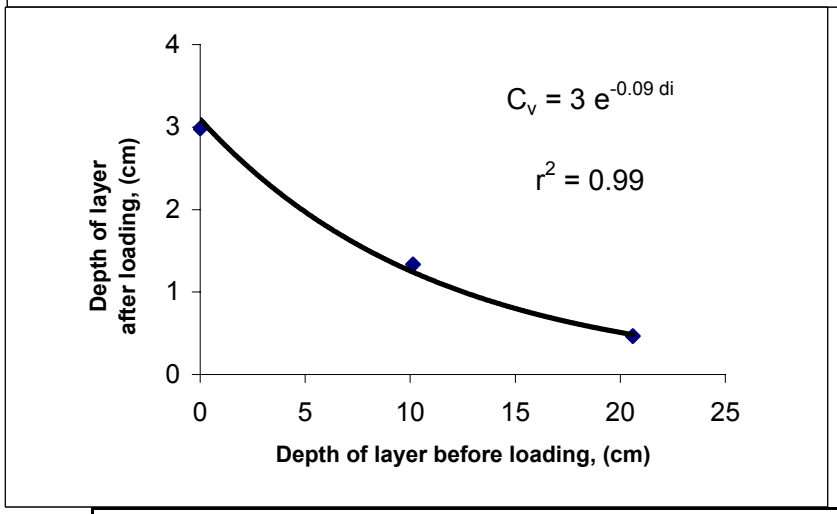
Pressure distribution calaculation						Moisture content calaculation				
Depth of sensor before load, (cm)	Depth of sensor after load, (cm)	Depth of sensor after load, (cm)	Output force, (N)	Area of the sensor, (cm^2)	Pressure, (kPa)	Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
						3.70	86.59	76.48	13.89	
						3.70	79.55	70.37	13.77	13.76
						3.70	129.11	114.07	13.63	
0.00	3.10	0.00	114.15	4.52	252.45					
5.10	7.15	4.05	53.57	4.52	118.48					
10.20	11.20	8.10	20.42	4.52	45.16					
15.30	16.15	13.05	7.36	4.52	16.28					
20.40	21.10									

Table D20. Average of trials 1, 2, and 3 for vertical displacement, pressure distribution, bulk density and moisture content using soil with low moisture content, high bulk density and an oval shaped contact surface

Average Pressure distribution	
Depth of sensor after load, (cm)	**Pressure, (kPa)**
2.98	265.75
7.23	134.44
11.47	50.83
16.27	25.55



Vertical displacement			
Layer	**Depth before Load, (cm)**	**Depth after load, (cm)**	**Vertical Displacement, (cm)**
Base	70.67	70.67	0.00
7th	60.47	60.57	0.10
6th	50.97	51.20	0.23
5th	40.77	40.92	0.15
4th	30.70	31.07	0.37
3rd	20.60	21.07	0.47
2nd	10.13	11.47	1.33
Surface	0.00	2.98	2.98



Bulk density of soil column, (kg/m^3)			
Trial 1	**Trial 2**	**Trial 3**	**Average**
1308.03	1312.98	1328.69	1316.57
1153.30	1158.22	1167.95	1159.82

Moisture content of soil column, (%)			
Trial 1	**Trial 2**	**Trial 3**	**Average**
13.42	13.36	13.76	13.51

Table D21. Trial 1 for soil vertical displacement using soil with low moisture content, high bulk density and a rectangular shaped contact surface

Vertical displacement and bulk density calculations										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	70.60	70.60	0.00
7^{th}	10.70	65.30	66.20	66.20	10.20	1301.50	66.50	60.40	60.70	0.30
6^{th}	10.70	55.90	56.10	56.10	10.10	1314.38	56.40	50.30	50.60	0.30
5^{th}	10.70	46.30	46.30	46.30	9.80	1354.62	46.80	40.50	41.00	0.50
4^{th}	10.70	35.65	36.30	36.30	10.00	1327.53	36.60	30.50	30.80	0.30
3^{rd}	10.70	25.60	26.30	26.30	10.00	1327.53	26.70	20.50	20.90	0.40
2^{nd}	10.70	15.30	16.10	16.10	10.20	1301.50	17.00	10.30	11.20	0.90
Surface	10.70	5.20	5.80	5.80	10.30	1288.86	8.80	0.00	3.00	3.00
		Bulk density of soil column, (kg/m^3)				1316.56				

Moisture content calaculation				
Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
3.70	82.44	73.30	13.13	13.68
3.70	147.46	129.88	13.93	
3.70	122.84	108.24	13.97	

Table D22. Trial 2 for soil vertical displacement using soil with low moisture content, high bulk density and a rectangular shaped contact surface

Vertical displacement and bulk density calculation										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	70.10	70.10	0.00
7th	10.70	65.50	66.20	66.20	10.20	1301.50	66.60	59.90	60.30	0.40
6th	10.70	56.00	56.15	56.15	10.05	1320.92	56.35	49.85	50.05	0.20
5th	10.70	46.30	46.10	46.10	10.05	1320.92	46.50	39.80	40.20	0.40
4th	10.70	35.55	36.10	36.10	10.00	1327.53	36.50	29.80	30.20	0.40
3rd	10.70	25.55	26.30	26.30	9.80	1354.62	26.75	20.00	20.45	0.45
2nd	10.70	15.90	16.30	16.30	10.00	1327.53	17.50	10.00	11.20	1.20
Surface	10.70	5.50	6.30	6.30	10.00	1327.53	9.40	0.00	3.10	3.10
		Bulk density of soil column, (kg/m^3)				1325.79				

Moisture content calaculation				
Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
3.70	149.45	131.88	13.71	13.41
3.70	111.62	99.01	13.23	
3.70	174.18	154.17	13.30	

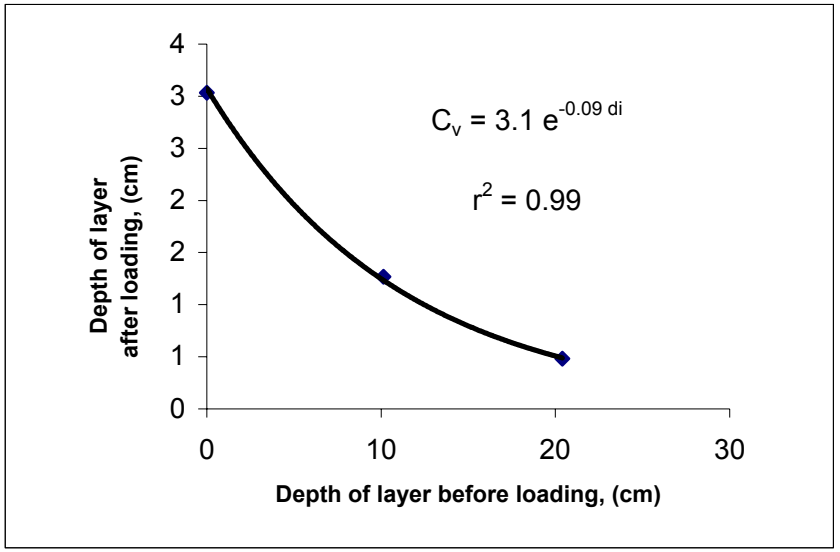
Table D23. Trial 3 for soil vertical displacement using soil with low moisture content, high bulk density and a rectangular shaped contact surface

Vertical displacement and bulk density calculation										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	70.20	70.20	0.00
7^{th}	10.70	65.30	66.40	66.40	10.00	1327.53	66.70	60.20	60.50	0.30
6^{th}	10.70	55.30	56.20	56.20	10.20	1301.50	56.70	50.00	50.50	0.50
5^{th}	10.70	45.30	46.30	46.30	9.90	1340.94	46.50	40.10	40.30	0.20
4^{th}	10.70	35.30	36.10	36.10	10.20	1301.50	36.60	29.90	30.40	0.50
3^{rd}	10.70	25.30	26.90	26.90	9.20	1442.96	27.50	20.70	21.30	0.60
2^{nd}	10.70	15.30	16.30	16.30	10.60	1252.38	18.00	10.10	11.80	1.70
Surface	10.70	5.30	6.20	6.20	10.10	1314.38	9.20	0.00	3.00	3.00
		Bulk density of soil column, (kg/m^3)				1325.88				

Moisture content calaculation				
Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
3.70	76.41	67.75	13.52	
3.70	149.77	132.00	13.85	13.55
3.70	142.87	126.55	13.28	

Table D24. Average of trials 1, 2, and 3 for vertical displacement, bulk density and moisture content using soil with low moisture content, high bulk density and a rectangular shaped contact surface

Vertical displacement			
Layer	**Depth before Load, (cm)**	**Depth after load, (cm)**	**Vertical Displacement, (cm)**
Base	70.30	70.30	0.00
7th	60.17	60.50	0.33
6th	50.05	50.38	0.33
5th	40.13	40.50	0.37
4th	30.07	30.47	0.40
3rd	20.40	20.88	0.48
2nd	10.13	11.40	1.27
Surface	0.00	3.03	3.03



Bulk density of soil column, (kg/m^3)			
Trial 1	**Trial 2**	**Trial 3**	**Average**
1316.56	1325.79	1325.88	1322.74

Moisture content of soil column, (%)			
Trial 1	**Trial 2**	**Trial 3**	**Average**
13.68	13.41	13.55	13.55

Table D25. Trial 1 for soil vertical displacement and pressure distribution using soil with medium moisture content, low bulk density and an oval shaped contact surface

Vertical displacement and bulk density calculations										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	71.00	71.00	0.00
7^{th}	9.20	64.90	66.10	66.50	9.90	1152.95	66.80	61.10	61.40	0.30
6^{th}	9.20	54.90	55.80	56.20	10.30	1108.18	57.20	50.80	51.80	1.00
5^{th}	9.20	44.80	45.80	46.00	10.20	1119.04	48.30	40.60	42.90	2.30
4^{th}	9.20	34.70	35.55	35.75	10.25	1113.59	40.00	30.35	34.60	4.25
3^{rd}	9.20	24.30	25.60	25.80	9.95	1147.16	34.40	20.40	29.00	8.60
2^{nd}	9.20	14.30	15.40	15.60	10.20	1119.04	30.00	10.20	24.60	14.40
Surface	9.20	4.30	5.20	5.40	10.20	1119.04	24.75	0.00	19.35	19.35
		Wet bulk density of soil column, (kg/m^3)				1125.57				
		Dry bulk density of soil column, (kg/m^3)				960.61				

Pressure distribution calaculation						Moisture content calaculation				
Depth of sensor before load, (cm)	Depth of sensor after load, (cm)	Depth of sensor after load, (cm)	Output force, (N)	Area of the sensor, (cm^2)	Pressure, (kPa)	Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
						3.70	73.92	63.86	16.72	
						3.70	92.54	79.33	17.47	17.17
						3.70	108.77	93.25	17.33	
0.00	19.35	0.00	86.91	4.52	192.21					
5.10	21.98	2.63	77.20	4.52	170.74					
10.20	24.60	5.25	57.20	4.52	126.50					
15.30	26.80	7.45	20.50	4.52	45.34					
20.40	29.00									

Table D26. Trial 2 for soil vertical displacement and pressure distribution using soil with medium moisture content, low bulk density and an oval shaped contact surface

Vertical displacement and bulk density calculation										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	75.10	76.40			76.40	72.50	72.50	0.00
7^{th}	9.20	64.70	64.80	65.20	11.20	1019.13	66.90	61.30	63.00	1.70
6^{th}	9.20	54.90	54.50	54.90	10.30	1108.18	57.50	51.00	53.60	2.60
5^{th}	9.20	45.00	44.50	44.70	10.20	1119.04	48.90	40.80	45.00	4.20
4^{th}	9.20	34.80	34.20	34.40	10.30	1108.18	40.30	30.50	36.40	5.90
3^{rd}	9.20	24.50	24.35	24.55	9.85	1158.81	35.00	20.65	31.10	10.45
2^{nd}	9.20	14.50	14.00	14.20	10.35	1102.83	30.00	10.30	26.10	15.80
Surface	9.20	4.40	3.70	3.90	10.30	1108.18	25.00	0.00	21.10	21.10
		Wet bulk density of soil column, (kg/m^3)				1103.48				
		Dry bulk density of soil column, (kg/m^3)				950.31				

Pressure distribution calaculation						Moisture content calaculation				
Depth of sensor before load, (cm)	Depth of sensor after load, (cm)	Depth of sensor after load, (cm)	Output force, (N)	Area of the sensor, (cm^2)	Pressure, (kPa)	Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
						3.70	119.62	103.54	16.11	
						3.70	102.96	89.27	16.00	16.12
						3.70	90.13	78.05	16.25	
0.00	21.10	0.00	95.07	4.52	210.26					
5.15	23.60	2.50	67.20	4.52	148.62					
10.30	26.10	5.00	51.20	4.52	113.23					
15.48	28.60	7.50	26.02	4.52	57.55					
20.65	31.10									

Table D27. Trial 3 for soil vertical displacement and pressure distribution using soil with medium moisture content, low bulk density and an oval shaped contact surface

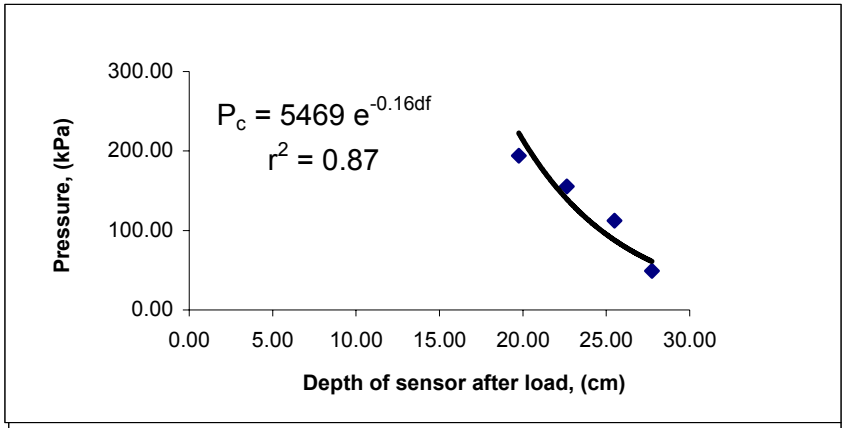
Vertical displacement and bulk density calculation										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	71.20	71.20	0.00
7^{th}	9.20	65.30	66.70	67.10	9.30	1227.34	67.50	61.90	62.30	0.40
6^{th}	9.20	54.95	55.80	56.20	10.90	1047.18	57.50	51.00	52.30	1.30
5^{th}	9.20	44.50	45.30	45.50	10.70	1066.75	48.50	40.30	43.30	3.00
4^{th}	9.20	34.75	35.40	35.60	9.90	1152.95	40.20	30.40	35.00	4.60
3^{rd}	9.20	24.50	25.65	25.85	9.75	1170.69	35.00	20.65	29.80	9.15
2^{nd}	9.20	14.20	15.30	15.50	10.35	1102.83	31.00	10.30	25.80	15.50
Surface	9.20	4.30	5.00	5.20	10.30	1108.18	24.00	0.00	18.80	18.80
		Wet bulk density of soil column, (kg/m^3)				1125.13				
		Dry bulk density of soil column, (kg/m^3)				968.96				

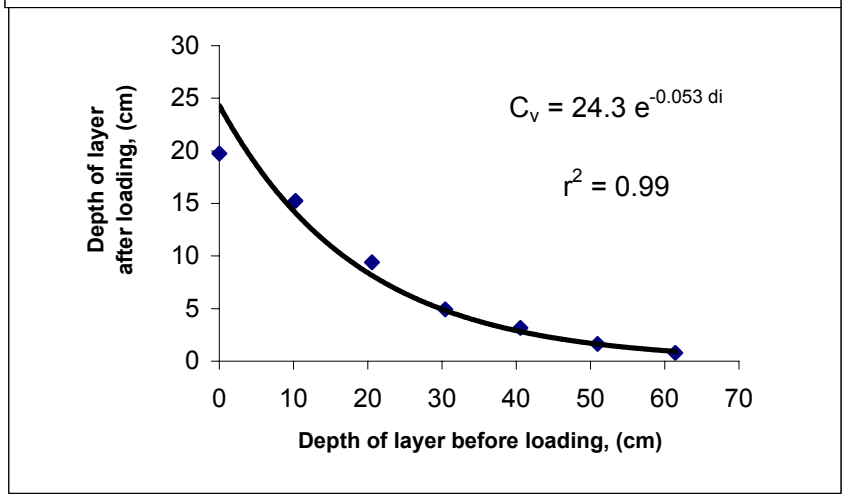
Pressure distribution calaculation						Moisture content calaculation				
Depth of sensor before load, (cm)	Depth of sensor after load, (cm)	Depth of sensor after load, (cm)	Output force, (N)	Area of the sensor, (cm^2)	Pressure, (kPa)	Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
						3.70	119.62	103.54	16.11	16.12
						3.70	102.96	89.27	16.00	
						3.70	90.13	78.05	16.25	
0.00	18.80	0.00	81.45	4.52	180.14					
5.15	22.30	3.50	66.45	4.52	146.96					
10.30	25.80	7.00	44	4.52	97.31					
15.48	27.80	9.00	20.21	4.52	44.70					
20.65	29.80									

Table D28. Average of trials 1, 2, and 3 for vertical displacement, pressure distribution, bulk density and moisture content using soil with medium moisture content, low bulk density and an oval shaped contact surface

Pressure distribution	
Depth of sensor after load, (cm)	**Pressure, (kPa)**
19.75	194.20
22.63	155.44
25.50	112.35
27.73	49.19

Vertical displacement			
Layer	**Depth before Load, (cm)**	**Depth after load, (cm)**	**Vertical Displacement, (cm)**
Base	71.57	71.57	0.00
7th	61.43	62.23	0.80
6th	50.93	52.57	1.63
5th	40.57	43.73	3.17
4th	30.42	35.33	4.92
3rd	20.57	29.97	9.40
2nd	10.27	25.50	15.23
Surface	0.00	19.75	19.75





Bulk density of soil column, (kg/m^3)			
Trial 1	**Trial 2**	**Trial 3**	**Average**
1125.57	1103.48	1125.13	1118.06
960.61	950.31	968.96	959.96

Moisture content of soil column, (%)			
Trial 1	**Trial 2**	**Trial 3**	**Average**
17.17	16.12	16.12	16.47

Table D29. Trial 1 for soil vertical displacement and pressure distribution using soil with medium moisture content, low bulk density and a rectangular shaped contact surface

Vertical displacement and bulk density calculations										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	71.00	71.00	0.00
7th	9.20	64.90	66.10	66.50	9.90	1152.95	66.75	61.10	61.35	0.25
6th	9.20	54.85	55.80	56.20	10.30	1108.18	56.85	50.80	51.45	0.65
5th	9.20	44.70	45.80	46.00	10.20	1119.04	47.90	40.60	42.50	1.90
4th	9.20	34.75	35.50	35.70	10.30	1108.18	38.70	30.30	33.30	3.00
3rd	9.20	24.30	25.40	25.60	10.10	1130.12	32.00	20.20	26.60	6.40
2nd	9.20	14.15	15.30	15.50	10.10	1130.12	28.00	10.10	22.60	12.50
Surface	9.20	4.20	5.20	5.40	10.10	1130.12	23.00	0.00	17.60	17.60
		Bulk density of soil column, (kg/m^3)				1125.53				
		Dry bulk density of soil column, (kg/m^3)				960.57				

Moisture content calaculation				
Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
3.70	73.92	63.86	16.72	17.17
3.70	92.54	79.33	17.47	
3.70	108.77	93.25	17.33	

Table D30. Trial 2 for soil vertical displacement and pressure distribution using soil with medium moisture content, low bulk density and an oval shaped contact surface

Vertical displacement and bulk density calculation											
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	71.10	71.10	0.00
7th	9.20	65.00	66.00	66.20	10.20	1119.04	66.80	60.90	61.50	0.60
6th	9.20	54.80	55.85	56.05	10.15	1124.56	56.35	50.75	51.05	0.30
5th	9.20	44.55	45.80	45.80	10.25	1113.59	48.00	40.50	42.70	2.20
4th	9.20	34.70	35.30	35.30	10.50	1087.07	39.00	30.00	33.70	3.70
3rd	9.20	24.40	25.20	25.20	10.10	1130.12	32.00	19.90	26.70	6.80
2nd	9.20	14.20	15.50	15.50	9.70	1176.73	28.25	10.20	22.95	12.75
Surface	9.20	4.30	5.30	5.30	10.20	1119.04	22.80	0.00	17.50	17.50
		Bulk density of soil column, (kg/m^3)				1124.31				
		Dry bulk density of soil column, (kg/m^3)				968.25				

Moisture content calaculation				
Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
3.70	119.62	103.54	16.11	16.12
3.70	102.96	89.27	16.00	
3.70	90.13	78.05	16.25	

