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DEPTH EFFECT OF SOIL
COMPACTION FROM WIDE TIRES

by

Ray A. Dilts

B.S., Kansas State University, 1974

A MASTER'S THESIS

submitted in partial fulfillment of the

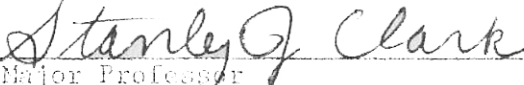
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INTRODUCTION

The topic of soil compaction has caused much research, debate, and some alarm. Most of the research has been in the area of compaction in the upper soil layers and at the tire-soil interface. There has also been much research on the methods of compaction and the effects of compaction on crops. The debate has been about what type of tire arrangements are best.

This research was sparked by a concern about the possibility of formation of a compacted layer below tillage or frost depth. This compacted layer could still be shallow enough to adversely affect the soil and crops in several ways. Compaction reduces permeability causing runoff, erosion, and preventing ground water recharge. A reduction of aeration hampering root metabolic activities is another effect of compaction. Compaction also increases soil mechanical strength, thus impeding root growth. It was felt that this compacted layer would result from the deeper pressure bulb under the new wide tires used on many large farm tractors. Although surface pressures are similar to those under narrower tires, the depth effect of compaction of wide tires was thought to be a possible problem of future agriculture.

REVIEW OF LITERATURE

Soil Compaction

Gill and Vanden Berg defined soil compaction as the action of soil becoming more compact. Soil compaction can be considered as a compression failure and representative of a yield criterion for soil. There are two types of compression failure. First, stress may cause compaction that is elastically recovered when the stress is removed. Second, there is compaction which is not recovered when the stress is removed. Nonrecoverable compaction is generally much larger than recoverable compaction.

For a soil to become more compact, the volume of a given amount of soil must be reduced. Harris (1971) stated that the change in volume can be attributed to one or a combination of four possible factors. The four possible factors are: (1) compression of the solid particles, (2) compression of the liquid and gas within the pore space, (3) a change in the liquid and gas contents in pore spaces, (4) a rearrangement of the soil particles. The first two factors of volume changes are mainly responsible for the recoverable portion of compaction. Any compression of solid particles would probably remain in the elastic ranges unless the particles were literally crushed. A liquid or gas in a compressed state will expand if the pressure is relieved. The last two factors of volume change will be mainly responsible for the nonrecoverable compaction. A change in the liquid and gas contents in the pore spaces results from the pore space decreasing or the liquid or gas moving to different pores. It will take time for the pore space to increase again or for the liquid or gas to move back into the pores. When a soil is compressed, the pore size distribution generally tends toward a

smaller portion of larger pores. Some other force will be required to again rearrange and loosen the soil particles which were rearranged during the compaction.

Different soils are affected to differing degrees by soil compaction forces. Sandy soils are more easily compacted by agricultural practices than fine clay soils. Loads on soil from agricultural practices are very transient and of short duration. Sands can be compacted by short duration loads because the liquid or gas in the pore space is held loosely and can move freely. Clay soils bind the water tightly and time is required for the water to be moved out of the soil by the load. Sand particles are also rearranged by loading especially if there is some vibration of the load. The clay particle structure must be collapsed rather than the particles just being rearranged for compaction to result in clay soils. Soils are more susceptible to compaction when wet up to some optimum moisture content. Above the optimum moisture content the soil will just move from under the load. A soil having a uniform particle size distribution is particularly sensitive to compaction.

Effects of Soil Compaction

Soil compaction has several effects on soil properties and plant growth. However, not all the effects of compaction are bad. Soehne (1969) stated that roots of plants thrive best in soils with an optimum porosity of around 40-50 percent. If the porosity is too high, plant growth could be improved by some soil compaction. Tire tracks may also bring dry soil up to optimum density and allow the soil to hold more rain water. In general, the bad effects of soil compaction overshadow the good effects and the problem of soils being too loose is minor in agriculture.

The bad effects of soil compaction could start with a reduction of soil permeability. The reduced permeability increases runoff causing more erosion and preventing ground water recharge. Reduced aeration from compaction hampers root metabolic activities. Thus, a good root system capable of providing nutrients and water to the plant will not develop. The plant then suffers during drouth or other stress periods. Compaction increases soil mechanical strength impeding root growth. The increased strength also causes tillage tools to wear faster and pull harder. A compacted soil can, in some cases, keep an implement from working properly.