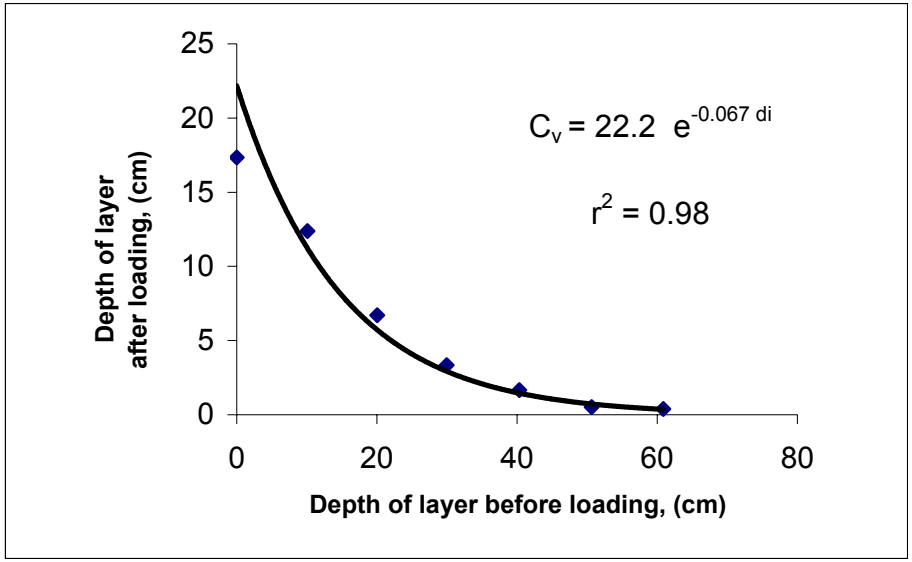
Table D31. Trial 3 for soil vertical displacement and pressure distribution using soil with medium moisture content, low bulk density and an oval shaped contact surface

Vertical displacement and bulk density calculation										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	70.30	70.30	0.00
7th	9.20	64.75	66.30	66.70	9.70	1176.73	67.00	60.60	60.90	0.30
6th	9.20	54.90	56.00	56.40	10.30	1108.18	57.00	50.30	50.90	0.60
5th	9.20	44.70	45.80	46.00	10.40	1097.52	46.90	39.90	40.80	0.90
4th	9.20	34.50	35.45	35.65	10.35	1102.83	39.00	29.55	32.90	3.35
3rd	9.20	24.10	25.90	26.10	9.55	1195.21	33.00	20.00	26.90	6.90
2nd	9.20	14.00	15.90	16.10	10.00	1141.43	28.00	10.00	21.90	11.90
Surface	9.20	4.50	5.90	6.10	10.00	1141.43	23.00	0.00	16.90	16.90
		Bulk density of soil column, (kg/m^3)				1137.62				
		Dry bulk density of soil column, (kg/m^3)				979.71				

Moisture content calaculation				
Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
3.70	119.62	103.54	16.11	16.12
3.70	102.96	89.27	16.00	
3.70	90.13	78.05	16.25	

Table D32. Average of trials 1, 2, and 3 for vertical displacement, pressure distribution, bulk density and moisture content using soil with medium moisture content, low bulk density and an oval shaped contact surface

Vertical displacement			
Layer	**Depth before Load, (cm)**	**Depth after load, (cm)**	**Vertical Displacement, (cm)**
Base	70.80	70.80	0.00
7th	60.87	61.25	0.38
6th	50.62	51.13	0.52
5th	40.33	42.00	1.67
4th	29.95	33.30	3.35
3rd	20.03	26.73	6.70
2nd	10.10	22.48	12.38
Surface	0.00	17.33	17.33



Bulk density of soil column, (kg/m^3)			
Trial 1	**Trial 2**	**Trial 3**	**Average**
1125.53	1124.31	1137.62	1129.15
960.57	968.25	979.71	969.51

Moisture content of soil column, (%)			
Trial 1	**Trial 2**	**Trial 3**	**Average**
17.17	16.12	16.12	16.47

Table D33. Trial 1 for soil vertical displacement and pressure distribution using soil with medium moisture content, medium bulk density and an oval shaped contact surface

Vertical displacement and bulk density calculations										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	74.10	74.10	0.00
7th	10.70	63.40	65.30	65.30	11.10	1195.97	65.70	63.00	63.40	0.40
6th	10.70	52.15	54.50	54.50	10.80	1229.19	55.00	52.20	52.70	0.50
5th	10.70	41.50	43.90	43.90	10.60	1252.38	44.50	41.60	42.20	0.60
4th	10.70	30.60	32.80	32.80	11.10	1195.97	33.50	30.50	31.20	0.70
3rd	10.70	19.50	22.00	22.00	10.80	1229.19	23.50	19.70	21.20	1.50
2nd	10.70	8.70	10.90	10.90	11.10	1195.97	15.70	8.60	13.40	4.80
Surface	10.70	0.30	2.30	2.30	8.60	1543.64	9.00	0.00	6.70	6.70
		Wet bulk density of soil column, (kg/m^3)				1263.19				
		Dry bulk density of soil column, (kg/m^3)				1079.16				

Pressure distribution calaculation						Moisture content calaculation				
Depth of sensor before load, (cm)	Depth of sensor after load, (cm)	Depth of sensor after load, (cm)	Output force, (N)	Area of the sensor, (cm^2)	Pressure, (kPa)	Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
						3.70	68.00	58.70	16.91	
						3.70	142.38	122.00	17.23	17.05
						3.70	163.20	140.00	17.02	
0.00	6.50	0.00	98.91	4.52	218.75					
4.30	9.85	3.35	78.90	4.52	174.50					
8.60	13.20	6.70	39.20	4.52	86.69					
14.15	17.10	10.60	11.38	4.52	25.17					
19.70	21.00									

Table D34. Trial 2 for soil vertical displacement and pressure distribution using soil with medium moisture content, medium bulk density and an oval shaped contact surface

Vertical displacement and bulk density calculation										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	75.10	75.10	0.00
7th	10.70	63.40	65.40	65.40	11.00	1206.84	65.70	64.10	64.40	0.30
6th	10.70	52.30	54.75	54.75	10.65	1246.50	55.00	53.45	53.70	0.25
5th	10.70	41.30	43.60	43.60	11.15	1190.61	44.50	42.30	43.20	0.90
4th	10.70	30.55	32.90	32.90	10.70	1240.68	33.50	31.60	32.20	0.60
3rd	10.70	19.30	21.85	21.85	11.05	1201.38	23.50	20.55	22.20	1.65
2nd	10.70	8.90	11.00	11.00	10.85	1223.53	15.70	9.70	14.40	4.70
Surface	10.70	-0.20	1.30	1.30	9.70	1368.58	8.00	0.00	6.70	6.70
		Wet bulk density of soil column, (kg/m^3)				1239.73				
		Dry bulk density of soil column, (kg/m^3)				1058.10				

Pressure distribution calaculation						Moisture content calaculation				
Depth of sensor before load, (cm)	Depth of sensor after load, (cm)	Depth of sensor after load, (cm)	Output force, (N)	Area of the sensor, (cm^2)	Pressure, (kPa)	Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
0.00	6.50	0.00	137.91	4.52	305.00	3.70	113.25	97.00	17.42	17.17
4.85	10.35	3.85	87.20	4.52	192.85	3.70	98.67	84.90	16.96	
9.70	14.20	7.70	28.70	4.52	63.47	3.70	102.00	87.63	17.12	
15.13	18.10	11.60	18.10	4.52	40.03					
20.55	22.00									

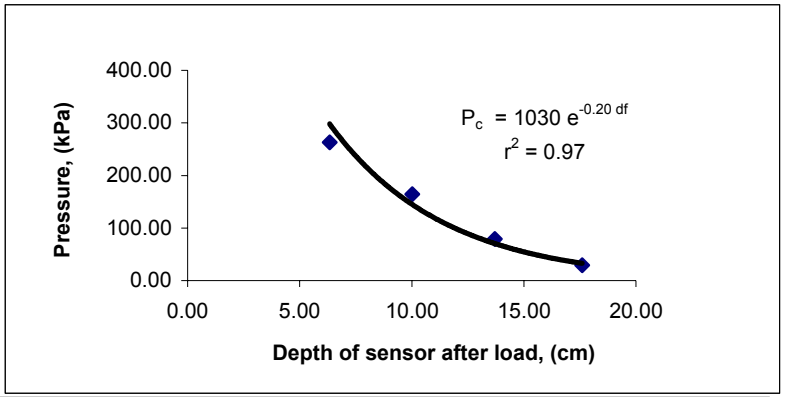
Table D35. Trial 3 for soil vertical displacement and pressure distribution using soil with medium moisture content, medium bulk density and an oval shaped contact surface

Vertical displacement and bulk density calculation										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	74.60	74.60	0.00
7^{th}	10.70	63.30	65.40	65.40	11.00	1206.84	65.70	63.60	63.90	0.30
6^{th}	10.70	52.30	54.75	54.75	10.65	1246.50	55.00	52.95	53.20	0.25
5^{th}	10.70	41.55	43.75	43.75	11.00	1206.84	44.50	41.95	42.70	0.75
4^{th}	10.70	30.70	32.95	32.95	10.80	1229.19	33.50	31.15	31.70	0.55
3^{rd}	10.70	19.50	21.95	21.95	11.00	1206.84	23.50	20.15	21.70	1.55
2^{nd}	10.70	8.60	10.90	10.90	11.05	1201.38	15.70	9.10	13.90	4.80
Surface	10.70	0.30	1.80	1.80	9.10	1458.82	8.00	0.00	6.20	6.20
		Wet bulk density of soil column, (kg/m^3)				1250.92				
		Dry bulk density of soil column, (kg/m^3)				1067.65				

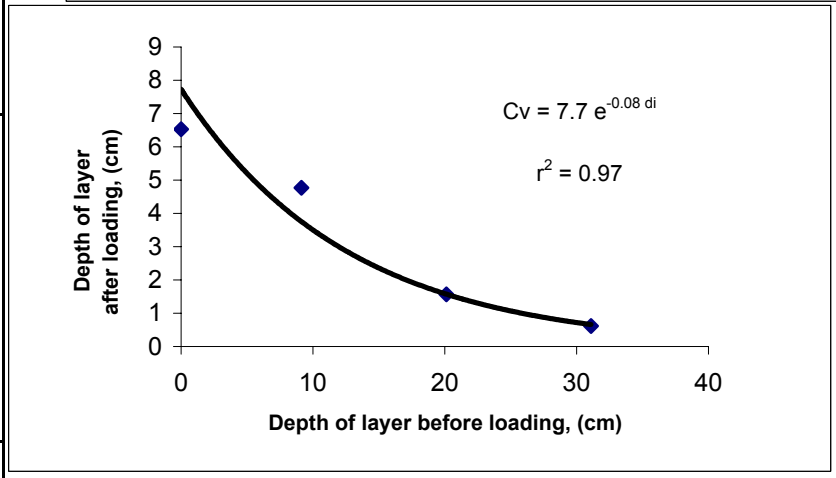
Pressure distribution calaculation						Moisture content calaculation				
Depth of sensor before load, (cm)	Depth of sensor after load, (cm)	Depth of sensor after load, (cm)	Output force, (N)	Area of the sensor, (cm^2)	Pressure, (kPa)	Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
						3.70	113.25	97.00	17.42	
						3.70	98.67	84.90	16.96	17.17
						3.70	102.00	87.63	17.12	
0.00	6.00	0.00	119.91	4.52	265.19					
4.55	9.85	3.85	57.2	4.52	126.50					
9.10	13.70	7.70	39.2	4.52	86.69					
14.63	17.60	11.60	10.18	4.52	22.51					
20.15	21.50									

Table D36. Average of trials 1, 2, and 3 for vertical displacement, pressure distribution, bulk density and moisture content using soil with medium moisture content, medium bulk density and an oval shaped contact surface

Pressure distribution	
Depth of sensor after load, (cm)	**Pressure, (kPa)**
6.33	262.98
10.02	164.62
13.70	78.95
17.60	29.24



Vertical displacement			
Layer	**Depth before Load, (cm)**	**Depth after load, (cm)**	**Vertical Displacement, (cm)**
Base	74.60	74.60	0.00
7th	63.57	63.90	0.33
6th	52.87	53.20	0.33
5th	41.95	42.70	0.75
4th	31.08	31.70	0.62
3rd	20.13	21.70	1.57
2nd	9.13	13.90	4.77
Surface	0.00	6.53	6.53



Bulk density of soil column, (kg/m^3)			
Trial 1	**Trial 2**	**Trial 3**	**Average**
1263.19	1239.73	1250.92	1251.28
1079.16	1058.10	1067.65	1068.31

Moisture content of soil column, (%)			
Trial 1	**Trial 2**	**Trial 3**	**Average**
17.05	17.17	17.17	17.13

Table D37. Trial 1 for soil vertical displacement and pressure distribution using soil with medium moisture content, medium bulk density and a rectangular shaped contact surface

Vertical displacement and bulk density calculations										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	75.10	75.10	0.00
7th	10.70	63.30	65.60	65.60	10.80	1229.19	66.00	64.30	64.70	0.40
6th	10.70	52.30	54.70	54.70	10.90	1217.91	55.40	53.40	54.10	0.70
5th	10.70	41.30	43.90	43.90	10.80	1229.19	44.20	42.60	42.90	0.30
4th	10.70	30.60	33.00	33.00	10.90	1217.91	33.80	31.70	32.50	0.80
3rd	10.70	19.30	21.95	21.95	11.05	1201.38	24.00	20.65	22.70	2.05
2nd	10.70	8.55	10.85	10.85	11.10	1195.97	15.00	9.55	13.70	4.15
Surface	10.70	-0.70	1.30	1.30	9.55	1390.08	8.00	0.00	6.70	6.70
		Bulk density of soil column, (kg/m^3)				1240.24				

Moisture content calaculation				
Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
3.70	68.00	58.70	16.91	17.05
3.70	142.38	122.00	17.23	
3.70	163.20	140.00	17.02	

Table D38. Trial 2 for soil vertical displacement and pressure distribution using soil with medium moisture content, medium bulk density and a rectangular shaped contact surface

Vertical displacement and bulk density calculation										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	74.10	74.10	0.00
7^{th}	10.70	63.30	65.30	65.30	11.10	1195.97	65.70	63.00	63.40	0.40
6^{th}	10.70	52.00	54.50	54.50	10.80	1229.19	55.10	52.20	52.80	0.60
5^{th}	10.70	41.50	43.90	43.90	10.60	1252.38	44.50	41.60	42.20	0.60
4^{th}	10.70	30.65	32.80	32.80	11.10	1195.97	33.50	30.50	31.20	0.70
3^{rd}	10.70	19.55	22.00	22.00	10.80	1229.19	23.25	19.70	20.95	1.25
2^{nd}	10.70	8.80	10.90	10.90	11.10	1195.97	15.25	8.60	12.95	4.35
Surface	10.70	0.30	2.30	2.30	8.60	1543.64	9.00	0.00	6.70	6.70
		Bulk density of soil column, (kg/m^3)				1263.19				

Moisture content calaculation				
Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
3.70	113.25	97.00	17.42	
3.70	98.67	84.90	16.96	17.17
3.70	102.00	87.63	17.12	

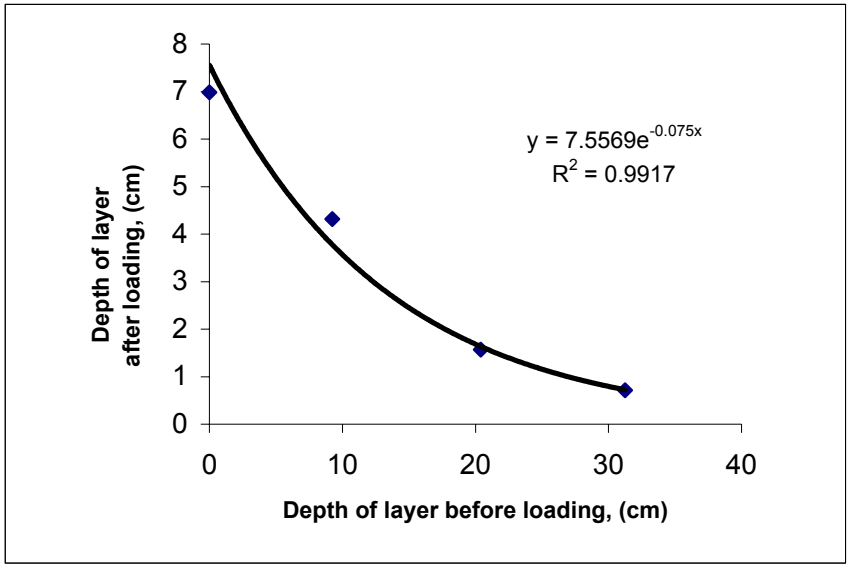
Table D39. Trial 3 for soil vertical displacement and pressure distribution using soil with medium moisture content, medium bulk density and a rectangular shaped contact surface

Vertical displacement and bulk density calculation										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	75.10	75.10	0.00
7th	10.70	63.40	65.50	65.50	10.90	1217.91	65.75	64.20	64.45	0.25
6th	10.70	52.15	54.60	54.60	10.90	1217.91	55.00	53.30	53.70	0.40
5th	10.70	41.50	43.95	43.95	10.65	1246.50	44.10	42.65	42.80	0.15
4th	10.70	30.60	32.80	32.80	11.15	1190.61	33.45	31.50	32.15	0.65
3rd	10.70	19.50	22.15	22.15	10.65	1246.50	23.55	20.85	22.25	1.40
2nd	10.70	8.70	10.85	10.85	11.30	1174.80	15.30	9.55	14.00	4.45
Surface	10.70	0.30	1.30	1.30	9.55	1390.08	8.85	0.00	7.55	7.55
		Bulk density of soil column, (kg/m^3)				1240.62				

Moisture content calaculation				
Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
3.70	113.25	97.00	17.42	17.17
3.70	98.67	84.90	16.96	
3.70	102.00	87.63	17.12	

Table D40. Average of trials 1, 2, and 3 for vertical displacement, pressure distribution, bulk density and moisture content using soil with medium moisture content, medium bulk density and a rectangular shaped contact surface

Vertical displacement			
Layer	**Depth before Load, (cm)**	**Depth after load, (cm)**	**Vertical Displacement, (cm)**
Base	74.77	74.77	0.00
7th	63.83	64.18	0.35
6th	52.97	53.53	0.57
5th	42.28	42.63	0.35
4th	31.23	31.95	0.72
3rd	20.40	21.97	1.57
2nd	9.23	13.55	4.32
Surface	0.00	6.98	6.98



Bulk density of soil column, (kg/m^3)				Moisture content of soil column, (%)			
Trial 1	**Trial 2**	**Trial 3**	**Average**	**Trial 1**	**Trial 2**	**Trial 3**	**Average**
1240.24	1263.19	1240.62	1248.01	17.05	17.17	17.17	17.13

Table D41. Trial 1 for soil vertical displacement and pressure distribution using soil with medium moisture content, high bulk density and an oval shaped contact surface

Vertical displacement and bulk density calculation										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is doil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	72.10	72.10	0.00
7th	11.00	63.30	65.90	65.90	10.50	1299.76	66.50	61.60	62.20	0.60
6th	11.00	52.55	55.70	55.70	10.20	1337.99	56.20	51.40	51.90	0.50
5th	11.00	42.30	45.40	45.40	10.30	1325.00	46.00	41.10	41.70	0.60
4th	11.00	32.20	35.00	35.00	10.40	1312.26	35.10	30.70	30.80	0.10
3rd	11.00	21.05	24.30	24.30	10.70	1275.46	24.90	20.00	20.60	0.60
2nd	11.00	10.80	14.40	14.40	9.90	1378.53	15.75	10.10	11.45	1.35
Surface	11.00	0.30	4.30	4.30	10.10	1351.23	8.00	0.00	3.70	3.70
		Wet bulk density of soil column, (kg/m^3)				1325.75				
		Dry bulk density of soil column, (kg/m^3)				1137.44				

Pressure distribution calaculation						Moisture content calaculation				
Depth of sensor before load, (cm)	Depth of sensor after load, (cm)	Depth of sensor after load, (cm)	Output force, (N)	Area of the sensor, (cm^2)	Pressure, (kPa)	Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
						3.70	89.45	77.20	16.67	
						3.70	97.40	84.33	16.21	16.56
						3.70	115.28	99.24	16.79	
0.00	3.70	0.00	119.91	4.52	265.19					
5.05	7.58	3.88	59.05	4.52	130.60					
10.10	11.45	7.75	19.25	4.52	42.57					
15.05	16.03	12.33	16.02	4.52	35.43					
20.00	20.60									

Table D42. Trial 2 for soil vertical displacement and pressure distribution using soil with medium moisture content, high bulk density and an oval shaped contact surface

Vertical displacement and bulk density calculation										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is doil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	72.10	72.10	0.00
7^{th}	11.00	63.30	65.90	65.90	10.50	1299.76	66.30	61.60	62.00	0.40
6^{th}	11.00	52.50	55.85	55.85	10.05	1357.96	56.20	51.55	51.90	0.35
5^{th}	11.00	42.10	45.30	45.30	10.55	1293.60	45.70	41.00	41.40	0.40
4^{th}	11.00	32.15	34.85	34.85	10.45	1305.98	35.10	30.55	30.80	0.25
3^{rd}	11.00	21.10	24.30	24.30	10.55	1293.60	24.70	20.00	20.40	0.40
2^{nd}	11.00	10.90	14.40	14.40	9.90	1378.53	16.00	10.10	11.70	1.60
Surface	11.00	0.30	4.30	4.30	10.10	1351.23	8.50	0.00	4.20	4.20
		Wet bulk density of soil column, (kg/m^3)				1325.81				
		Dry bulk density of soil column, (kg/m^3)				1137.52				

Pressure distribution calaculation						Moisture content calaculation				
Depth of sensor before load, (cm)	Depth of sensor after load, (cm)	Depth of sensor after load, (cm)	Output force, (N)	Area of the sensor, (cm^2)	Pressure, (kPa)	Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
						3.70	154.10	132.89	16.42	
						3.70	114.68	99.10	16.33	16.55
						3.70	87.01	74.96	16.91	
0.00	4.20	0.00	103.29	4.52	228.44					
5.05	7.95	3.75	48.50	4.52	107.26					
10.10	11.70	7.50	14.96	4.52	33.09					
15.05	16.05	11.85	15.70	4.52	34.72					
20.00	20.40									

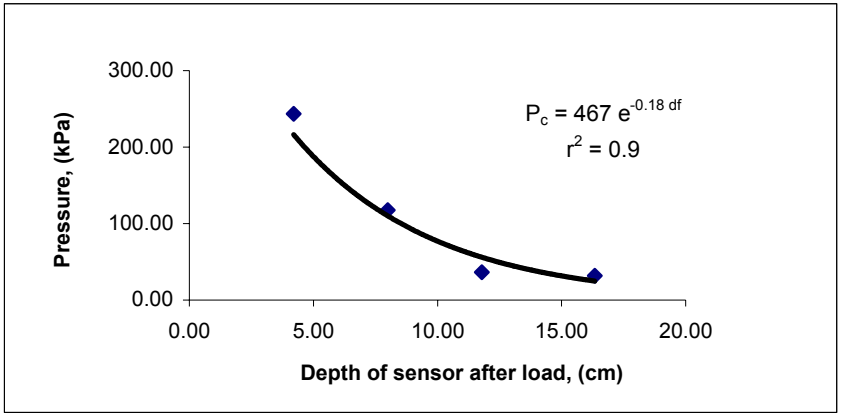
Table D43. Trial 3 for soil vertical displacement and pressure distribution using soil with medium moisture content, high bulk density and an oval shaped contact surface

Vertical displacement and bulk density calculations										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	72.60	72.60	0.00
7^{th}	11.00	63.30	65.80	65.80	10.60	1287.50	66.30	62.00	62.50	0.50
6^{th}	11.00	52.30	55.60	55.60	10.20	1337.99	56.20	51.80	52.40	0.60
5^{th}	11.00	42.20	45.30	45.30	10.30	1325.00	45.70	41.50	41.90	0.40
4^{th}	11.00	32.30	34.30	34.30	11.00	1240.68	34.50	30.50	30.70	0.20
3^{rd}	11.00	21.05	24.70	24.70	9.60	1421.61	25.50	20.90	21.70	0.80
2^{nd}	11.00	10.80	14.40	14.40	10.30	1325.00	16.00	10.60	12.20	1.60
Surface	11.00	0.30	3.80	3.80	10.60	1287.50	8.50	0.00	4.70	4.70
		Wet bulk density of soil column, (kg/m^3)				1317.90				
		Dry bulk density of soil column, (kg/m^3)				1128.28				

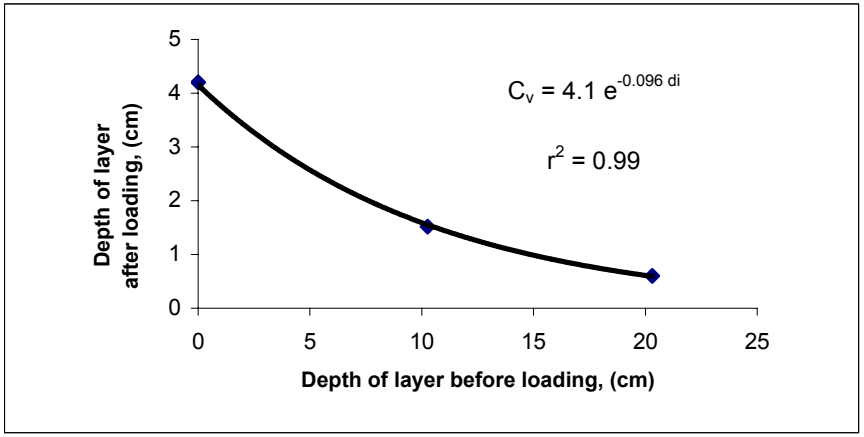
Pressure distribution calaculation						Moisture content calaculation				
Depth of sensor before load, (cm)	Depth of sensor after load, (cm)	Depth of sensor after load, (cm)	Output force, (N)	Area of the sensor, (cm^2)	Pressure, (kPa)	Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
						3.70	135.00	115.74	17.19	
						3.70	110.12	95.00	16.56	16.81
						3.70	125.50	108.10	16.67	
0.00	4.70	0.00	107.31	4.52	237.33					
5.30	8.45	3.75	52.20	4.52	115.45					
10.60	12.20	7.50	14.90	4.52	32.95					
15.75	16.95	12.25	11.69	4.52	25.85					
20.90	21.70									

Table D44. Average of trials 1, 2, and 3 for vertical displacement, pressure distribution, bulk density and moisture content using soil with medium moisture content, high bulk density and an oval shaped contact surface

Pressure distribution	
Depth of sensor after load, (cm)	**Pressure, (kPa)**
4.20	243.65
7.99	117.77
11.78	36.20
16.34	32.00



Vertical displacement			
Layer	**Depth before Load, (cm)**	**Depth after load, (cm)**	**Vertical Displacement, (cm)**
Base	72.27	72.27	0.00
7th	61.73	62.23	0.50
6th	51.58	52.07	0.48
5th	41.20	41.67	0.47
4th	30.58	30.77	0.18
3rd	20.30	20.90	0.60
2nd	10.27	11.78	1.52
Surface	0.00	4.20	4.20



Bulk density of soil column, (kg/m^3)			
Trial 1	**Trial 2**	**Trial 3**	**Average**
1317.90	1325.81	1325.75	1323.15
1137.44	1137.52	1128.28	1134.41

Moisture content of soil column, (%)			
Trial 1	**Trial 2**	**Trial 3**	**Average**
16.81	16.55	16.56	16.64

Table D45. Trial 1 for soil vertical displacement and pressure distribution using soil with medium moisture content, high bulk density and a rectangular shaped contact surface

Vertical displacement and bulk density calculations										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	72.10	72.10	0.00
7^{th}	11.00	63.30	66.00	66.00	10.40	1312.26	66.20	61.70	61.90	0.20
6^{th}	11.00	52.30	55.50	55.50	10.50	1299.76	55.80	51.20	51.50	0.30
5^{th}	11.00	43.30	45.50	45.50	10.00	1364.75	46.00	41.20	41.70	0.50
4^{th}	11.00	32.15	35.10	35.10	10.40	1312.26	35.40	30.80	31.10	0.30
3^{rd}	11.00	21.00	24.90	24.90	10.20	1337.99	25.50	20.60	21.20	0.60
2^{nd}	11.00	10.90	14.00	14.00	10.90	1252.06	15.75	9.70	11.45	1.75
Surface	11.00	0.30	4.30	4.30	9.70	1406.96	8.00	0.00	3.70	3.70
		Bulk density of soil column, (kg/m^3)				1326.58				

Moisture content calaculation				
Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
3.70	89.45	77.20	16.67	16.56
3.70	97.40	84.33	16.21	
3.70	115.28	99.24	16.79	

Table D46. Trial 2 for soil vertical displacement and pressure distribution using soil with medium moisture content, high bulk density and a rectangular shaped contact surface

Vertical displacement and bulk density calculation										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	71.90	71.90	0.00
7th	11.00	63.60	65.80	65.80	10.60	1287.50	66.40	61.30	61.90	0.60
6th	11.00	52.65	55.85	55.85	9.95	1371.61	56.00	51.35	51.50	0.15
5th	11.00	42.50	45.45	45.45	10.40	1312.26	45.90	40.95	41.40	0.45
4th	11.00	32.30	35.00	35.00	10.45	1305.98	35.25	30.50	30.75	0.25
3rd	11.00	21.05	24.20	24.20	10.80	1263.65	24.70	19.70	20.20	0.50
2nd	11.00	10.90	14.30	14.30	9.90	1378.53	15.80	9.80	11.30	1.50
Surface	11.00	0.30	4.50	4.50	9.80	1392.60	7.85	0.00	3.35	3.35
		Bulk density of soil column, (kg/m^3)				1330.30				

Moisture content calaculation				
Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
3.70	154.10	132.89	16.42	16.55
3.70	114.68	99.10	16.33	
3.70	87.01	74.96	16.91	

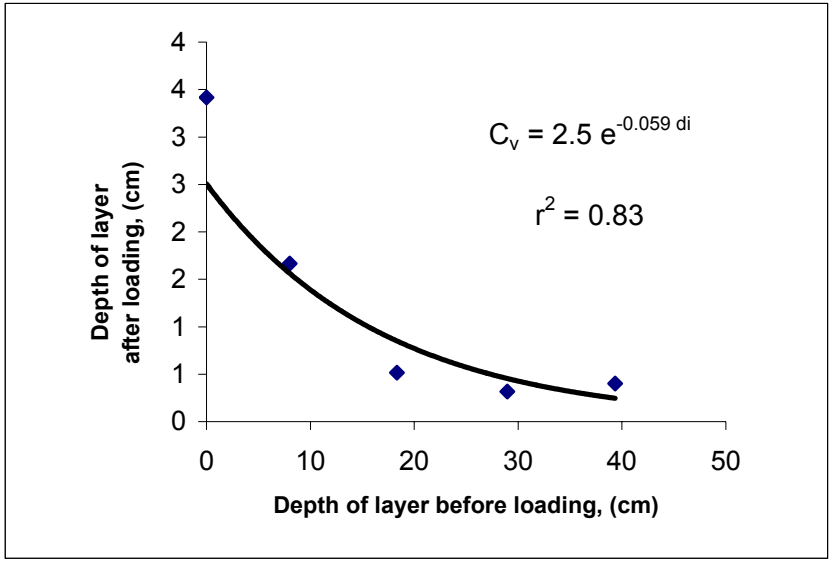
Table D47. Trial 3 for soil vertical displacement and pressure distribution using soil with medium moisture content, high bulk density and a rectangular shaped contact surface

Vertical displacement and bulk density calculation										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	66.80	66.80	0.00
7^{th}	11.00	63.40	65.70	65.70	10.70	1275.46	66.25	56.10	56.65	0.55
6^{th}	11.00	52.50	55.65	55.65	10.05	1357.96	56.10	46.05	46.50	0.45
5^{th}	11.00	42.30	45.50	45.50	10.15	1344.58	45.75	35.90	36.15	0.25
4^{th}	11.00	32.30	35.20	35.20	10.30	1325.00	35.60	25.60	26.00	0.40
3^{rd}	11.00	21.10	24.30	24.30	10.90	1252.06	24.75	14.70	15.15	0.45
2^{nd}	11.00	10.90	14.10	14.10	10.20	1337.99	15.85	4.50	6.25	1.75
Surface	11.00	0.30	3.80	3.80	10.30	1325.00	7.00	0.00	3.20	3.20
		Bulk density of soil column, (kg/m^3)				1316.86				

Moisture content calaculation				
Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
3.70	135.00	115.74	17.19	16.81
3.70	110.12	95.00	16.56	
3.70	125.50	108.10	16.67	

Table D48. Average of trials 1, 2, and 3 for vertical displacement, pressure distribution, bulk density and moisture content using soil with medium moisture content, high bulk density and a rectangular shaped contact surface

Vertical displacement			
Layer	**Depth before Load, (cm)**	**Depth after load, (cm)**	**Vertical Displacement, (cm)**
Base	70.27	70.27	0.00
7th	59.70	60.15	0.45
6th	49.53	49.83	0.30
5th	39.35	39.75	0.40
4th	28.97	29.28	0.32
3rd	18.33	18.85	0.52
2nd	8.00	9.67	1.67
Surface	0.00	3.42	3.42



Bulk density of soil column, (kg/m^3)			
Trial 1	**Trial 2**	**Trial 3**	**Average**
1326.58	1330.30	1316.86	1324.58

Moisture content of soil column, (%)			
Trial 1	**Trial 2**	**Trial 3**	**Average**
16.56	16.55	16.81	16.64

Table D49. Trial 1 for soil vertical displacement and pressure distribution using soil with high moisture content low bulk density and an oval shaped contact surface

Vertical displacement and bulk density calculations										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.4	76.40	76.40			76.40	69.15	69.15	0.00
7th	9.20	64.9	66.50	66.90	9.50	1201.50	67.60	59.65	60.35	0.70
6th	9.20	54.3	56.50	56.90	10.00	1141.43	58.20	49.65	50.95	1.30
5th	9.20	45.1	46.80	47.00	9.90	1152.95	50.90	39.75	43.65	3.90
4th	9.20	36.05	37.30	37.50	9.50	1201.50	46.00	30.25	38.75	8.50
3rd	9.20	25.8	27.80	28.00	9.50	1201.50	42.10	20.75	34.85	14.10
2nd	9.20	15.8	17.70	17.90	10.10	1130.12	39.60	10.65	32.35	21.70
Surface	9.20	5.55	7.05	7.25	10.65	1071.76	35.00	0.00	27.75	27.75
		Wet bulk density of soil column, (kg/m^3)				1157.25				
		Dry bulk density of soil column, (kg/m^3)				965.87				

Pressure distribution calaculation						Moisture content calaculation				
Depth of sensor before load, (cm)	Depth of sensor after load, (cm)	Depth of sensor after load, (cm)	Output force, (N)	Area of the sensor, (cm^2)	Pressure, (kPa)	Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
						3.70	78.61	65.69	20.84	
						3.70	100.10	84.38	19.48	19.81
						3.70	67.63	57.37	19.12	
0.00	27.75	0.00	94.40	4.52	208.78					
5.33	30.05	2.30	64.60	4.52	142.87					
10.65	32.35	4.60	46.50	4.52	102.84					
15.70	33.60	5.85	18.20	4.52	40.25					
20.75	34.85									

Table D50. Trial 2 for soil vertical displacement and pressure distribution using soil with high moisture content low bulk density and an oval shaped contact surface

Vertical displacement and bulk density calculation										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	69.20	69.20	0.00
7th	9.20	64.90	66.50	66.90	9.50	1201.50	67.50	59.70	60.30	0.60
6th	9.20	54.15	56.55	56.95	9.95	1147.16	58.00	49.75	50.80	1.05
5th	9.20	45.00	46.30	46.50	10.45	1092.27	51.20	39.30	44.00	4.70
4th	9.20	35.90	37.30	37.50	9.00	1268.25	45.00	30.30	37.80	7.50
3rd	9.20	25.80	26.70	26.90	10.60	1076.82	42.30	19.70	35.10	15.40
2nd	9.20	15.75	17.70	17.90	9.00	1268.25	40.00	10.70	32.80	22.10
Surface	9.20	5.50	7.00	7.20	10.70	1066.75	37.00	0.00	29.80	29.80
		Wet bulk density of soil column, (kg/m^3)				1160.14				
		Dry bulk density of soil column, (kg/m^3)				967.95				

Pressure distribution calaculation						Moisture content calaculation				
Depth of sensor before load, (cm)	Depth of sensor after load, (cm)	Depth of sensor after load, (cm)	Output force, (N)	Area of the sensor, (cm^2)	Pressure, (kPa)	Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
						3.70	123.56	103.58	20.00	19.86
						3.70	89.86	75.81	19.48	
						3.70	113.08	94.79	20.08	
0.00	29.80	0.00	101.00	4.52	223.37					
5.35	31.30	1.50	64.14	4.52	141.85					
10.70	32.80	3.00	42.90	4.52	94.88					
15.20	33.95	4.15	24.45	4.52	54.07					
19.70	35.10									

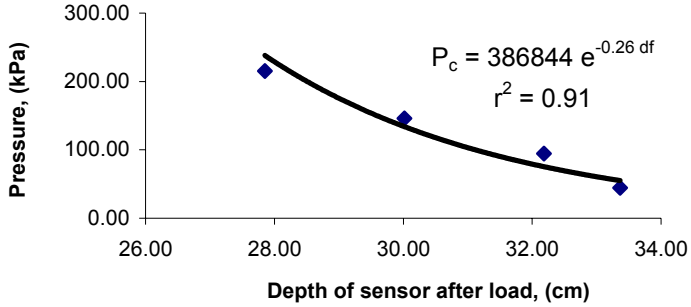
Table D51. Trial 3 for soil vertical displacement and pressure distribution using soil with high moisture content low bulk density and an oval shaped contact surface

Vertical displacement and bulk density calculation										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	68.90	68.90	0.00
7th	9.20	64.90	66.30	66.70	9.70	1176.73	67.40	59.20	59.90	0.70
6th	9.20	54.50	56.30	56.70	10.00	1141.43	58.00	49.20	50.50	1.30
5th	9.20	45.10	46.30	46.50	10.20	1119.04	50.00	39.00	42.50	3.50
4th	9.20	35.95	36.20	36.40	10.10	1130.12	45.00	28.90	37.50	8.60
3rd	9.20	25.70	26.70	26.90	9.50	1201.50	41.20	19.40	33.70	14.30
2nd	9.20	16.00	17.55	17.75	9.15	1247.46	38.90	10.25	31.40	21.15
Surface	9.20	5.55	7.30	7.50	10.25	1113.59	33.50	0.00	26.00	26.00
		Wet bulk density of soil column, (kg/m^3)				1161.41				
		Dry bulk density of soil column, (kg/m^3)				969.01				

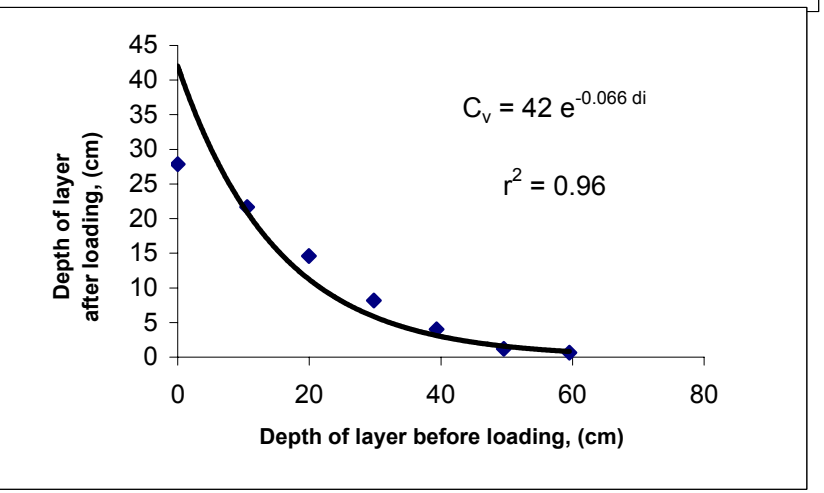
Pressure distribution calaculation						Moisture content calaculation				
Depth of sensor before load, (cm)	Depth of sensor after load, (cm)	Depth of sensor after load, (cm)	Output force, (N)	Area of the sensor, (cm^2)	Pressure, (kPa)	Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
						3.70	123.56	103.58	20.00	
						3.70	89.86	75.81	19.48	19.86
						3.70	113.08	94.79	20.08	
0.00	26.00	0.00	96.32	4.52	213.02					
5.13	28.70	2.70	69.64	4.52	154.02					
10.25	31.40	5.40	39	4.52	86.25					
14.83	32.55	6.55	17.7	4.52	39.15					
19.40	33.70									

Table D52. Average of trials 1, 2, and 3 for vertical displacement, pressure distribution, bulk density and moisture content using soil with high moisture content, low bulk density and an oval shaped contact surface

Pressure distribution	
Depth of sensor after load, (cm)	**Pressure, (kPa)**
27.85	215.06
30.02	146.25
32.18	94.66
33.37	44.49



Vertical displaceemnt			
Layer	**Depth before Load, (cm)**	**Depth after load, (cm)**	**Vertical Displacement, (cm)**
Base	69.08	69.08	0.00
7th	59.52	60.18	0.67
6th	49.53	50.75	1.22
5th	39.35	43.38	4.03
4th	29.82	38.02	8.20
3rd	19.95	34.55	14.60
2nd	10.53	32.18	21.65
Surface	0.00	27.85	27.85



Bulk density of soil column, (kg/m^3)			
Trial 1	**Trial 2**	**Trial 3**	**Average**
1157.25	1160.14	1161.41	1159.60
965.87	967.95	969.01	967.61

Moisture content of soil column, (%)			
Trial 1	**Trial 2**	**Trial 3**	**Average**
19.81	19.86	19.86	19.84

Table D53. Trial 1 for soil vertical displacement and pressure distribution using soil with high moisture content, low bulk density and an oval shaped contact surface