Causes of Soil Compaction

The causes of soil compaction could be classified either as natural or mechanical. The natural causes would be forces of nature. The mechanical causes would be forces of men or machines.

One natural force is rain pounding on the soil surface. This type of compaction is limited to shallow depths. Drying can cause compaction in some soil types. The compaction from drying can be as great as the compaction from mechanical forces. Drying compaction can extend to the depth of drying. The last natural compaction force would be the weight of the overburden which will increase with depth but is relatively insignificant in the surface layers.

The mechanical forces result from vehicular traffic and tillage tools. The major portion of compaction results from the vehicular traffic. Compaction will vary with the number of passes over a soil mass by a vehicle. Gill and Reaves (1956) found that 90 percent of the increase in density of moist soil is caused by the first pass with further small increases up to the

third and fourth. Davies, Finney, and Richardson (1973) determined that wheelslip is more important in causing compaction than is wheel loading in the surface soil layer.

Measuring Soil Compaction

A study of soil compaction requires some method of determining and evaluating the state of soil compactness. There are four parameters for defining compaction. The first parameter is void ratio which is defined as the ratio of the volume of the voids to the volume of solids in a given soil volume. The porosity of a soil is defined as the ratio of the volume of the voids to the total soil volume for a given soil volume. The third parameter, dry density, is defined as the weight of the oven dry solids per unit of volume. The apparent specific gravity of a soil is defined as the ratio of the unit dry weight of soil to the unit weight of water. A soil penetrometer or a sheargraph could also be used as indicators of soil compaction. The results from these instruments are quite variable depending on soil type and moisture making it hard to relate the data back to any standards.

Jumikis (1965) related that during a typical compression of a soil element, both the numerator and the denominator of the porosity decrease, whereas only the numerator of the void ratio decreases. This fact results in void ratio being more useful than porosity for studying soil compression. For a large number of samples, bulk density is easier to use than apparent specific gravity because it is easier to get a given volume of soil than to determine the volume of just the solid soil particles.

The soil volume changes caused by compaction can be shown by density measurements. Davies, Finney, and Richardson (1973) found that for unsaturated soils, 80-100 percent of the volume displaced by wheels in a soil tank was accounted for by the integrated increase in density in the total volume of soil affected. Field tests resulted in slightly different data. In one test with a single pass treatment, 17-43 percent of the measured sinkage was accounted for by the increased density to 15 centimeters depth of compacted soil. At another location, 47 percent was accounted for in the one treatment where density was measured. However, not all soil displacement caused by a driven wheel is taken up in reduced soil pore space; some soil may be displaced by plastic flow around the tire causing heave. In the above tests heave was negligible, so most of the additional sinkage could be accounted for by compaction below 15 centimeters and at the side of the track.

Stress and Pressure Under Tires

The capability of a vehicle to move on soil depends mainly on the magnitude and distribution of stresses developed at the wheel or track and soil interface. Elsammy and Ghobarah (1972) stated that these stresses are functions of wheel geometry, soil characteristics, and vehicle speed.

Transmission of stress in soil is through the points of contact of the granular media. Points of contact are randomly spaced in various directions. This randomness leads to stress being transmitted in directions determined by the points of contact and has been termed arching. Soehne (1957) found that the pressure stress-field under a tractor, trailer, or implement tire depends on the amount of load, the size of the contact area between the tire

and soil, the distribution of surface pressure within the contact area and the soil physical characteristics such as moisture content and density. Also, the compressive stress in the soil has a tendency to concentrate around the load axis. The tendency increases when soil becomes more plastic due to increased water content and if a less cohesive soil, for instance sand, is used for the test. Onafeko and Reece (1967) found that the assumption that the radial stresses beneath a rigid wheel are equal to the pressure beneath a strip footing of the same width at the same depth is not generally true. The peak value of the actual stress distribution is forward of bottom dead center and this moves further forward with increasing slip or skid. Davies, Finney, and Richardson (1973) found that the compressive effect of a tractor tire tends to concentrate below the center line of the track. McLeod, Reed, Johnson, and Gill (1966) concluded that the vertical soil stresses under a tire at a six-inch depth are at their maximum value under the center of the tire in Hiwassee Sandy Loam. This location was the same for both the 13.6X38 conventional tire as well as the 46X26-16R Terra-Tire. In each case, the soil pressure at the six-inch depth was greater than the tire inflation pressure.