Vertical displacement and bulk density calculations										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	68.90	68.90	0.00
7^{th}	9.20	64.70	66.30	66.70	9.70	1176.73	67.50	59.20	60.00	0.80
6^{th}	9.20	54.50	56.30	56.70	10.00	1141.43	57.90	49.20	50.40	1.20
5^{th}	9.20	44.80	46.80	47.00	9.70	1176.73	48.85	39.50	41.35	1.85
4^{th}	9.20	35.90	37.30	37.50	9.50	1201.50	43.00	30.00	35.50	5.50
3^{rd}	9.20	25.55	27.65	27.85	9.65	1182.82	40.00	20.35	32.50	12.15
2^{nd}	9.20	15.70	17.30	17.50	10.35	1102.83	37.00	10.00	29.50	19.50
Surface	9.20	5.30	7.30	7.50	10.00	1141.43	30.00	0.00	22.50	22.50
		Bulk density of soil column, (kg/m^3)				1160.49				

Moisture content calaculation				
Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
3.70	157.38	132.00	19.78	19.50
3.70	128.64	108.65	19.05	
3.70	86.40	72.80	19.68	

Table D54. Trial 2 for soil vertical displacement and pressure distribution using soil with high moisture content, low bulk density and an oval shaped contact surface

Vertical displacement and bulk density calculation										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	68.60	68.60	0.00
7^{th}	9.20	65.00	66.60	67.00	9.40	1214.28	67.70	59.20	59.90	0.70
6^{th}	9.20	54.50	56.50	56.90	10.10	1130.12	58.00	49.10	50.20	1.10
5^{th}	9.20	45.30	46.60	46.80	10.10	1130.12	48.75	39.00	40.95	1.95
4^{th}	9.20	36.30	37.30	37.50	9.30	1227.34	42.60	29.70	34.80	5.10
3^{rd}	9.20	26.15	27.65	27.85	9.65	1182.82	39.00	20.05	31.20	11.15
2^{nd}	9.20	16.30	17.45	17.65	10.20	1119.04	36.80	9.85	29.00	19.15
Surface	9.20	5.30	7.60	7.80	9.85	1158.81	29.85	0.00	22.05	22.05
		Bulk density of soil column, (kg/m^3)				1166.08				

Moisture content calaculation				
Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
3.70	77.61	65.73	19.15	19.46
3.70	118.40	99.86	19.28	
3.70	106.00	88.99	19.94	

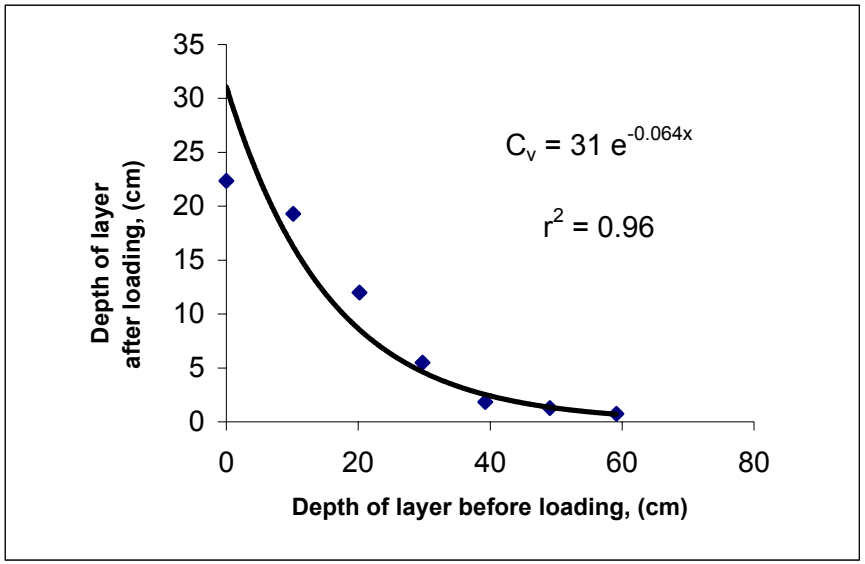
Table D55. Trial 3 for soil vertical displacement and pressure distribution using soil with high moisture content, low bulk density and an oval shaped contact surface

Vertical displacement and bulk density calculation										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	68.70	68.70	0.00
7^{th}	9.20	64.95	66.30	66.70	9.70	1176.73	67.40	59.00	59.70	0.70
6^{th}	9.20	54.50	56.10	56.50	10.20	1119.04	58.00	48.80	50.30	1.50
5^{th}	9.20	44.95	46.80	47.00	9.50	1201.50	48.70	39.30	41.00	1.70
4^{th}	9.20	36.10	37.00	37.20	9.80	1164.72	43.10	29.50	35.40	5.90
3^{rd}	9.20	25.70	27.65	27.85	9.35	1220.78	40.55	20.15	32.85	12.70
2^{nd}	9.20	15.90	18.00	18.20	9.65	1182.82	37.40	10.50	29.70	19.20
Surface	9.20	5.50	7.50	7.70	10.50	1087.07	30.20	0.00	22.50	22.50
		Bulk density of soil column, (kg/m^3)				1164.67				

Moisture content calaculation				
Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
3.70	77.61	65.73	19.15	
3.70	118.40	99.86	19.28	19.46
3.70	106.00	88.99	19.94	

Table D56. Average of trials 1, 2, and 3 for vertical displacement, pressure distribution, bulk density and moisture content using soil with high moisture content, low bulk density and an oval shaped contact surface

Vertical displacement			
Layer	**Depth before Load, (cm)**	**Depth after load, (cm)**	**Vertical Displacement, (cm)**
Base	68.73	68.73	0.00
7th	59.13	59.87	0.73
6th	49.03	50.30	1.27
5th	39.27	41.10	1.83
4th	29.73	35.23	5.50
3rd	20.18	32.18	12.00
2nd	10.12	29.40	19.28
Surface	0.00	22.35	22.35



Bulk density of soil column, (kg/m^3)			
Trial 1	**Trial 2**	**Trial 3**	**Average**
1160.49	1166.08	1164.67	1163.75

Moisture content of soil column, (%)			
Trial 1	**Trial 2**	**Trial 3**	**Average**
19.50	19.46	19.46	19.47

Table D57. Trial 1 for soil vertical displacement and pressure distribution using soil with high moisture content, medium bulk density and an oval shaped contact surface

Vertical displacement and bulk density calculations										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	76.10	76.10	0.00
7th	10.70	61.30	65.15	65.15	11.25	1180.02	66.20	64.85	65.90	1.05
6th	10.70	52.30	54.30	54.30	10.85	1223.53	54.90	54.00	54.60	0.60
5th	10.70	39.95	43.20	43.20	11.10	1195.97	44.00	42.90	43.70	0.80
4th	10.70	29.30	32.30	32.30	10.90	1217.91	33.60	32.00	33.30	1.30
3rd	10.70	18.80	21.70	21.70	10.60	1252.38	24.00	21.40	23.70	2.30
2nd	10.70	7.30	10.80	10.80	10.90	1217.91	15.30	10.50	15.00	4.50
Surface	10.70	-2.70	0.30	0.30	10.50	1264.31	9.00	0.00	8.70	8.70
		Wet bulk density of soil column, (kg/m^3)				1221.72				
		Dry bulk density of soil column, (kg/m^3)				1020.13				

Pressure distribution calaculation						Moisture content calaculation				
Depth of sensor before load, (cm)	Depth of sensor after load, (cm)	Depth of sensor after load, (cm)	Output force, (N)	Area of the sensor, (cm^2)	Pressure, (kPa)	Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
						3.70	68.59	57.90	19.72	
						3.70	79.15	66.85	19.48	19.76
						3.70	125.80	105.38	20.08	
0.00	8.70	0.00	103.40	4.52	228.68					
5.25	11.85	3.15	47.80	4.52	105.71					
10.50	15.00	6.30	17.40	4.52	38.48					
17.45	19.35	10.65	13.20	4.52	29.19					
24.40	23.70									

Table D58. Trial 2 for soil vertical displacement and pressure distribution using soil with high moisture content, medium bulk density and an oval shaped contact surface

Vertical displacement and bulk density calculation										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	76.10	76.10	0.00
7th	10.70	61.60	65.30	65.30	11.10	1195.97	66.00	65.00	65.70	0.70
6th	10.70	52.10	54.40	54.40	10.90	1217.91	55.00	54.10	54.70	0.60
5th	10.70	38.30	41.60	41.60	12.80	1037.13	42.00	41.30	41.70	0.40
4th	10.70	29.80	32.30	32.30	9.30	1427.45	33.60	32.00	33.30	1.30
3rd	10.70	18.30	21.30	21.30	11.00	1206.84	23.30	21.00	23.00	2.00
2nd	10.70	6.30	10.30	10.30	11.00	1206.84	15.00	10.00	14.70	4.70
Surface	10.70	-2.70	0.30	0.30	10.00	1327.53	8.30	0.00	8.00	8.00
		Wet bulk density of soil column, (kg/m^3)				1231.38				
		Dry bulk density of soil column, (kg/m^3)				1030.07				

Pressure distribution calaculation						Moisture content calaculation				
Depth of sensor before load, (cm)	Depth of sensor after load, (cm)	Depth of sensor after load, (cm)	Output force, (N)	Area of the sensor, (cm^2)	Pressure, (kPa)	Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
						3.70	141.35	118.84	19.55	
						3.70	129.00	108.69	19.34	19.54
						3.70	98.77	83.10	19.74	
0.00	8.00	0.00	112.40	4.52	248.58					
5.00	11.35	3.35	52.00	4.52	115.00					
10.00	14.70	6.70	24.00	4.52	53.08					
15.50	18.85	10.85	9.45	4.52	20.90					
21.00	23.00									

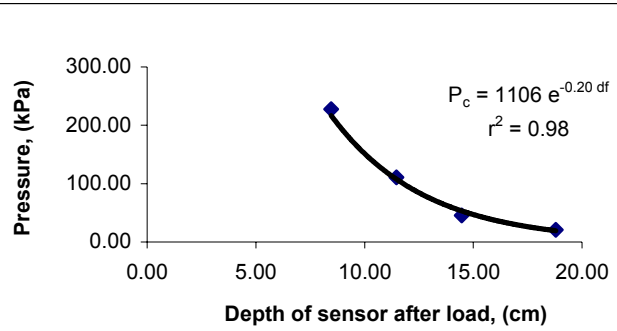
Table D59. Trial 3 for soil vertical displacement and pressure distribution using soil with high moisture content, medium bulk density and an oval shaped contact surface

Vertical displacement and bulk density calculation										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	75.10	75.10	0.00
7th	10.70	62.30	65.80	65.80	10.60	1252.38	66.85	64.50	65.55	1.05
6th	10.70	52.30	54.90	54.90	10.90	1217.91	55.80	53.60	54.50	0.90
5th	10.70	40.30	43.80	43.80	11.10	1195.97	44.30	42.50	43.00	0.50
4th	10.70	29.30	32.30	32.30	11.50	1154.37	33.60	31.00	32.30	1.30
3rd	10.70	18.15	21.30	21.30	11.00	1206.84	24.00	20.00	22.70	2.70
2nd	10.70	6.60	10.30	10.30	11.00	1206.84	15.00	9.00	13.70	4.70
Surface	10.70	-2.70	1.30	1.30	9.00	1475.03	10.00	0.00	8.70	8.70
		Wet bulk density of soil column, (kg/m^3)				1244.19				
		Dry bulk density of soil column, (kg/m^3)				1040.79				

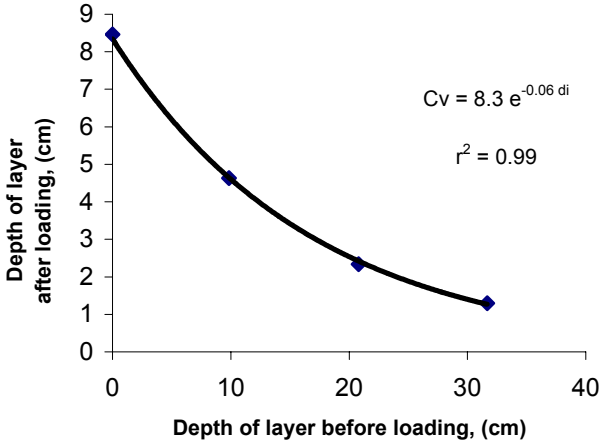
Pressure distribution calaculation						Moisture content calaculation				
Depth of sensor before load, (cm)	Depth of sensor after load, (cm)	Depth of sensor after load, (cm)	Output force, (N)	Area of the sensor, (cm^2)	Pressure, (kPa)	Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
						3.70	141.35	118.84	19.55	
						3.70	129.00	108.69	19.34	19.54
						3.70	98.77	83.10	19.74	
0.00	8.70	0.00	92.6	4.52	204.79					
4.50	11.20	2.50	50.32	4.52	111.29					
9.00	13.70	5.00	20.1	4.52	44.45					
14.50	18.20	9.50	5.95	4.52	13.16					
20.00	22.70									

Table D60. Average of trials 1, 2, and 3 for vertical displacement, pressure distribution, bulk density and moisture content using soil with high moisture content, medium bulk density and an oval shaped contact surface

Pressure distribution	
Depth of sensor after load, (cm)	**Pressure, (kPa)**
8.47	227.35
11.47	110.67
14.47	45.34
18.80	21.08



Vertical displaceemnt			
Layer	**Depth before Load, (cm)**	**Depth after load, (cm)**	**Vertical Displacement, (cm)**
Base	75.77	75.77	0.00
7th	64.78	65.72	0.93
6th	53.90	54.60	0.70
5th	42.23	42.80	0.57
4th	31.67	32.97	1.30
3rd	20.80	23.13	2.33
2nd	9.83	14.47	4.63
Surface	0.00	8.47	8.47



Bulk density of soil column, (kg/m^3)			
Trial 1	**Trial 2**	**Trial 3**	**Average**
1221.72	1231.38	1244.19	1232.43
1020.13	1030.07	1040.79	1030.33

Moisture content of soil column, (%)			
Trial 1	**Trial 2**	**Trial 3**	**Average**
19.76	19.54	19.54	19.62

Table D61. Trial 1 for soil vertical displacement and pressure distribution using soil with high moisture content, medium bulk density and a rectangular shaped contact surface

Vertical displacement and bulk density calculations										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	76.40	76.40	0.00
7th	10.70	62.30	65.30	65.30	11.10	1195.97	66.00	65.30	66.00	0.70
6th	10.70	51.55	54.50	54.50	10.80	1229.19	55.10	54.50	55.10	0.60
5th	10.70	40.45	43.30	43.30	11.20	1185.29	43.60	43.30	43.60	0.30
4th	10.70	29.55	32.40	32.40	10.90	1217.91	33.00	32.40	33.00	0.60
3rd	10.70	18.50	21.30	21.30	11.10	1195.97	22.80	21.30	22.80	1.50
2nd	10.70	7.05	10.15	10.15	11.15	1190.61	14.00	10.15	14.00	3.85
Surface	10.70	-2.70	0.00	0.00	10.15	1307.91	7.50	0.00	7.50	7.50
		Bulk density of soil column, (kg/m^3)				1217.55				

Moisture content calaculation				
Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
3.70	66.20	56.09	19.30	19.62
3.70	80.98	68.15	19.91	
3.70	61.32	51.85	19.67	

Table D62. Trial 2 for soil vertical displacement and pressure distribution using soil with high moisture content, medim bulk density and a rectangular shaped contact surface

Vertical displacement and bulk density calculation										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	75.10	75.10	0.00
7th	10.70	62.10	65.30	65.30	11.10	1195.97	66.80	64.00	65.50	1.50
6th	10.70	51.30	54.60	54.60	10.70	1240.68	55.30	53.30	54.00	0.70
5th	10.70	40.30	43.30	43.30	11.30	1174.80	44.00	42.00	42.70	0.70
4th	10.70	29.30	32.30	32.30	11.00	1206.84	33.20	31.00	31.90	0.90
3rd	10.70	18.50	21.55	21.55	10.75	1234.91	23.25	20.25	21.95	1.70
2nd	10.70	6.95	10.30	10.30	11.25	1180.02	15.00	9.00	13.70	4.70
Surface	10.70	-0.70	1.30	1.30	9.00	1475.03	9.00	0.00	7.70	7.70
		Bulk density of soil column, (kg/m^3)				1244.04				

Moisture content calaculation				
Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
3.70	89.64	75.30	20.03	19.81
3.70	94.90	79.67	20.05	
3.70	142.66	120.12	19.36	

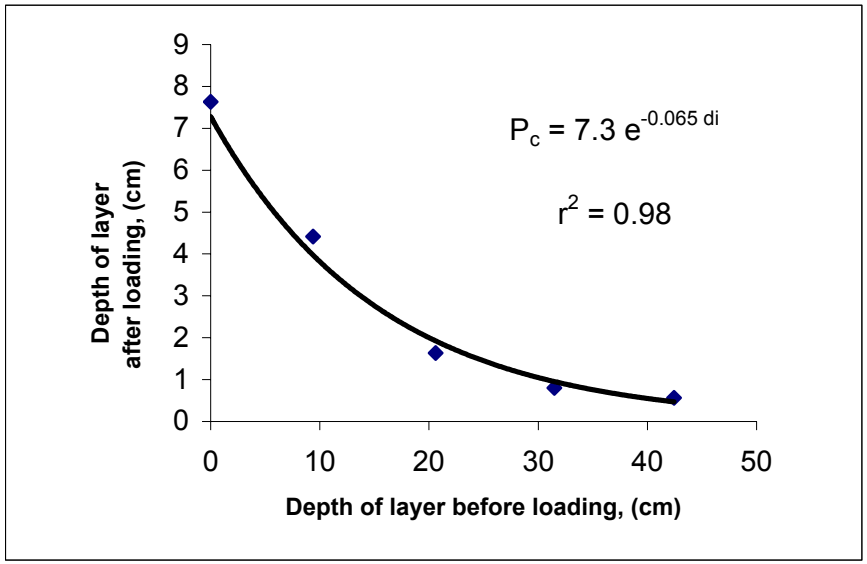
Table D63. Trial 3 for soil vertical displacement and pressure distribution using soil with high moisture content, medium bulk density and a rectangular shaped contact surface

Vertical displacement and bulk density calculation										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	75.10	75.10	0.00
7th	10.70	62.10	65.30	65.30	11.10	1195.97	66.80	64.00	65.50	1.50
6th	10.70	51.30	54.60	54.60	10.70	1240.68	55.30	53.30	54.00	0.70
5th	10.70	40.30	43.30	43.30	11.30	1174.80	44.00	42.00	42.70	0.70
4th	10.70	29.30	32.30	32.30	11.00	1206.84	33.20	31.00	31.90	0.90
3rd	10.70	18.50	21.55	21.55	10.75	1234.91	23.25	20.25	21.95	1.70
2nd	10.70	6.95	10.30	10.30	11.25	1180.02	15.00	9.00	13.70	4.70
Surface	10.70	-0.70	1.30	1.30	9.00	1475.03	9.00	0.00	7.70	7.70
		Bulk density of soil column, (kg/m^3)				1244.04				

Moisture content calaculation				
Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
3.70	89.64	75.30	20.03	19.81
3.70	94.90	79.67	20.05	
3.70	142.66	120.12	19.36	

Table D64. Average of trials 1, 2, and 3 for vertical displacement, pressure distribution, bulk density and moisture content using soil with high moisture content, medium bulk density and a rectangular shaped contact surface

Vertical displacement			
Layer	**Depth before Load, (cm)**	**Depth after load, (cm)**	**Vertical Displacement, (cm)**
Base	75.53	75.53	0.00
7th	64.43	65.67	1.23
6th	53.70	54.37	0.67
5th	42.43	43.00	0.57
4th	31.47	32.27	0.80
3rd	20.60	22.23	1.63
2nd	9.38	13.80	4.42
Surface	0.00	7.63	7.63



Bulk density of soil column, (kg/m^3)			
Trial 1	**Trial 2**	**Trial 3**	**Average**
1217.55	1244.04	1244.04	1235.21

Moisture content of soil column, (%)			
Trial 1	**Trial 2**	**Trial 3**	**Average**
19.62	19.81	19.81	19.75

Table D65. Trial 1 for soil vertical displacement and pressure distribution using soil with high moisture content, high bulk density and an oval shaped contact surface

Vertical displacement and bulk density calculations										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	73.10	73.10	0.00
7th	11.00	63.30	66.30	66.30	10.10	1351.23	66.70	63.00	63.40	0.40
6th	11.00	53.00	55.80	55.80	10.50	1299.76	56.00	52.50	52.70	0.20
5th	11.00	42.00	45.30	45.30	10.50	1299.76	45.80	42.00	42.50	0.50
4th	11.00	32.00	34.30	34.30	11.00	1240.68	35.00	31.00	31.70	0.70
3rd	11.00	21.00	23.30	23.30	11.00	1240.68	24.30	20.00	21.00	1.00
2nd	11.00	10.00	12.50	12.50	10.80	1263.65	15.00	9.20	11.70	2.50
Surface	11.00	-2.00	3.30	3.30	9.20	1483.42	9.00	0.00	5.70	5.70
		Wet bulk density of soil column, (kg/m^3)				1311.31				
		Dry bulk density of soil column, (kg/m^3)				1094.35				

Pressure distribution calaculation						Moisture content calaculation				
Depth of sensor before load, (cm)	Depth of sensor after load, (cm)	Depth of sensor after load, (cm)	Output force, (N)	Area of the sensor, (cm^2)	Pressure, (kPa)	Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
						3.70	56.28	47.66	19.61	
						3.70	78.15	66.00	19.50	19.83
						3.70	95.66	80.10	20.37	
0.00	5.70	0.00	108.20	4.52	239.30					
4.60	8.70	3.00	55.15	4.52	121.97					
9.20	11.70	6.00	29.50	4.52	65.24					
14.60	16.35	10.65	3.95	4.52	8.74					
20.00	21.00									

Table D66. Trial 2 for soil vertical displacement and pressure distribution using soil with high moisture content, high bulk density and an oval shaped contact surface

Vertical displacement and bulk density calculation										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	73.10	73.10	0.00
7^{th}	11.00	63.30	66.30	66.30	10.10	1351.23	66.70	63.00	63.40	0.40
6^{th}	11.00	53.00	55.65	55.65	10.65	1281.45	55.85	52.35	52.55	0.20
5^{th}	11.00	42.30	45.20	45.20	10.45	1305.98	46.00	41.90	42.70	0.80
4^{th}	11.00	31.30	33.90	33.90	11.30	1207.74	35.00	30.60	31.70	1.10
3^{rd}	11.00	20.30	23.30	23.30	10.60	1287.50	24.40	20.00	21.10	1.10
2^{nd}	11.00	9.60	12.50	12.50	10.80	1263.65	15.00	9.20	11.70	2.50
Surface	11.00	-0.70	3.30	3.30	9.20	1483.42	8.70	0.00	5.40	5.40
		Wet bulk density of soil column, (kg/m^3)				1311.57				
		Dry bulk density of soil column, (kg/m^3)				1097.90				

Pressure distribution calaculation						Moisture content calaculation				
Depth of sensor before load, (cm)	Depth of sensor after load, (cm)	Depth of sensor after load, (cm)	Output force, (N)	Area of the sensor, (cm^2)	Pressure, (kPa)	Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
						3.70	94.77	80.15	19.12	
						3.70	110.80	93.20	19.66	19.46
						3.70	124.66	104.84	19.60	
0.00	5.40	0.00	119.00	4.52	263.18					
4.60	8.55	3.15	59.98	4.52	132.65					
9.20	11.70	6.30	24.60	4.52	54.41					
14.60	16.40	11.00	4.70	4.52	10.39					
20.00	21.10									

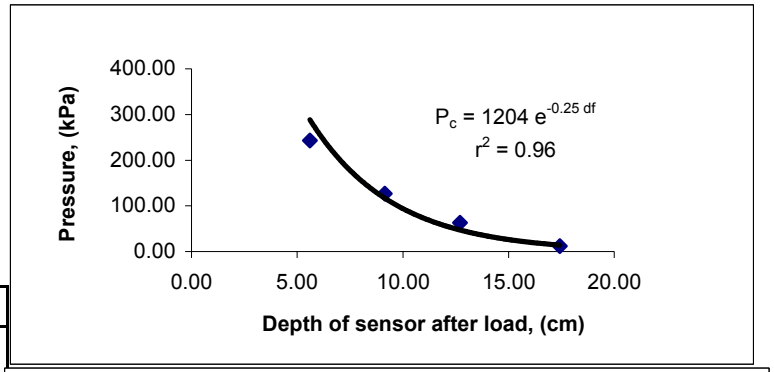
Table D67. Trial 3 for soil vertical displacement and pressure distribution using soil with high moisture content, high bulk density and an oval shaped contact surface

Vertical displacement and bulk density calculation										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	75.10	75.10	0.00
7th	11.00	62.80	65.80	65.80	10.60	1287.50	66.30	64.50	65.00	0.50
6th	11.00	52.95	55.30	55.30	10.50	1299.76	55.50	54.00	54.20	0.20
5th	11.00	42.50	45.65	45.65	9.65	1414.25	46.00	44.35	44.70	0.35
4th	11.00	31.55	34.50	34.50	11.15	1223.99	35.00	33.20	33.70	0.50
3rd	11.00	21.30	24.30	24.30	10.20	1337.99	25.65	23.00	24.35	1.35
2nd	11.00	10.30	12.90	12.90	11.40	1197.15	16.00	11.60	14.70	3.10
Surface	11.00	-1.70	1.30	1.30	11.60	1176.51	7.00	0.00	5.70	5.70
		Wet bulk density of soil column, (kg/m^3)				1276.73				
		Dry bulk density of soil column, (kg/m^3)				1068.74				

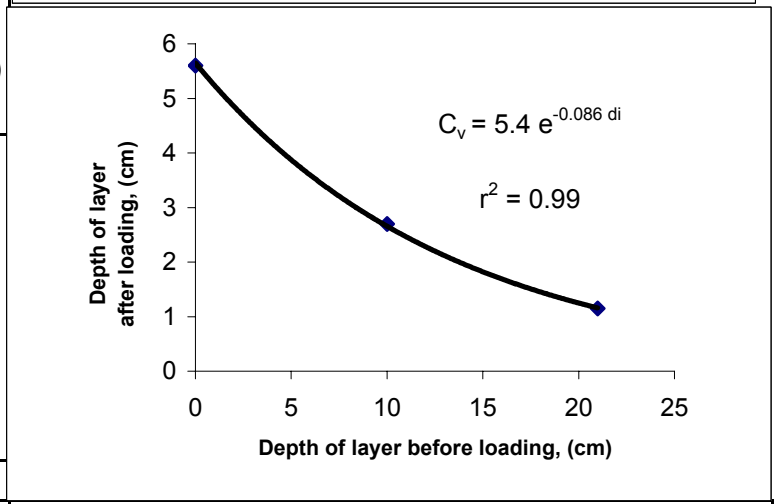
Pressure distribution calaculation						Moisture content calaculation				
Depth of sensor before load, (cm)	Depth of sensor after load, (cm)	Depth of sensor after load, (cm)	Output force, (N)	Area of the sensor, (cm^2)	Pressure, (kPa)	Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
						3.70	94.77	80.15	19.12	19.46
						3.70	110.80	93.20	19.66	
						3.70	124.66	104.84	19.60	
0.00	5.70	0.00	102.2	4.52	226.03					
5.80	10.20	4.50	56.62	4.52	125.22					
11.60	14.70	9.00	31.51	4.52	69.69					
17.30	19.53	13.83	7.08	4.52	15.66					
23.00	24.35									

Table D68. Average of trials 1, 2, and 3 for vertical displacement, pressure distribution, bulk density and moisture content using soil with high moisture content, high bulk density and an oval shaped contact surface

Pressure distribution	
Depth of sensor after load, (cm)	**Pressure, (kPa)**
5.60	242.83
9.15	126.61
12.70	63.11
17.43	11.60



Vertical displaceemnt			
Layer	**Depth before Load, (cm)**	**Depth after load, (cm)**	**Vertical Displacement, (cm)**
Base	73.77	73.77	0.00
7th	63.50	63.93	0.43
6th	52.95	53.15	0.20
5th	42.75	43.30	0.55
4th	31.60	32.37	0.77
3rd	21.00	22.15	1.15
2nd	10.00	12.70	2.70
Surface	0.00	5.60	5.60



Bulk density of soil column, (kg/m^3)			
Trial 1	**Trial 2**	**Trial 3**	**Average**
1311.31	1311.57	1276.73	1299.87
1094.35	1097.90	1068.74	1087.00

Moisture content of soil column, (%)			
Trial 1	**Trial 2**	**Trial 3**	**Average**
19.83	19.46	19.46	19.58

Table D69. Trial 1 for soil vertical displacement and pressure distribution using soil with high moisture content, high bulk density and a rectangular shaped contact surface

Vertical displacement and bulk density calculations										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	72.10	72.10	0.00
7th	11.00	63.15	66.50	66.50	9.90	1378.53	66.70	62.20	62.40	0.20
6th	11.00	53.00	55.75	55.75	10.75	1269.53	56.20	51.45	51.90	0.45
5th	11.00	42.00	45.50	45.50	10.25	1331.46	45.70	41.20	41.40	0.20
4th	11.00	32.00	34.40	34.40	11.10	1229.50	34.65	30.10	30.35	0.25
3rd	11.00	21.00	23.30	23.30	11.10	1229.50	24.70	19.00	20.40	1.40
2nd	11.00	10.00	12.60	12.60	10.70	1275.46	15.10	8.30	10.80	2.50
Surface	11.00	-2.00	4.30	4.30	8.30	1644.27	9.20	0.00	4.90	4.90
		Bulk density of soil column, (kg/m^3)				1336.90				

Moisture content calaculation				
Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
3.70	53.12	46.13	16.47	18.87
3.70	75.67	63.40	20.55	
3.70	95.06	80.10	19.58	

Table D70. Trial 2 for soil vertical displacement and pressure distribution using soil with high moisture content, high bulk density and a rectangular shaped contact surface

Vertical displacement and bulk density calculation										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	74.10	74.10	0.00
7th	11.00	63.30	66.30	66.30	10.10	1351.23	66.70	64.00	64.40	0.40
6th	11.00	53.00	55.75	55.75	10.55	1293.60	56.20	53.45	53.90	0.45
5th	11.00	42.00	45.50	45.50	10.25	1331.46	45.70	43.20	43.40	0.20
4th	11.00	32.00	34.90	34.90	10.60	1287.50	35.20	32.60	32.90	0.30
3rd	11.00	21.00	23.30	23.30	11.60	1176.51	24.70	21.00	22.40	1.40
2nd	11.00	10.00	12.60	12.60	10.70	1275.46	15.10	10.30	12.80	2.50
Surface	11.00	-2.00	2.30	2.30	10.30	1325.00	7.60	0.00	5.30	5.30
		Bulk density of soil column, (kg/m^3)				1291.54				

Moisture content calaculation				
Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
3.70	102.58	86.00	20.15	19.64
3.70	84.95	71.66	19.56	
3.70	112.41	94.88	19.23	

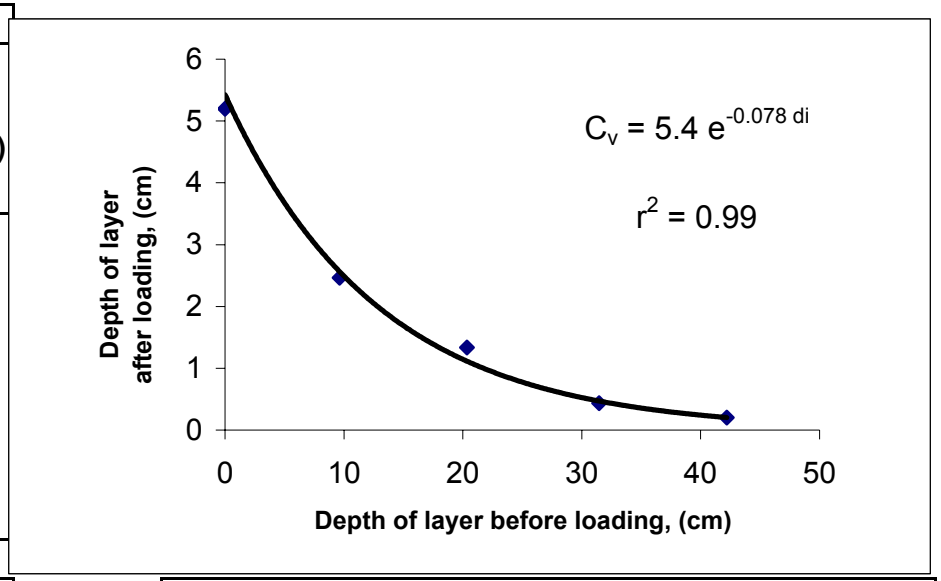
Table D71. Trial 3 for soil vertical displacement and pressure distribution using soil with high moisture content, high bulk density and a rectangular shaped contact surface

Vertical displacement and bulk density calculation										
Layer	Soil Mass, (kg)	Depth of layer before packing , (cm)	Depth of layer after packing, (cm)	Actual depth due to movement, (cm)	Thickness of layer, (cm)	Density of layers after packing, (kg/m^3)	Depth after load , (cm)	Datum is soil surface		Vertical displacement, (cm)
								Depth before load , (cm)	Depth after load , (cm)	
Base		76.40	76.40	76.40			76.40	73.10	73.10	0.00
7^{th}	11.00	63.30	66.05	66.05	10.35	1318.60	66.70	62.75	63.40	0.65
6^{th}	11.00	53.00	55.75	55.75	10.30	1325.00	56.20	52.45	52.90	0.45
5^{th}	11.00	42.00	45.50	45.50	10.25	1331.46	45.70	42.20	42.40	0.20
4^{th}	11.00	32.00	34.95	34.95	10.55	1293.60	35.70	31.65	32.40	0.75
3^{rd}	11.00	21.00	24.30	24.30	10.65	1281.45	25.50	21.00	22.20	1.20
2^{nd}	11.00	10.00	13.60	13.60	10.70	1275.46	16.00	10.30	12.70	2.40
Surface	11.00	-2.00	3.30	3.30	10.30	1325.00	8.70	0.00	5.40	5.40
		Bulk density of soil column, (kg/m^3)				1307.22				

Moisture content calaculation				
Mass of case, (gm)	Mass of wet soil, (gm)	Mass of dry soil, (gm)	Soil moisture content, (%)	Average soil moisture content, (%)
3.70	102.58	86.00	20.15	19.64
3.70	84.95	71.66	19.56	
3.70	112.41	94.88	19.23	

Table D72. Average of trials 1, 2, and 3 for vertical displacement, pressure distribution, bulk density and moisture content using soil with high moisture content, high bulk density and a rectangular shaped contact surface

Vertical displaceemnt			
Layer	**Depth before Load, (cm)**	**Depth after load, (cm)**	**Vertical Displacement, (cm)**
Base	73.10	73.10	0.00
7th	62.98	63.40	0.42
6th	52.45	52.90	0.45
5th	42.20	42.40	0.20
4th	31.45	31.88	0.43
3rd	20.33	21.67	1.33
2nd	9.63	12.10	2.47
Surface	0.00	5.20	5.20



Bulk density of soil column, (kg/m^3)			
Trial 1	**Trial 2**	**Trial 3**	**Average**
1336.90	1291.54	1307.22	1311.89

Moisture content of soil column, (%)			
Trial 1	**Trial 2**	**Trial 3**	**Average**
18.87	19.64	19.64	19.38

APPENDIX E

Program written in Edlog for Campbell 21X Datalogger. This program was used to record the output voltage from the sensors excitation circuit

INSTRONF.CSI, Table 1

{21X}

Table program

```
   01: 1       Execution Interval (seconds)

1: Set Port (P20)
1: 1        Set High
2: 1        Port Number

2: Batt Voltage (P10)
1: 1        Loc [ battv    ]

3: Volt (SE) (P1)
 1: 1       Reps
 2: 15 5000 mV Fast Range
 3: 9       SE Channel
 4: 13 Loc [ trig]
 5: 1.0 Mult
 6: 0.0 Offset

4: If (X<=>F) (P89)
 1: 13 X Loc [ trig]
 2:4 <
 3: 1500. F
 4: 10 Set Output Flag High

5: Volt (SE) (P1)
 1: 4       Reps
 2: 5       5000 mV Slow Range
 3: 1       SE Channel
 4: 2       Loc [
 5: 1.0 Mult
 6: 0.0 Offset

6: Real Time (P77)
1: 1111 Year,Day,Hour/Minute,Seconds (midnight = 0000)

7: Sample (P70)
 1: 8       Reps
 2: 2       Lac [ ____ ]

End Program
```

APPENDIX F

Results from the Analysis of Variance (F-test), using Microsoft Excel® spreadsheets follows. The analysis were to determine the significant difference among the trials (three trials were done for each test) and among the treatments (Bulk density (three levels), moisture content (three levels), shape of loading surface (two shapes)) on vertical soil displacement and pressure distribution.

F with 2 degrees of freedom for nominator and 4 degrees of freedom for denominator with 95% confidence level (P=0.05) = 7

F with 2 degrees of freedom for nominator and 2 degrees of freedom for denominator with 95% confidence level (P=0.05) = 19

F with 1 degree of freedom for nominator and 2 degrees of freedom for denominator with 95% confidence level (P=0.05) = 18.5

Legend

** Highly significant

* Significant

NS Not significant

Table F1. F-test for soil vertical displacements with low moisture contents and three (treatments) bulk densities using an oval shaped contact surface

Soil surface 0 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Low	11.00	11.95	10.15	33.10	11.03
	Medium	6.20	5.80	6.20	18.20	6.07
	High	2.70	3.15	3.10	8.95	2.98
	Sum	19.90	20.90	19.45	60.25	
	Aver	6.63	6.97	6.48		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	98.98	49.49	133.50	**
Due to replicats	2.00	0.37	0.18	0.50	NS
Due to Error	4.00	1.48	0.37		
Total	8.00	100.83			
Correction Factor			403.34		

2nd layer 100 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Low	6.80	8.00	6.50	21.30	7.10
	Medium	4.20	3.30	3.90	11.40	3.80
	High	1.50	1.50	1.00	4.00	1.33
	Sum	12.50	12.80	11.40	36.70	
	Aver	4.17	4.27	3.80		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	50.23	25.11	67.67	**
Due to replicats	2.00	0.36	0.18	0.49	NS
Due to Error	4.00	1.48	0.37		
Total	8.00	52.08			
Correction Factor			149.65		

3rd layer 200 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Low	3.70	4.50	2.90	11.10	3.70
	Medium	1.40	1.80	1.90	5.10	1.70
	High	0.40	0.30	0.70	1.40	0.47
	Sum	5.50	6.60	5.50	17.60	
	Aver	1.83	2.20	1.83		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	15.98	7.99	25.81	*
Due to replicats	2.00	0.27	0.13	0.43	NS
Due to Error	4.00	1.24	0.31		
Total	8.00	17.48			
Correction Factor			34.42		

4th layer 300 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Low	1.65	2.30	1.00	4.95	1.65
	Medium	0.60	0.70	0.20	1.50	0.50
	High	0.30	0.30	0.50	1.10	0.37
	Sum	2.55	3.30	1.70	7.55	
	Aver	0.85	1.10	0.57		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	2.99	1.49	10.22	*
Due to replicats	2.00	0.43	0.21	1.46	NS
Due to Error	4.00	0.58	0.15		
Total	8.00	4.00			
Correction Factor			6.33		

Table F1. Continue

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
5th layer 400 mm Depth	Low	0.90	1.40	0.35	2.65	0.88
	Medium	0.65	-0.20	0.20	0.65	0.22
	High	0.25	0.10	0.10	0.45	0.15
	Sum	1.80	1.30	0.65	3.75	
	Aver	0.60	0.43	0.22		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	0.99	0.49	2.79	NS
Due to replicats	2.00	0.22	0.11	0.63	NS
Due to Error	4.00	0.71	0.18		
Total	8.00	1.92			

Correction Factor	1.56

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
6th layer 500 mm Depth	Low	0.40	1.30	0.35	2.05	0.68
	Medium	0.10	0.00	-0.10	0.00	0.00
	High	0.20	0.30	0.20	0.70	0.23
	Sum	0.70	1.60	0.45	2.75	
	Aver	0.23	0.53	0.15		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	0.72	0.36	4.08	NS
Due to replicats	2.00	0.24	0.12	1.38	NS
Due to Error	4.00	0.35	0.09		
Total	8.00	1.32			

Correction Factor	0.84

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
7th layer 600 mm Depth	Low	0.30	0.40	0.00	0.70	0.23
	Medium	0.20	0.20	0.00	0.40	0.13
	High	0.10	0.20	0.00	0.30	0.10
	Sum	0.60	0.80	0.00	1.40	
	Aver	0.20	0.27	0.00		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	0.03	0.01	3.25	NS
Due to replicats	2.00	0.12	0.06	13.00	*
Due to Error	4.00	0.02	0.00		
Total	8.00	0.16			

Correction Factor	0.22

Table F2. F-test for soil vertical displacement with medium moisture contents and three (treatments) bulk densities using an oval shaped contact surface

Soil surface 0 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Low	19.35	21.10	18.80	59.25	19.75
	Medium	6.70	6.70	6.20	19.60	6.53
	High	3.70	4.20	4.70	12.60	4.20
	Sum	29.75	32.00	29.70	91.45	
	Aver	9.92	10.67	9.90		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	421.93	210.96	351.44	**
Due to replicats	2.00	1.15	0.58	0.96	NS
Due to Error	4.00	2.40	0.60		
Total	8.00	425.48			
Correction Factor			929.23		

2nd layer 100 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Low	14.40	15.80	15.50	45.70	15.23
	Medium	4.80	4.70	4.80	14.30	4.77
	High	1.35	1.60	1.60	4.55	1.52
	Sum	20.55	22.10	21.90	64.55	
	Aver	6.85	7.37	7.30		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	308.26	154.13	932.55	**
Due to replicats	2.00	0.47	0.24	1.43	NS
Due to Error	4.00	0.66	0.17		
Total	8.00	309.40			
Correction Factor			462.97		