Soil pressures being higher than the tire inflation pressure have been confirmed by other research and are generally attributed to tire carcass rigidity. The pressure distributions under tires are not uniform and pressures may run from two to five times the inflation pressure as found by Vanden Berg and Gill (1962). A very flexible, low ply, low inflation tire will cause the most uniform pressure distribution.

McLeod, Reed, Johnson, and Gill (1966) found that the highest penetration resistance generally resulted from the highest inflation treatment for

a particular tire. They also found that penetration resistances between the two tires of a dual unit were much less than those under one of the pair for the first few inches of depth. However, the readings under the tires and between them converged with increased depth until, at 10 to 14 inches deep, the between-tire resistance was generally highest. This leads to a discussion of the stress field or pressure bulb under a tractor tire.

Soehne (1969) calculated the equi-pressure curves under different width tires and under a dual wheel unit (Fig. 1). His curves show the general shape of the pressure bulb under tires and the overlap that occurs between dual wheels. However, he used different inflation pressures for each tire configuration so the pressure-depth effect of wider tires is not shown.

There are two possible ways of calculating the pressure at a certain depth in soil resulting from a given surface pressure. The first method is given by Jumikis (1965) and involves use of the Steinbrenner influence values. Table 1 shows the calculations for the pressure at depths from 1/2 to 5 feet under the center of loaded areas. The loaded areas are considered to be tractor tires. One tire is 30 inches wide and the other tire is 18 inches wide. The 30-inch tire has a 42-inch long tire print and the 18-inch tire makes a 31-inch long print. Certain assumptions were made for these calculations. The surface pressure was assumed to equal the tire pressure. Steinbrenner's theory also assumes a uniformly loaded area and a rectangular area. These assumptions are not completely accurate but the theory helps to give an indication of the way the pressure varies with depth for different loaded areas if the surface pressure is the same. Figure 2 shows a plot of the data from Table 1.

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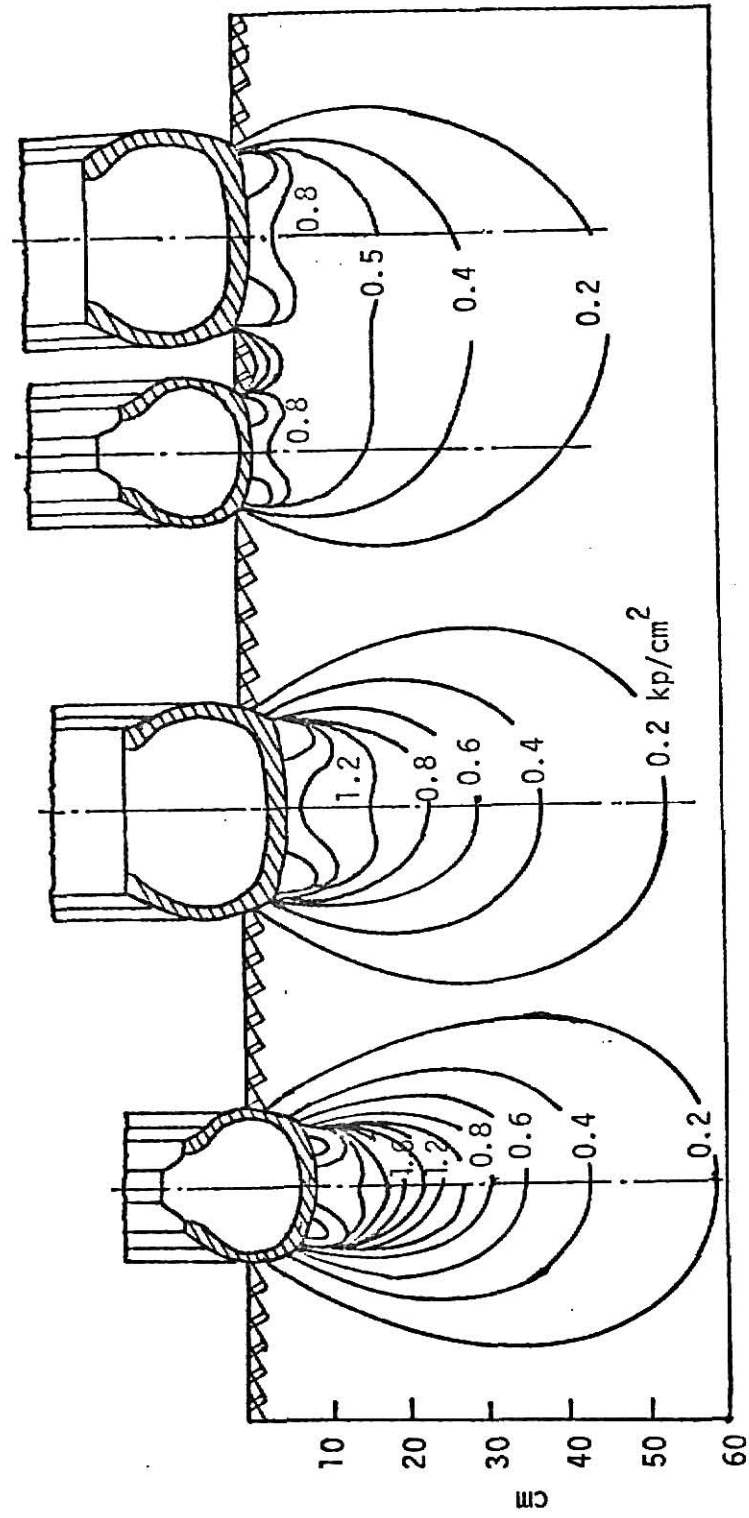


Figure 1. Calculated equal-pressure curves under tires with 710 Kp (1,565 lbs.) axle loads (left to right - narrow tires, wide tires and dual trailer tires at inflation pressures of 3, 1.5 and 0.75 Kp/cm² / 43, 2.5, and 11 psi² respectively). (Soehne 1969).

Table 1. Calculated Vertical Soil Stresses Under Tires Using Steinbrenner's Influence Values.

Tire Width (b) ft.	Depth (z) ft.	$\frac{z}{b}$	Steinbrenner's Influence Value $i_u = \frac{z}{\sigma_o} *$	Stress at Free Corner q_{za}	Midpoint Stress $\sigma_{zm} = 4\sigma_{za}$ psi
2.5	.5	.2	.249	3.486	13.944
	1.0	.4	.242	3.388	13.552
	1.5	.6	.230	3.220	12.880
	2.0	.8	.214	2.996	11.984
	2.5	1.0	.193	2.702	10.808
	3.0	1.2	.170	2.380	9.520
	3.5	1.4	.152	2.128	8.512
	4.0	1.6	.133	1.862	7.448
	4.5	1.8	.118	1.652	6.608
	5.0	2.0	.104	1.456	5.824
1.5	.5	.33	.246	3.444	13.776
	1.0	.67	.228	3.192	12.768
	1.5	1.00	.198	2.772	11.088
	2.0	1.33	.166	2.324	9.296
	2.5	1.67	.137	1.918	7.672
	3.0	2.00	.113	1.582	6.328
	3.5	2.33	.096	1.344	5.376
	4.0	2.67	.076	1.064	4.256
	4.5	3.00	.064	.896	3.584
	5.0	3.33	.058	.812	3.248