3rd layer 200 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Low	8.60	10.45	9.15	28.20	9.40
	Medium	1.50	1.65	1.55	4.70	1.57
	High	0.60	0.40	0.80	1.80	0.60
	Sum	10.70	12.50	11.50	34.70	
	Aver	3.57	4.17	3.83		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	139.74	69.87	206.34	**
Due to replicats	2.00	0.54	0.27	0.80	NS
Due to Error	4.00	1.35	0.34		
Total	8.00	141.63			
Correction Factor			133.79		

4th layer 300 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Low	4.25	5.90	4.60	14.75	4.92
	Medium	0.70	0.60	0.55	1.85	0.62
	High	0.10	0.25	0.20	0.55	0.18
	Sum	5.05	6.75	5.35	17.15	
	Aver	1.68	2.25	1.78		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	41.08	20.54	83.32	*
Due to replicats	2.00	0.55	0.27	1.11	NS
Due to Error	4.00	0.99	0.25		
Total	8.00	42.62			
Correction Factor			32.68		

Table F2. Continue

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
5th layer 400 mm Depth	Low	2.30	4.20	3.00	9.50	3.17
	Medium	0.60	0.90	0.75	2.25	0.75
	High	0.60	0.40	0.40	1.40	0.47
	Sum	3.50	5.50	4.15	13.15	
	Aver	1.17	1.83	1.38		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	13.21	6.61	21.58	*
Due to replicats	2.00	0.69	0.35	1.13	NS
Due to Error	4.00	1.22	0.31		
Total	8.00	15.13			

Correction Factor	19.21

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
6th layer 500 mm Depth	Low	1.00	2.60	1.30	4.90	1.63
	Medium	0.50	0.25	0.25	1.00	0.33
	High	0.50	0.35	0.60	1.45	0.48
	Sum	2.00	3.20	2.15	7.35	
	Aver	0.67	1.07	0.72		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	3.04	1.52	4.91	NS
Due to replicats	2.00	0.28	0.14	0.46	NS
Due to Error	4.00	1.24	0.31		
Total	8.00	4.56			

Correction Factor	6.00

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
7th layer 600 mm Depth	Low	0.30	1.70	0.40	2.40	0.80
	Medium	0.40	0.30	0.30	1.00	0.33
	High	0.60	0.40	0.50	1.50	0.50
	Sum	1.30	2.40	1.20	4.90	
	Aver	0.43	0.80	0.40		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	0.34	0.17	0.71	NS
Due to replicats	2.00	0.30	0.15	0.62	NS
Due to Error	4.00	0.95	0.24		
Total	8.00	1.58			

Correction Factor	2.67

Table F3. F-test for soil vertical displacement with high moisture contents and three (treatments) bulk densities using oval shaped contact surface

Soil surface 0 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Low	27.75	29.80	26.00	83.55	27.85
	Medium	8.70	8.00	8.70	25.40	8.47
	High	5.70	5.40	5.70	16.80	5.60
	Sum	42.15	43.20	40.40	125.75	
	Aver	14.05	14.40	13.47		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	878.99	439.50	279.59	**
Due to replicats	2.00	1.33	0.67	0.42	NS
Due to Error	4.00	6.29	1.57		
Total	8.00	886.62			
Correction Factor			1757.01		

2nd layer 100 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Low	21.70	22.10	21.15	64.95	21.65
	Medium	4.50	4.70	4.70	13.90	4.63
	High	2.50	2.50	3.10	8.10	2.70
	Sum	28.70	29.30	28.95	86.95	
	Aver	9.57	9.77	9.65		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	652.41	326.20	1973.67	**
Due to replicats	2.00	0.06	0.03	0.18	NS
Due to Error	4.00	0.66	0.17		
Total	8.00	653.13			
Correction Factor			840.03		

3rd layer 200 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Low	14.10	15.40	14.30	43.80	14.60
	Medium	2.30	2.00	2.70	7.00	2.33
	High	1.00	1.10	1.35	3.45	1.15
	Sum	17.40	18.50	18.35	54.25	
	Aver	5.80	6.17	6.12		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	332.77	166.39	631.18	**
Due to replicats	2.00	0.24	0.12	0.45	NS
Due to Error	4.00	1.05	0.26		
Total	8.00	334.07			
Correction Factor			327.01		

4th layer 300 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Low	8.50	7.50	8.60	24.60	8.20
	Medium	1.30	1.30	1.30	3.90	1.30
	High	0.70	1.10	0.50	2.30	0.77
	Sum	10.50	9.90	10.40	30.80	
	Aver	3.50	3.30	3.47		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	103.15	51.57	240.50	**
Due to replicats	2.00	0.07	0.03	0.16	NS
Due to Error	4.00	0.86	0.21		
Total	8.00	104.08			
Correction Factor			105.40		

Table F3. Continue

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
5th layer 400 mm Depth	Low	3.90	4.70	3.50	12.10	4.03
	Medium	0.80	0.40	0.50	1.70	0.57
	High	0.50	0.80	0.35	1.65	0.55
	Sum	5.20	5.90	4.35	15.45	
	Aver	1.73	1.97	1.45		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	24.15	12.08	90.01	*
Due to replicats	2.00	0.40	0.20	1.50	NS
Due to Error	4.00	0.54	0.13		
Total	8.00	25.09			

Correction Factor	26.52

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
6th layer 500 mm Depth	Low	1.30	1.05	1.30	3.65	1.22
	Medium	0.60	0.60	0.90	2.10	0.70
	High	0.20	0.20	0.20	0.60	0.20
	Sum	2.10	1.85	2.40	6.35	
	Aver	0.70	0.62	0.80		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	1.55	0.78	60.67	*
Due to replicats	2.00	0.05	0.03	1.98	NS
Due to Error	4.00	0.05	0.01		
Total	8.00	1.65			

Correction Factor	4.48

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
7th layer 600 mm Depth	Low	0.70	0.60	0.70	2.00	0.67
	Medium	1.05	0.70	1.05	2.80	0.93
	High	0.40	0.40	0.50	1.30	0.43
	Sum	2.15	1.70	2.25	6.10	
	Aver	0.72	0.57	0.75		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	0.38	0.19	19.88	*
Due to replicats	2.00	0.06	0.03	3.03	NS
Due to Error	4.00	0.04	0.01		
Total	8.00	0.47			

Correction Factor	4.13

Table F4. F-test for soil vertical displacement with low bulk density and three (treatments) moisture contents using an oval shaped contact surface

Soil surface 0 mm Depth	Moisture content	Trial 1	Trial 2	Trial 3	Sum	Aver
	Low	11.00	11.95	10.15	33.10	11.03
	Medium	19.35	21.10	18.80	59.25	19.75
	High	27.75	29.80	26.00	83.55	27.85
	Sum	58.10	62.85	54.95	175.90	
	Aver	19.37	20.95	18.32		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	424.39	212.20	708.63	**
Due to replicats	2.00	10.54	5.27	17.61	NS
Due to Error	4.00	1.20	0.30		
Total	8.00	436.13			
Correction Factor			3437.87		

2nd layer 100 mm Depth	Moisture content	Trial 1	Trial 2	Trial 3	Sum	Aver
	Low	6.80	8.00	6.50	21.30	7.10
	Medium	14.40	15.80	15.50	45.70	15.23
	High	21.70	22.10	21.15	64.95	21.65
	Sum	42.90	45.90	43.15	131.95	
	Aver	14.30	15.30	14.38		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	319.03	159.51	668.51	*
Due to replicats	2.00	1.85	0.92	3.87	NS
Due to Error	4.00	0.95	0.24		
Total	8.00	321.83			
Correction Factor			1934.53		

3rd layer 200 mm Depth	Moisture content	Trial 1	Trial 2	Trial 3	Sum	Aver
	Low	3.70	4.50	2.90	11.10	3.70
	Medium	8.60	10.45	9.15	28.20	9.40
	High	14.10	15.40	14.30	43.80	14.60
	Sum	26.40	30.35	26.35	83.10	
	Aver	8.80	10.12	8.78		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	178.34	89.17	644.60	*
Due to replicats	2.00	3.51	1.76	12.69	NS
Due to Error	4.00	0.55	0.14		
Total	8.00	182.41			
Correction Factor			767.29		

4th layer 300 mm Depth	Moisture content	Trial 1	Trial 2	Trial 3	Sum	Aver
	Low	1.65	2.30	1.00	4.95	1.65
	Medium	4.25	5.90	4.60	14.75	4.92
	High	8.50	7.50	8.60	24.60	8.20
	Sum	14.40	15.70	14.20	44.30	
	Aver	4.80	5.23	4.73		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	64.35	32.18	48.49	*
Due to replicats	2.00	0.44	0.22	0.33	NS
Due to Error	4.00	2.65	0.66		
Total	8.00	67.45			
Correction Factor			218.05		

Table F4. Continue

	Moisture content	Trial 1	Trial 2	Trial 3	Sum	Aver
5th layer 400 mm Depth	Low	0.90	1.40	0.35	2.65	0.88
	Medium	2.30	4.20	3.00	9.50	3.17
	High	3.90	4.70	3.50	12.10	4.03
	Sum	7.10	10.30	6.85	24.25	
	Aver	2.37	3.43	2.28		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	15.89	7.94	46.88	*
Due to replicats	2.00	2.47	1.23	7.28	NS
Due to Error	4.00	0.68	0.17		
Total	8.00	19.03			

Correction Factor	65.34

	Moisture content	Trial 1	Trial 2	Trial 3	Sum	Aver
6th layer 500 mm Depth	Low	0.40	1.30	0.35	2.05	0.68
	Medium	1.00	2.60	1.30	4.90	1.63
	High	1.30	1.05	1.30	3.65	1.22
	Sum	2.70	4.95	2.95	10.60	
	Aver	0.90	1.65	0.98		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	1.36	0.68	2.60	NS
Due to replicats	2.00	1.01	0.51	1.94	NS
Due to Error	4.00	1.05	0.26		
Total	8.00	3.42			

Correction Factor	12.48

	Moisture content	Trial 1	Trial 2	Trial 3	Sum	Aver
7th layer 600 mm Depth	Low	0.30	0.40	0.00	0.70	0.23
	Medium	0.30	1.70	0.40	2.40	0.80
	High	0.70	0.60	1.70	3.00	1.00
	Sum	1.30	2.70	2.10	6.10	
	Aver	0.43	0.90	0.70		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	0.95	0.47	1.10	NS
Due to replicats	2.00	0.33	0.16	0.38	NS
Due to Error	4.00	1.72	0.43		
Total	8.00	3.00			

Correction Factor	4.13

Table F5. F-test for soil vertical displacement with medium bulk density and three (treatments) moisture contents using oval shaped contact surface

	Moisture content	Trial 1	Trial 2	Trial 3	Sum	Aver
Soil surface 0 mm Depth	Low	6.20	5.80	6.20	18.20	6.07
	Medium	6.70	6.70	6.20	19.60	6.53
	High	8.70	8.00	8.70	25.40	8.47
	Sum	21.60	20.50	21.10	63.20	
	Aver	7.20	6.83	7.03		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	9.72	4.86	48.85	**
Due to replicats	2.00	0.20	0.10	1.02	NS
Due to Error	4.00	0.40	0.10		
Total	8.00	10.32			
Correction Factor			443.80		

	Moisture content	Trial 1	Trial 2	Trial 3	Sum	Aver
2nd layer 100 mm Depth	Low	4.20	3.30	3.90	11.40	3.80
	Medium	4.80	4.70	4.80	14.30	4.77
	High	4.50	4.70	4.70	13.90	4.63
	Sum	13.50	12.70	13.40	39.60	
	Aver	4.50	4.23	4.47		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	1.65	0.82	10.08	**
Due to replicats	2.00	0.13	0.06	0.78	NS
Due to Error	4.00	0.33	0.08		
Total	8.00	2.10			
Correction Factor			174.24		

	Moisture content	Trial 1	Trial 2	Trial 3	Sum	Aver
3rd layer 200 mm Depth	Low	1.40	1.80	1.90	5.10	1.70
	Medium	1.50	1.65	1.55	4.70	1.57
	High	2.30	2.00	2.70	7.00	2.33
	Sum	5.20	5.45	6.15	16.80	
	Aver	1.73	1.82	2.05		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	1.01	0.50	8.51	*
Due to replicats	2.00	0.16	0.08	1.37	NS
Due to Error	4.00	0.24	0.06		
Total	8.00	1.41			
Correction Factor			31.36		

	Moisture content	Trial 1	Trial 2	Trial 3	Sum	Aver
4th layer 300 mm Depth	Low	0.60	0.70	0.20	1.50	0.50
	Medium	0.70	0.60	0.55	1.85	0.62
	High	1.30	1.30	1.30	3.90	1.30
	Sum	2.60	2.60	2.05	7.25	
	Aver	0.87	0.87	0.68		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	1.12	0.56	26.54	*
Due to replicats	2.00	0.07	0.03	1.59	NS
Due to Error	4.00	0.08	0.02		
Total	8.00	1.27			
Correction Factor			5.84		

Table F5. Continue

	Moisture content	Trial 1	Trial 2	Trial 3	Sum	Aver
5th layer 400 mm Depth	Low	0.65	-0.20	0.20	0.65	0.22
	Medium	0.60	0.90	0.75	2.25	0.75
	High	0.80	0.40	0.50	1.70	0.57
	Sum	2.05	1.10	1.45	4.60	
	Aver	0.68	0.37	0.48		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	0.44	0.22	2.60	NS
Due to replicats	2.00	0.15	0.08	0.91	NS
Due to Error	4.00	0.34	0.08		
Total	8.00	0.93			

Correction Factor	2.35

	Moisture content	Trial 1	Trial 2	Trial 3	Sum	Aver
6th layer 500 mm Depth	Low	0.10	0.00	-0.10	0.00	0.00
	Medium	0.50	0.25	0.25	1.00	0.33
	High	0.60	0.60	0.90	2.10	0.70
	Sum	1.20	0.85	1.05	3.10	
	Aver	0.40	0.28	0.35		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	0.74	0.37	14.55	*
Due to replicats	2.00	0.02	0.01	0.41	NS
Due to Error	4.00	0.10	0.03		
Total	8.00	0.86			

Correction Factor	1.07

	Moisture content	Trial 1	Trial 2	Trial 3	Sum	Aver
7th layer 600 mm Depth	Low	0.20	0.20	0.00	0.40	0.13
	Medium	0.40	0.30	0.30	1.00	0.33
	High	1.05	0.70	1.05	2.80	0.93
	Sum	1.65	1.20	1.35	4.20	
	Aver	0.55	0.40	0.45		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	1.04	0.52	26.00	*
Due to replicats	2.00	0.04	0.02	0.88	NS
Due to Error	4.00	0.08	0.02		
Total	8.00	1.16			

Correction Factor	1.96

Table F6. F-test for soil vertical displacement with high bulk density and three (treatments) moisture contents using an oval shaped contact surface

	Moisture content	Trial 1	Trial 2	Trial 3	Sum	Aver
Soil surface 0 mm Depth	Low	2.70	3.15	3.10	8.95	2.98
	Medium	3.70	4.20	4.70	12.60	4.20
	High	5.70	5.40	5.70	16.80	5.60
	Sum	12.10	12.75	13.50	38.35	
	Aver	4.03	4.25	4.50		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	10.29	5.14	58.05	**
Due to replicats	2.00	0.33	0.16	1.85	NS
Due to Error	4.00	0.35	0.09		
Total	8.00	10.97			
Correction Factor			163.41		

	Moisture content	Trial 1	Trial 2	Trial 3	Sum	Aver
2nd layer 100 mm Depth	Low	1.50	1.50	1.00	4.00	1.33
	Medium	1.35	1.60	1.60	4.55	1.52
	High	2.50	2.50	3.10	8.10	2.70
	Sum	5.35	5.60	5.70	16.65	
	Aver	1.78	1.87	1.90		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	3.30	1.65	15.48	*
Due to replicats	2.00	0.02	0.01	0.10	NS
Due to Error	4.00	0.43	0.11		
Total	8.00	3.75			
Correction Factor			30.80		

	Moisture content	Trial 1	Trial 2	Trial 3	Sum	Aver
3rd layer 200 mm Depth	Low	0.40	0.30	0.70	1.40	0.47
	Medium	0.60	0.40	0.80	1.80	0.60
	High	1.00	1.10	1.35	3.45	1.15
	Sum	2.00	1.80	2.85	6.65	
	Aver	0.67	0.60	0.95		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	0.79	0.39	64.41	*
Due to replicats	2.00	0.21	0.10	16.95	NS
Due to Error	4.00	0.02	0.01		
Total	8.00	1.02			
Correction Factor			4.91		

	Moisture content	Trial 1	Trial 2	Trial 3	Sum	Aver
4th layer 300 mm Depth	Low	0.30	0.30	0.50	1.10	0.37
	Medium	0.10	0.25	0.20	0.55	0.18
	High	0.70	1.10	0.50	2.30	0.77
	Sum	1.10	1.65	1.20	3.95	
	Aver	0.37	0.55	0.40		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	0.53	0.27	6.36	NS
Due to replicats	2.00	0.06	0.03	0.68	NS
Due to Error	4.00	0.17	0.04		
Total	8.00	0.76			
Correction Factor			1.73		

Table F6. F-test for soil vertical displacement with high bulk density and three (treatments) moisture contents using an oval shaped contact surface

	Moisture content	Trial 1	Trial 2	Trial 3	Sum	Aver
5th layer 400 mm Depth	Low	0.25	0.10	0.10	0.45	0.15
	Medium	0.60	0.40	0.40	1.40	0.47
	High	0.50	0.80	0.35	1.65	0.55
	Sum	1.35	1.30	0.85	3.50	
	Aver	0.45	0.43	0.28		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	0.27	0.13	5.56	NS
Due to replicats	2.00	0.05	0.03	1.05	NS
Due to Error	4.00	0.10	0.02		
Total	8.00	0.41			
Correction Factor			1.36		

	Moisture content	Trial 1	Trial 2	Trial 3	Sum	Aver
6th layer 500 mm Depth	Low	0.20	0.30	0.20	0.70	0.23
	Medium	0.50	0.35	0.60	1.45	0.48
	High	0.20	0.20	0.20	0.60	0.20
	Sum	0.90	0.85	1.00	2.75	
	Aver	0.30	0.28	0.33		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	0.14	0.07	8.35	*
Due to replicats	2.00	0.00	0.00	0.23	NS
Due to Error	4.00	0.03	0.01		
Total	8.00	0.18			
Correction Factor			0.84		

	Moisture content	Trial 1	Trial 2	Trial 3	Sum	Aver
7th layer 600 mm Depth	Low	0.10	0.20	0.00	0.30	0.10
	Medium	0.60	0.40	0.50	1.50	0.50
	High	0.40	0.40	0.50	1.30	0.43
	Sum	1.10	1.00	1.00	3.10	
	Aver	0.37	0.33	0.33		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	0.28	0.14	12.40	*
Due to replicats	2.00	0.00	0.00	0.10	NS
Due to Error	4.00	0.04	0.01		
Total	8.00	0.32			
Correction Factor			1.07		

Table F7. F-test for soil vertical displacement with low moisture contents, low bulk density using two treatments (oval and rectangular shaped contact surfaces)

Soil surface 0 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Rect.	9.20	8.50	9.90	27.60	9.20
	Oval	11.00	11.95	10.15	33.10	11.03
	Sum	20.20	20.45	20.05	60.70	
	Aver	10.10	10.23	10.03		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	5.04	5.04	3.94	NS
Due to replicats	2.00	0.04	0.02	0.02	NS
Due to Error	2.00	2.56	1.28		
Total	5.00	7.64			
Correction Factor			614.08		

2nd layer 100 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Rect.	5.50	4.50	5.50	15.50	5.17
	Oval	6.80	8.00	6.50	21.30	7.10
	Sum	12.30	12.50	12.00	36.80	
	Aver	6.15	6.25	6.00		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	5.61	5.61	6.02	NS
Due to replicats	2.00	0.06	0.03	0.03	NS
Due to Error	2.00	1.86	0.93		
Total	5.00	7.53			
Correction Factor			225.71		

3rd layer 200 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Rect.	3.10	2.70	3.50	9.30	3.10
	Oval	3.70	4.50	2.90	11.10	3.70
	Sum	6.80	7.20	6.40	20.40	
	Aver	3.40	3.60	3.20		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.54	0.54	0.75	NS
Due to replicats	2.00	0.16	0.08	0.11	NS
Due to Error	2.00	1.44	0.72		
Total	5.00	2.14			
Correction Factor			69.36		

4th layer 300 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Rect.	1.40	1.30	1.80	4.50	1.50
	Oval	1.65	2.30	1.00	4.95	1.65
	Sum	3.05	3.60	2.80	9.45	
	Aver	1.53	1.80	1.40		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.03	0.03	0.08	NS
Due to replicats	2.00	0.17	0.08	0.20	NS
Due to Error	2.00	0.82	0.41		
Total	5.00	1.02			
Correction Factor			14.88		

Table F7. Continue

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
5th layer 400 mm Depth	Rect.	0.70	0.90	1.10	2.70	0.90
	Oval	0.90	1.40	0.35	2.65	0.88
	Sum	1.60	2.30	1.45	5.35	
	Aver	0.80	1.15	0.73		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.00	0.00	0.00	NS
Due to replicats	2.00	0.21	0.10	0.48	NS
Due to Error	2.00	0.43	0.21		
Total	5.00	0.63			

Correction Factor	4.77

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
6th layer 500 mm Depth	Rect.	0.40	0.40	0.30	1.10	0.37
	Oval	0.40	1.30	0.35	2.05	0.68
	Sum	0.80	1.70	0.65	3.15	
	Aver	0.40	0.85	0.33		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.15	0.15	1.18	NS
Due to replicats	2.00	0.32	0.16	1.26	NS
Due to Error	2.00	0.26	0.13		
Total	5.00	0.73			

Correction Factor	1.65

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
7th layer 600 mm Depth	Rect.	0.30	0.20	0.15	0.65	0.22
	Oval	0.30	0.40	0.00	0.70	0.23
	Sum	0.60	0.60	0.15	1.35	
	Aver	0.30	0.30	0.08		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.00	0.00	0.03	NS
Due to replicats	2.00	0.07	0.03	2.19	NS
Due to Error	2.00	0.03	0.02		
Total	5.00	0.10			

Correction Factor	0.30

Table F8. F-test for soil vertical displacement with low moisture contents, medium bulk density using two treatments (oval and rectangular shaped contact surfaces)

Soil surface 0 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Rect.	5.90	5.50	5.90	17.30	5.77
	Oval	6.20	5.80	6.20	18.20	6.07
	Sum	12.10	11.30	12.10	35.50	
	Aver	6.05	5.65	6.05		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.13	0.13	13.50	**
Due to replicats	2.00	0.21	0.11	10.67	NS
Due to Error	2.00	0.00	0.01		
Total	5.00	0.35			
Correction Factor			210.04		

2nd layer 100 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Rect.	2.80	2.70	4.10	9.60	3.20
	Oval	4.20	3.30	3.90	11.40	3.80
	Sum	7.00	6.00	8.00	21.00	
	Aver	3.50	3.00	4.00		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	25.04	25.04	51.45	*
Due to replicats	2.00	0.67	0.33	0.68	NS
Due to Error	2.00	0.97	0.49		
Total	5.00	26.68			
Correction Factor			49.00		

3rd layer 200 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Rect.	1.30	1.20	1.70	4.20	1.40
	Oval	1.40	1.80	1.90	5.10	1.70
	Sum	2.70	3.00	3.60	9.30	
	Aver	1.35	1.50	1.80		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.13	0.13	3.86	*
Due to replicats	2.00	0.21	0.10	3.00	NS
Due to Error	2.00	0.07	0.04		
Total	5.00	0.41			
Correction Factor			14.42		

4th layer 300 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Rect.	0.40	0.30	0.70	1.40	0.47
	Oval	0.60	0.70	0.20	1.50	0.50
	Sum	1.00	1.00	0.90	2.90	
	Aver	0.50	0.50	0.45		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.00	0.00	0.01	NS
Due to replicats	2.00	0.00	0.00	0.01	NS
Due to Error	2.00	0.22	0.11		
Total	5.00	0.23			
Correction Factor			1.40		

Table F8. Continue

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
5th layer 400 mm Depth	Rect.	0.20	0.10	0.30	0.60	0.20
	Oval	0.65	-0.20	0.20	0.65	0.22
	Sum	0.85	-0.10	0.50	1.25	
	Aver	0.43	-0.05	0.25		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.00	0.00	0.01	NS
Due to replicats	2.00	0.23	0.12	1.53	NS
Due to Error	2.00	0.15	0.08		
Total	5.00	0.38			

Correction Factor	0.26

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
6th layer 500 mm Depth	Rect.	0.00	0.05	0.10	0.15	0.05
	Oval	0.10	0.00	-0.10	0.00	0.00
	Sum	0.10	0.05	0.00	0.15	
	Aver	0.05	0.03	0.00		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.00	0.00	0.33	NS
Due to replicats	2.00	0.00	0.00	0.11	NS
Due to Error	2.00	0.02	0.01		
Total	5.00	0.03			

Correction Factor	0.00

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
7th layer 600 mm Depth	Rect.	0.20	0.00	0.00	0.20	0.07
	Oval	0.20	0.20	0.00	0.40	0.13
	Sum	0.40	0.20	0.00	0.60	
	Aver	0.20	0.10	0.00		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.01	0.01	1.00	NS
Due to replicats	2.00	0.04	0.02	3.00	NS
Due to Error	2.00	0.01	0.01		
Total	5.00	0.06			

Correction Factor	0.06

Table F9. F-test for soil vertical displacement with low moisture contents, high bulk density using two treatments (oval and rectangular shaped contact surfaces)

Soil surface 0 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Rect.	3.00	3.10	3.00	9.10	3.03
	Oval	2.70	3.15	3.10	8.95	2.98
	Sum	5.70	6.25	6.10	18.05	
	Aver	2.85	3.13	3.05		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.00	0.00	0.16	NS
Due to replicats	2.00	0.08	0.04	1.70	NS
Due to Error	2.00	0.05	0.02		
Total	5.00	0.13			
Correction Factor			54.30		

2nd layer 100 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Rect.	0.90	1.20	1.70	3.80	1.27
	Oval	1.50	1.50	1.00	4.00	1.33
	Sum	2.40	2.70	2.70	7.80	
	Aver	1.20	1.35	1.35		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.01	0.01	0.03	NS
Due to replicats	2.00	0.03	0.02	0.06	NS
Due to Error	2.00	0.46	0.23		
Total	5.00	0.50			
Correction Factor			10.14		

3rd layer 200 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Rect.	0.40	0.45	0.60	1.45	0.48
	Oval	0.40	0.30	0.70	1.40	0.47
	Sum	0.80	0.75	1.30	2.85	
	Aver	0.40	0.38	0.65		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.00	0.00	0.05	NS
Due to replicats	2.00	0.09	0.05	5.84	NS
Due to Error	2.00	0.02	0.01		
Total	5.00	0.11			
Correction Factor			1.35		

4th layer 300 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Rect.	0.30	0.40	0.50	1.20	0.40
	Oval	0.30	0.30	0.50	1.10	0.37
	Sum	0.60	0.70	1.00	2.30	
	Aver	0.30	0.35	0.50		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.00	0.00	1.00	NS
Due to replicats	2.00	0.04	0.02	13.00	NS
Due to Error	2.00	0.00	0.00		
Total	5.00	0.05			
Correction Factor			0.88		

Table F9. Continue

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
5th layer 400 mm Depth	Rect.	0.50	0.40	0.20	1.10	0.37
	Oval	0.25	0.10	0.10	0.45	0.15
	Sum	0.75	0.50	0.30	1.55	
	Aver	0.38	0.25	0.15		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.07	0.07	13.00	NS
Due to replicats	2.00	0.05	0.03	4.69	NS
Due to Error	2.00	0.01	0.01		
Total	5.00	0.13			

Correction Factor	0.40

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
6th layer 500 mm Depth	Rect.	0.30	0.20	0.50	1.00	0.33
	Oval	0.20	0.30	0.20	0.70	0.23
	Sum	0.50	0.50	0.70	1.70	
	Aver	0.25	0.25	0.35		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.02	0.02	0.75	NS
Due to replicats	2.00	0.01	0.01	0.33	NS
Due to Error	2.00	0.04	0.02		
Total	5.00	0.07			

Correction Factor	0.48

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
7th layer 600 mm Depth	Rect.	0.30	0.40	0.30	1.00	0.33
	Oval	0.10	0.20	0.00	0.30	0.10
	Sum	0.40	0.60	0.30	1.30	
	Aver	0.20	0.30	0.15		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.08	0.08	49.00	*
Due to replicats	2.00	0.02	0.01	7.00	NS
Due to Error	2.00	0.00	0.00		
Total	5.00	0.11			

Correction Factor	0.28

Table F10. F-test for soil vertical displacement with medium moisture contents, low bulk density using two treatments (oval and rectangular shaped contact surfaces)

Soil surface 0 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Rect.	17.60	17.50	16.90	52.00	17.33
	Oval	19.35	21.10	18.80	59.25	19.75
	Sum	36.95	38.60	35.70	111.25	
	Aver	18.48	19.30	17.85		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	8.76	8.76	16.59	NS
Due to replicats	2.00	2.12	1.06	2.00	NS
Due to Error	2.00	1.06	0.53		
Total	5.00	11.93			
Correction Factor			2062.76		

2nd layer 100 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Rect.	12.50	12.75	11.90	37.15	12.38
	Oval	14.40	15.80	15.50	45.70	15.23
	Sum	26.90	28.55	27.40	82.85	
	Aver	13.45	14.28	13.70		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	12.18	12.18	32.38	*
Due to replicats	2.00	0.72	0.36	0.95	NS
Due to Error	2.00	0.75	0.38		
Total	5.00	13.65			
Correction Factor			1144.02		

3rd layer 200 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Rect.	6.40	6.80	6.90	20.10	6.70
	Oval	8.60	10.45	9.15	28.20	9.40
	Sum	15.00	17.25	16.05	48.30	
	Aver	7.50	8.63	8.03		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	10.93	10.93	32.28	*
Due to replicats	2.00	1.27	0.63	1.87	NS
Due to Error	2.00	0.68	0.34		
Total	5.00	12.88			
Correction Factor			388.82		

4th layer 300 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Rect.	3.00	3.70	3.35	10.05	3.35
	Oval	4.20	5.90	4.60	14.70	4.90
	Sum	7.20	9.60	7.95	24.75	
	Aver	3.60	4.80	3.98		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	3.60	3.60	22.70	*
Due to replicats	2.00	1.51	0.75	4.75	NS
Due to Error	2.00	0.32	0.16		
Total	5.00	5.43			
Correction Factor			102.09		

Table F10. Continue

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
5th layer 400 mm Depth	Rect.	1.90	2.20	0.90	5.00	1.67
	Oval	2.30	4.20	3.00	9.50	3.17
	Sum	4.20	6.40	3.90	14.50	
	Aver	2.10	3.20	1.95		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	3.38	3.38	7.42	NS
Due to replicats	2.00	1.86	0.93	2.05	NS
Due to Error	2.00	0.91	0.45		
Total	5.00	6.15			

Correction Factor	35.04

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
6th layer 500 mm Depth	Rect.	0.65	0.30	0.60	1.55	0.52
	Oval	1.00	2.60	1.30	4.90	1.63
	Sum	1.65	2.90	1.90	6.45	
	Aver	0.83	1.45	0.95		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	1.87	1.87	3.46	NS
Due to replicats	2.00	0.44	0.22	0.40	NS
Due to Error	2.00	1.08	0.54		
Total	5.00	3.39			

Correction Factor	6.93

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
7th layer 600 mm Depth	Rect.	0.25	0.60	0.30	1.15	0.38
	Oval	0.30	1.70	0.40	2.40	0.80
	Sum	0.55	2.30	0.70	3.55	
	Aver	0.28	1.15	0.35		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.26	0.26	1.48	NS
Due to replicats	2.00	0.94	0.47	2.68	NS
Due to Error	2.00	0.35	0.18		
Total	5.00	1.55			

Correction Factor	2.10

Table F11. F-test for soil vertical displacement with medium moisture contents, medium bulk density using two treatments (oval and rectangular shaped contact surfaces)

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
Soil surface 0 mm Depth	Rect.	6.70	6.70	7.55	20.95	6.98
	Oval	6.70	6.70	6.20	19.60	6.53
	Sum	13.40	13.40	13.75	40.55	
	Aver	6.70	6.70	6.88		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.30	0.30	1.00	NS
Due to replicats	2.00	0.04	0.02	0.07	NS
Due to Error	2.00	0.61	0.30		
Total	5.00	0.95			
Correction Factor			274.05		

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
2nd layer 100 mm Depth	Rect.	4.15	4.35	4.45	12.95	4.32
	Oval	4.80	4.70	4.80	14.30	4.77
	Sum	8.95	9.05	9.25	27.25	
	Aver	4.48	4.53	4.63		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.30	0.30	20.25	NS
Due to replicats	2.00	0.02	0.01	0.78	NS
Due to Error	2.00	0.03	0.02		
Total	5.00	0.36			
Correction Factor			123.76		

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
3rd layer 200 mm Depth	Rect.	2.05	1.25	1.40	4.70	1.57
	Oval	1.50	1.65	1.55	4.70	1.57
	Sum	3.55	2.90	2.95	9.40	
	Aver	1.78	1.45	1.48		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.00	0.00	0.00	NS
Due to replicats	2.00	0.13	0.07	0.54	NS
Due to Error	2.00	0.24	0.12		
Total	5.00	0.37			
Correction Factor			14.73		

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
4th layer 300 mm Depth	Rect.	0.80	0.70	0.65	2.15	0.72
	Oval	0.70	0.60	0.55	1.85	0.62
	Sum	1.50	1.30	1.20	4.00	
	Aver	0.75	0.65	0.60		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.01	0.01	15.00	NS
Due to replicats	2.00	0.02	0.01	11.67	NS
Due to Error	2.00	0.00	0.00		
Total	5.00	0.04			
Correction Factor			2.67		

Table F11. Continue

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
5th layer 400 mm Depth	Rect.	0.30	0.60	0.15	1.05	0.35
	Oval	0.60	0.90	0.75	2.25	0.75
	Sum	0.90	1.50	0.90	3.30	
	Aver	0.45	0.75	0.45		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.24	0.24	16.00	NS
Due to replicats	2.00	0.12	0.06	4.00	NS
Due to Error	2.00	0.03	0.02		
Total	5.00	0.39			

Correction Factor	1.82

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
6th layer 500 mm Depth	Rect.	0.70	0.60	0.40	1.70	0.57
	Oval	0.50	0.25	0.25	1.00	0.33
	Sum	1.20	0.85	0.65	2.70	
	Aver	0.60	0.43	0.33		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.08	0.08	15.08	NS
Due to replicats	2.00	0.08	0.04	7.15	NS
Due to Error	2.00	0.01	0.01		
Total	5.00	0.17			

Correction Factor	1.22

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
7th layer 600 mm Depth	Rect.	0.40	0.40	0.25	1.05	0.35
	Oval	0.40	0.30	0.30	1.00	0.33
	Sum	0.80	0.70	0.55	2.05	
	Aver	0.40	0.35	0.28		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.00	0.00	0.14	NS
Due to replicats	2.00	0.02	0.01	2.71	NS
Due to Error	2.00	0.01	0.00		
Total	5.00	0.02			

Correction Factor	0.70

Table F12. F-test for soil vertical displacement with medium moisture contents, high bulk density using two treatments (oval and rectangular shaped contact surfaces)

Soil surface 0 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Rect.	3.70	3.35	3.20	10.25	3.42
	Oval	3.70	4.20	4.70	12.60	4.20
	Sum	7.40	7.55	7.90	22.85	
	Aver	3.70	3.78	3.95		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.92	0.92	3.25	NS
Due to replicats	2.00	0.07	0.03	0.12	NS
Due to Error	2.00	0.57	0.28		
Total	5.00	1.55			
Correction Factor			87.02		

2nd layer 100 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Rect.	1.75	1.50	1.75	5.00	1.67
	Oval	1.35	1.60	1.60	4.55	1.52
	Sum	3.10	3.10	3.35	9.55	
	Aver	1.55	1.55	1.68		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.03	0.03	1.08	NS
Due to replicats	2.00	0.02	0.01	0.33	NS
Due to Error	2.00	0.06	0.03		
Total	5.00	0.12			
Correction Factor			15.20		

3rd layer 200 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Rect.	0.60	0.50	0.45	1.55	0.52
	Oval	0.40	0.20	0.20	0.80	0.27
	Sum	1.00	0.70	0.65	2.35	
	Aver	0.50	0.35	0.33		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.09	0.09	75.00	*
Due to replicats	2.00	0.04	0.02	14.33	NS
Due to Error	2.00	0.00	0.00		
Total	5.00	0.13			
Correction Factor			0.92		

4th layer 300 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Rect.	0.30	0.25	0.40	0.95	0.32
	Oval	0.30	0.50	0.50	1.30	0.43
	Sum	0.60	0.75	0.90	2.25	
	Aver	0.30	0.38	0.45		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.02	0.02	2.58	NS
Due to replicats	2.00	0.02	0.01	1.42	NS
Due to Error	2.00	0.02	0.01		
Total	5.00	0.06			
Correction Factor			0.84		

Table F12. Continue

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
5th layer 400 mm Depth	Rect.	0.50	0.45	0.25	1.20	0.40
	Oval	0.60	0.40	0.40	1.40	0.47
	Sum	1.10	0.85	0.65	2.60	
	Aver	0.55	0.43	0.33		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.01	0.01	1.23	NS
Due to replicats	2.00	0.05	0.03	4.69	NS
Due to Error	2.00	0.01	0.01		
Total	5.00	0.07			

Correction Factor	1.13

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
6th layer 500 mm Depth	Rect.	0.30	0.15	0.45	0.90	0.30
	Oval	0.50	0.35	0.60	1.45	0.48
	Sum	0.80	0.50	1.05	2.35	
	Aver	0.40	0.25	0.53		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.05	0.05	121.00	*
Due to replicats	2.00	0.08	0.04	91.00	NS
Due to Error	2.00	0.00	0.00		
Total	5.00	0.13			

Correction Factor	0.92

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
7th layer 600 mm Depth	Rect.	0.20	0.60	0.55	1.35	0.45
	Oval	0.60	0.40	0.50	1.50	0.50
	Sum	0.80	1.00	1.05	2.85	
	Aver	0.40	0.50	0.53		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.00	0.00	0.08	NS
Due to replicats	2.00	0.02	0.01	0.18	NS
Due to Error	2.00	0.10	0.05		
Total	5.00	0.12			

Correction Factor	1.35

Table F13. F-test for soil vertical displacement with high moisture contents, low bulk density using two treatments (oval and rectangular shaped contact surfaces)

Soil surface 0 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Rect.	22.50	22.05	22.50	67.05	22.35
	Oval	27.75	29.80	26.00	83.55	27.85
	Sum	50.25	51.85	48.50	150.60	
	Aver	25.13	25.93	24.25		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	45.38	45.38	19.89	*
Due to replicats	2.00	2.81	1.40	0.62	NS
Due to Error	2.00	4.56	2.28		
Total	5.00	52.75			
Correction Factor			3780.06		

2nd layer 100 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Rect.	19.50	19.15	19.20	57.85	19.28
	Oval	21.75	22.10	21.15	65.00	21.67
	Sum	41.25	41.25	40.35	122.85	
	Aver	20.63	20.63	20.18		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	8.52	8.52	64.71	*
Due to replicats	2.00	0.27	0.13	1.03	NS
Due to Error	2.00	0.26	0.13		
Total	5.00	9.05			
Correction Factor			2515.35		

3rd layer 200 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Rect.	12.15	11.15	12.70	36.00	12.00
	Oval	14.10	15.40	14.30	43.80	14.60
	Sum	26.25	26.55	27.00	79.80	
	Aver	13.13	13.28	13.50		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	10.14	10.14	9.79	NS
Due to replicats	2.00	0.14	0.07	0.07	NS
Due to Error	2.00	2.07	1.04		
Total	5.00	12.36			
Correction Factor			1061.34		

4th layer 300 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Rect.	5.50	5.10	5.90	16.50	5.50
	Oval	8.50	7.50	8.60	24.60	8.20
	Sum	14.00	12.60	14.50	41.10	
	Aver	7.00	6.30	7.25		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	10.94	10.94	243.00	*
Due to replicats	2.00	0.97	0.48	10.78	NS
Due to Error	2.00	0.09	0.04		
Total	5.00	11.99			
Correction Factor			281.54		

Table F13. Continue

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
5th layer 400 mm Depth	Rect.	1.85	1.95	1.70	5.50	1.83
	Oval	3.90	4.70	3.50	12.10	4.03
	Sum	5.75	6.65	5.20	17.60	
	Aver	2.88	3.33	2.60		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	7.26	7.26	59.88	*
Due to replicats	2.00	0.54	0.27	2.21	NS
Due to Error	2.00	0.24	0.12		
Total	5.00	8.04			

Correction Factor	51.63

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
6th layer 500 mm Depth	Rect.	1.20	1.10	1.50	3.80	1.27
	Oval	1.30	1.05	1.30	3.65	1.22
	Sum	2.50	2.15	2.80	7.45	
	Aver	1.25	1.08	1.40		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.00	0.00	0.33	NS
Due to replicats	2.00	0.11	0.05	4.70	NS
Due to Error	2.00	0.02	0.01		
Total	5.00	0.13			

Correction Factor	9.25

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
7th layer 600 mm Depth	Rect.	0.80	0.70	1.70	3.20	1.07
	Oval	0.70	0.60	0.70	2.00	0.67
	Sum	1.50	1.30	2.40	5.20	
	Aver	0.75	0.65	1.20		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.24	0.24	1.78	NS
Due to replicats	2.00	0.34	0.17	1.27	NS
Due to Error	2.00	0.27	0.14		
Total	5.00	0.85			

Correction Factor	4.51

Table F14. F-test for soil vertical displacement with high moisture contents, medium bulk density using two treatments (oval rectangular shaped contact surfaces)

Soil surface 0 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Rect.	7.50	7.70	7.70	22.90	7.63
	Oval	8.70	8.00	8.70	25.40	8.47
	Sum	16.20	15.70	16.40	48.30	
	Aver	8.10	7.85	8.20		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	1.04	1.04	9.33	NS
Due to replicats	2.00	0.13	0.06	0.58	NS
Due to Error	2.00	0.22	0.11		
Total	5.00	1.39			
Correction Factor			388.82		

2nd layer 100 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Rect.	3.85	4.70	4.70	13.25	4.42
	Oval	4.50	4.70	4.70	13.90	4.63
	Sum	8.35	9.40	9.40	27.15	
	Aver	4.18	4.70	4.70		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.07	0.07	1.00	NS
Due to replicats	2.00	0.37	0.18	2.61	NS
Due to Error	2.00	0.14	0.07		
Total	5.00	0.58			
Correction Factor			122.85		

3rd layer 200 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Rect.	1.50	1.70	1.70	4.90	1.63
	Oval	2.30	2.00	2.70	7.00	2.33
	Sum	3.80	3.70	4.40	11.90	
	Aver	1.90	1.85	2.20		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.73	0.73	11.31	NS
Due to replicats	2.00	0.14	0.07	1.10	NS
Due to Error	2.00	0.13	0.06		
Total	5.00	1.01			
Correction Factor			23.60		

4th layer 300 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Rect.	0.60	0.90	0.90	2.40	0.80
	Oval	1.30	1.30	1.30	3.90	1.30
	Sum	1.90	2.20	2.20	6.30	
	Aver	0.95	1.10	1.10		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.37	0.37	25.00	*
Due to replicats	2.00	0.03	0.01	1.00	NS
Due to Error	2.00	0.03	0.02		
Total	5.00	0.43			
Correction Factor			6.62		

Table F14. Continue

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
5th layer 400 mm Depth	Rect.	0.30	0.70	0.70	1.70	0.57
	Oval	0.80	0.40	0.50	1.70	0.57
	Sum	1.10	1.10	1.20	3.40	
	Aver	0.55	0.55	0.60		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.00	0.00	0.00	NS
Due to replicats	2.00	0.00	0.00	0.02	NS
Due to Error	2.00	0.19	0.10		
Total	5.00	0.19			

Correction Factor	1.93

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
6th layer 500 mm Depth	Rect.	0.60	0.70	0.70	2.00	0.67
	Oval	0.60	0.60	0.90	2.10	0.70
	Sum	1.20	1.30	1.60	4.10	
	Aver	0.60	0.65	0.80		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.00	0.00	0.14	NS
Due to replicats	2.00	0.04	0.02	1.86	NS
Due to Error	2.00	0.02	0.01		
Total	5.00	0.07			

Correction Factor	2.80

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
7th layer 600 mm Depth	Rect.	0.70	1.50	1.50	3.70	1.23
	Oval	1.05	0.70	1.05	2.80	0.93
	Sum	1.75	2.20	2.55	6.50	
	Aver	0.88	1.10	1.28		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.14	0.14	0.78	NS
Due to replicats	2.00	0.16	0.08	0.46	NS
Due to Error	2.00	0.35	0.17		
Total	5.00	0.64			

Correction Factor	7.04

Table F15. F-test for soil vertical displacement with high moisture contents, high bulk density using two treatments (oval and rectangular shaped contact surfaces)

Soil surface 0 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Rect.	4.90	5.30	5.40	15.60	5.20
	Oval	5.70	5.40	5.70	16.80	5.60
	Sum	10.60	10.70	11.10	32.40	
	Aver	5.30	5.35	5.55		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.24	0.24	3.69	NS
Due to replicats	2.00	0.07	0.04	0.54	NS
Due to Error	2.00	0.13	0.06		
Total	5.00	0.44			
Correction Factor			174.96		

2nd layer 100 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Rect.	2.50	2.50	2.40	7.40	2.47
	Oval	2.50	2.50	3.10	8.10	2.70
	Sum	5.00	5.00	5.50	15.50	
	Aver	2.50	2.50	2.75		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.08	0.08	1.00	NS
Due to replicats	2.00	0.08	0.04	0.51	NS
Due to Error	2.00	0.16	0.08		
Total	5.00	0.33			
Correction Factor			40.04		

3rd layer 200 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Rect.	1.40	1.40	1.20	4.00	1.33
	Oval	1.00	1.10	1.35	3.45	1.15
	Sum	2.40	2.50	2.55	7.45	
	Aver	1.20	1.25	1.28		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.05	0.05	1.17	NS
Due to replicats	2.00	0.01	0.00	0.07	NS
Due to Error	2.00	0.09	0.04		
Total	5.00	0.14			
Correction Factor			9.25		

4th layer 300 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Rect.	0.25	0.30	0.75	1.30	0.43
	Oval	0.70	1.10	0.50	2.30	0.77
	Sum	0.95	1.40	1.25	3.60	
	Aver	0.48	0.70	0.63		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.17	0.17	1.17	NS
Due to replicats	2.00	0.05	0.03	0.18	NS
Due to Error	2.00	0.29	0.14		
Total	5.00	0.51			
Correction Factor			2.16		

Table F15. Continue

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
5th layer 400 mm Depth	Rect.	0.20	0.20	0.20	0.60	0.20
	Oval	0.50	0.80	0.35	1.65	0.55
	Sum	0.70	1.00	0.55	2.25	
	Aver	0.35	0.50	0.28		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.18	0.18	7.00	NS
Due to replicats	2.00	0.05	0.03	1.00	NS
Due to Error	2.00	0.05	0.03		
Total	5.00	0.29			

Correction Factor	0.84

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
6th layer 500 mm Depth	Rect.	0.45	0.45	0.45	1.35	0.45
	Oval	0.20	0.20	0.20	0.60	0.20
	Sum	0.65	0.65	0.65	1.95	
	Aver	0.33	0.33	0.33		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.09	0.09	9.37	NS
Due to replicats	2.00	0.00	0.00	0.00	NS
Due to Error	2.00	0.00	0.01		
Total	5.00	0.09			

Correction Factor	0.63

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
7th layer 600 mm Depth	Rect.	0.20	0.40	0.65	1.25	0.42
	Oval	0.40	0.40	0.50	1.30	0.43
	Sum	0.60	0.80	1.15	2.55	
	Aver	0.30	0.40	0.58		

Source of variance	DF	SS	MS	F	
Due to treatments	1.00	0.00	0.00	0.03	NS
Due to replicats	2.00	0.08	0.04	2.51	NS
Due to Error	2.00	0.03	0.02		
Total	5.00	0.11			

Correction Factor	1.08

Table F16. F-test for soil pressure distribution with low bulk density and three (treatments) moisture contents using an oval shaped contact surface

	Moisture content	Trial 1	Trial 2	Trial 3	Sum	Aver
Soil surface 0 mm Depth	Low	267.49	239.67	269.88	777.04	259.01
	Medium	192.21	210.26	180.14	582.61	194.20
	High	208.78	223.37	213.02	645.17	215.06
	Sum	668.48	673.30	663.04	2004.82	
	Aver	222.83	224.43	221.01		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	6567.39	3283.69	11.74	*
Due to replicats	2.00	17.57	8.78	0.03	NS
Due to Error	4.00	1118.76	279.69		
Total	8.00	7703.71			
Correction Factor			446589.25		

	Moisture content	Trial 1	Trial 2	Trial 3	Sum	Aver
2nd layer 50 mm Depth	Low	143.87	155.21	133.01	432.09	144.03
	Medium	170.74	148.62	146.96	466.32	155.44
	High	142.87	141.85	154.02	438.74	146.25
	Sum	457.48	445.68	433.99	1337.15	
	Aver	152.49	148.56	144.66		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	219.62	109.81	0.73	NS
Due to replicats	2.00	91.96	45.98	0.31	NS
Due to Error	4.00	598.16	149.54		
Total	8.00	909.75			
Correction Factor			198663.35		

	Moisture content	Trial 1	Trial 2	Trial 3	Sum	Aver
3rd layer 100 mm Depth	Low	49.41	76.28	21.64	147.33	49.11
	Medium	126.50	113.23	97.31	337.04	112.35
	High	102.84	94.88	86.25	283.97	94.66
	Sum	278.75	284.39	205.20	768.34	
	Aver	92.92	94.80	68.40		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	6386.31	3193.16	16.89	*
Due to replicats	2.00	1301.39	650.69	3.44	NS
Due to Error	4.00	756.40	189.10		
Total	8.00	8444.10			
Correction Factor			65594.04		

	Moisture content	Trial 1	Trial 2	Trial 3	Sum	Aver
4th layer 150 mm Depth	Low	32.38	39.03	41.58	112.99	37.66
	Medium	45.34	57.55	44.70	147.59	49.20
	High	40.25	54.07	39.15	133.47	44.49
	Sum	117.97	150.65	125.43	394.05	
	Aver	39.32	50.22	41.81		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	201.77	100.89	4.35	NS
Due to replicats	2.00	195.52	97.76	4.22	NS
Due to Error	4.00	92.74	23.19		
Total	8.00	490.04			
Correction Factor			17252.82		

Table F17. F-test for soil pressure distribution with medium bulk density and three (treatments) moisture contents using an oval shaped contact surface

Soil surface 0 mm Depth	Moisture content	Trial 1	Trial 2	Trial 3	Sum	Aver
	Low	243.96	331.98	299.03	874.97	291.66
	Medium	218.75	305.00	265.19	788.94	262.98
	High	228.68	248.58	204.79	682.05	227.35
	Sum	691.39	885.56	769.01	2345.96	
	Aver	230.46	295.19	256.34		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	6227.20	3113.60	5.47	NS
Due to replicats	2.00	6367.86	3183.93	5.60	NS
Due to Error	4.00	2275.74	568.94		
Total	8.00	14870.80			
Correction Factor			611503.15		

2nd layer 50 mm Depth	Moisture content	Trial 1	Trial 2	Trial 3	Sum	Aver
	Low	111.58	116.04	144.77	372.39	124.13
	Medium	174.50	192.85	126.50	493.85	164.62
	High	105.71	115.00	111.29	332.00	110.67
	Sum	391.79	423.89	382.56	1198.24	
	Aver	130.60	141.30	127.52		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	4731.03	2365.52	3.47	NS
Due to replicats	2.00	313.75	156.88	0.23	NS
Due to Error	4.00	2726.62	681.66		
Total	8.00	7771.41			
Correction Factor			159531.01		

3rd layer 100 mm Depth	Moisture content	Trial 1	Trial 2	Trial 3	Sum	Aver
	Low	63.12	54.47	67.48	185.07	61.69
	Medium	86.69	63.47	86.69	236.85	78.95
	High	38.48	53.08	44.45	136.01	45.34
	Sum	188.29	171.02	198.62	557.93	
	Aver	62.76	57.01	66.21		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	1695.20	847.60	7.97	NS
Due to replicats	2.00	129.64	64.82	0.61	NS
Due to Error	4.00	425.27	106.32		
Total	8.00	2250.10			
Correction Factor			34587.32		

4th layer 150 mm Depth	Moisture content	Trial 1	Trial 2	Trial 3	Sum	Aver
	Low	32.60	19.48	28.22	80.30	26.77
	Medium	25.17	40.03	22.51	87.71	29.24
	High	29.19	20.90	13.16	63.25	21.08
	Sum	86.96	80.41	63.89	231.26	
	Aver	28.99	26.80	21.30		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	104.88	52.44	0.69	NS
Due to replicats	2.00	94.23	47.11	0.62	NS
Due to Error	4.00	301.82	75.46		
Total	8.00	500.93			
Correction Factor			5942.35		

Table F18. F-test for soil pressure distribution with high bulk density and three (treatments) moisture contents using an oval shaped contact surface

Soil surface 0 mm Depth	Moisture content	Trial 1	Trial 2	Trial 3	Sum	Aver
	Low	267.38	277.40	252.45	797.23	265.74
	Medium	265.19	228.44	237.33	730.96	243.65
	High	239.30	263.18	226.03	728.51	242.84
	Sum	771.87	769.02	715.81	2256.70	
	Aver	257.29	256.34	238.60		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	1013.35	506.68	1.85	NS
Due to replicats	2.00	664.68	332.34	1.21	NS
Due to Error	4.00	1094.67	273.67		
Total	8.00	2772.70			
Correction Factor			565854.99		

2nd layer 50 mm Depth	Moisture content	Trial 1	Trial 2	Trial 3	Sum	Aver
	Low	143.87	140.99	118.48	403.34	134.45
	Medium	130.60	107.26	115.45	353.31	117.77
	High	121.97	132.65	125.22	379.84	126.61
	Sum	396.44	380.90	359.15	1136.49	
	Aver	132.15	126.97	119.72		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	417.68	208.84	1.69	NS
Due to replicats	2.00	233.90	116.95	0.95	NS
Due to Error	4.00	493.04	123.26		
Total	8.00	1144.62			
Correction Factor			143512.17		

3rd layer 100 mm Depth	Moisture content	Trial 1	Trial 2	Trial 3	Sum	Aver
	Low	49.41	57.92	45.16	152.49	50.83
	Medium	42.57	33.09	32.95	108.61	36.20
	High	65.24	54.49	69.69	189.42	63.14
	Sum	157.22	145.50	147.80	450.52	
	Aver	52.41	48.50	49.27		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	1091.06	545.53	9.03	NS
Due to replicats	2.00	25.71	12.85	0.21	NS
Due to Error	4.00	241.67	60.42		
Total	8.00	1358.44			
Correction Factor			22552.03		

4th layer 150 mm Depth	Moisture content	Trial 1	Trial 2	Trial 3	Sum	Aver
	Low	32.38	28.00	16.28	76.66	25.55
	Medium	35.43	34.72	25.85	96.00	32.00
	High	8.74	10.39	15.66	34.79	11.60
	Sum	76.55	73.11	57.79	207.45	
	Aver	25.52	24.37	19.26		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	652.64	326.32	8.41	*
Due to replicats	2.00	66.50	33.25	0.86	NS
Due to Error	4.00	155.20	38.80		
Total	8.00	874.34			
Correction Factor			4781.72		

Table F19. F-test for soil pressure distribution with low moisture content and three (treatments) bulk densities using an oval shaped contact surface

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
Soil surface 0 mm Depth	Low	267.49	359.10	389.31	1015.90	338.63
	Medium	243.96	331.98	299.03	874.97	291.66
	High	267.38	277.40	252.45	797.23	265.74
	Sum	778.83	968.48	940.79	2688.10	
	Aver	259.61	322.83	313.60		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	8191.26	4095.63	3.08	NS
Due to replicats	2.00	6996.10	3498.05	2.63	NS
Due to Error	4.00	5322.86	1330.72		
Total	8.00	20510.22			
Correction Factor			802875.73		

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
2nd layer 50 mm Depth	Low	143.49	155.21	133.01	431.71	143.90
	Medium	111.58	116.04	144.77	372.39	124.13
	High	143.87	140.99	118.48	403.34	134.45
	Sum	398.94	412.24	396.26	1207.44	
	Aver	132.98	137.41	132.09		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	586.85	293.42	0.95	NS
Due to replicats	2.00	48.83	24.41	0.08	NS
Due to Error	4.00	1233.36	308.34		
Total	8.00	1869.03			
Correction Factor			161990.15		

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
3rd layer 100 mm Depth	Low	49.41	76.28	51.64	177.33	59.11
	Medium	63.12	54.47	67.48	185.07	61.69
	High	49.41	57.92	45.16	152.49	50.83
	Sum	161.94	188.67	164.28	514.89	
	Aver	53.98	62.89	54.76		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	193.15	96.58	0.82	NS
Due to replicats	2.00	146.09	73.05	0.62	NS
Due to Error	4.00	470.74	117.68		
Total	8.00	809.98			
Correction Factor			29456.86		

	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
4th layer 150 mm Depth	Low	32.38	39.03	41.58	112.99	37.66
	Medium	32.60	19.48	28.22	80.30	26.77
	High	32.38	28.00	16.28	76.66	25.55
	Sum	97.36	86.51	86.08	269.95	
	Aver	32.45	28.84	28.69		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	266.86	133.43	2.17	NS
Due to replicats	2.00	27.24	13.62	0.22	NS
Due to Error	4.00	245.70	61.43		
Total	8.00	539.80			
Correction Factor			8097.00		

Table F20. F-test for soil pressure distribution with medium moisture content and three (treatments) bulk densities using an oval shaped contact surface

Soil surface 0 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Low	192.21	210.26	180.14	582.61	194.20
	Medium	218.75	305.00	265.19	788.94	262.98
	High	265.19	228.44	237.33	730.96	243.65
	Sum	676.15	743.70	682.66	2102.51	
	Aver	225.38	247.90	227.55		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	7549.05	3774.53	3.78	NS
Due to replicats	2.00	925.70	462.85	0.46	NS
Due to Error	4.00	3995.99	999.00		
Total	8.00	12470.74			
Correction Factor			491172.03		

2nd layer 50 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Low	170.74	148.62	146.96	466.32	155.44
	Medium	174.50	192.85	126.50	493.85	164.62
	High	130.60	107.26	115.45	353.31	117.77
	Sum	475.84	448.73	388.91	1313.48	
	Aver	158.61	149.58	129.64		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	3697.85	1848.93	4.45	NS
Due to replicats	2.00	1318.91	659.46	1.59	NS
Due to Error	4.00	1661.73	415.43		
Total	8.00	6678.50			
Correction Factor			191692.19		

3rd layer 100 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Low	126.50	113.23	97.31	337.04	112.35
	Medium	86.69	63.47	86.69	236.85	78.95
	High	42.57	33.09	32.95	108.61	36.20
	Sum	255.76	209.79	216.95	682.50	
	Aver	85.25	69.93	72.32		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	8740.42	4370.21	39.77	*
Due to replicats	2.00	407.86	203.93	1.86	NS
Due to Error	4.00	439.60	109.90		
Total	8.00	9587.88			
Correction Factor			51756.25		

4th layer 150 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Low	45.34	57.55	44.70	147.59	49.20
	Medium	25.17	40.03	22.51	87.71	29.24
	High	35.43	34.72	25.85	96.00	32.00
	Sum	105.94	132.30	93.06	331.30	
	Aver	35.31	44.10	31.02		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	701.76	350.88	19.12	*
Due to replicats	2.00	266.72	133.36	7.27	NS
Due to Error	4.00	73.42	18.35		
Total	8.00	1041.90			
Correction Factor			12195.52		

Table F21. F-test for soil pressure distribution with high moisture content and three (treatments) bulk densities using an oval shaped contact surface

Soil surface 0 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Low	208.78	223.37	213.02	645.17	215.06
	Medium	228.68	248.58	204.79	682.05	227.35
	High	239.30	263.18	226.03	728.51	242.84
	Sum	676.76	735.13	643.84	2055.73	
	Aver	225.59	245.04	214.61		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	1162.69	581.35	6.50	NS
Due to replicats	2.00	1424.96	712.48	7.96	NS
Due to Error	4.00	357.95	89.49		
Total	8.00	2945.61			
Correction Factor			469558.43		

2^{nd} layer 50 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Low	142.87	141.85	154.02	438.74	146.25
	Medium	105.71	115.00	111.29	332.00	110.67
	High	121.97	132.65	125.22	379.84	126.61
	Sum	370.55	389.50	390.53	1150.58	
	Aver	123.52	129.83	130.18		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	1905.70	952.85	34.50	*
Due to replicats	2.00	84.37	42.19	1.53	NS
Due to Error	4.00	110.46	27.62		
Total	8.00	2100.54			
Correction Factor			147092.70		

3^{rd} layer 100 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Low	102.84	94.88	86.25	283.97	94.66
	Medium	38.71	53.08	44.45	136.24	45.41
	High	43.46	39.48	46.44	129.38	43.13
	Sum	185.01	187.44	177.14	549.59	
	Aver	61.67	62.48	59.05		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	5085.48	2542.74	41.11	*
Due to replicats	2.00	19.33	9.66	0.16	NS
Due to Error	4.00	247.39	61.85		
Total	8.00	5352.19			
Correction Factor			33561.02		

4^{th} layer 150 mm Depth	Bulk Density	Trial 1	Trial 2	Trial 3	Sum	Aver
	Low	40.25	54.07	39.15	133.47	44.49
	Medium	29.19	20.90	13.16	63.25	21.08
	High	8.74	10.39	15.66	34.79	11.60
	Sum	78.18	85.36	67.97	231.51	
	Aver	26.06	28.45	22.66		

Source of variance	DF	SS	MS	F	
Due to treatments	2.00	1719.84	859.92	14.21	*
Due to replicats	2.00	50.91	25.46	0.42	NS
Due to Error	4.00	242.02	60.50		
Total	8.00	2012.77			
Correction Factor			5955.21		