* σ_o = tire pressure = 14 psi

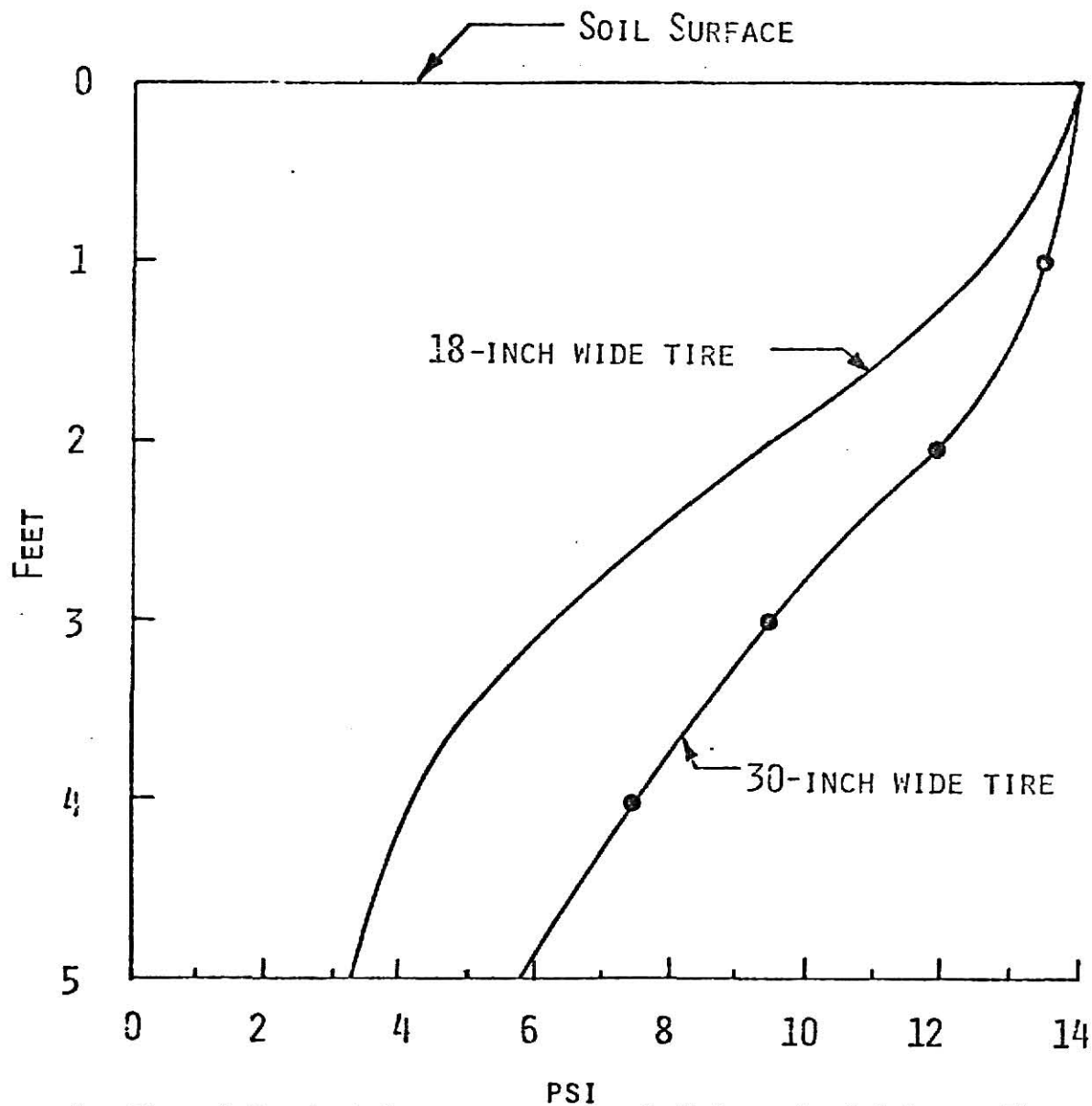


Figure 2. Plot of Vertical Stress versus Depth Under a Loaded Area. The loaded area is considered to be a tractor tire with surface pressure equal to inflation pressure equal to fourteen pounds per square inch. Tire width is taken into consideration by Steinbrenner's Influence Values.

The second method of calculation was taken from Compaction of Agricultural Soils and is given by Equation 1.

$$Q_z/Q_o = 0.3(b/z) \quad (1)$$

Q_z = imposed stress at depth z below the soil surface
for b/z less than 3.3

Q_o = imposed stress on the soil surface

b = smallest dimension of loaded area in inches

z = depth below surface in inches

The equation is approximately correct for depths greater than 0.3 times the smallest dimension of the loaded area for stresses within the elastic limits of a soil. The equation can be used for both circular and square flexible loads and is approximately correct for a purely elastic material where Q_z is measured beneath the center of the loaded area. Table 2 shows the calculations for a 30-inch and 18-inch wide loaded area with a surface pressure of 14 psi. Figure 3 shows a plot of the data from Table 2. The stress values are smaller than those calculated using Steinbrenner's method but they still demonstrate the depth effect caused by the wider loaded area. This depth effect just refers to the fact that a given pressure level in the soil is at a deeper depth under the wider loaded area.

Table 2. Calculated Vertical Soil Stresses Under Tires Using Equation 1.

Tire Width (b) ft	Depth (z) ft	$\frac{b}{z}$	Q_z
2.5	1.0	2.50	10.50
	1.5	1.67	7.00
	2.0	1.25	5.25
	2.5	1.00	4.20
	3.0	.83	3.50
	3.5	.71	3.00
	4.0	.63	2.63
	4.5	.56	2.33
	5.0	.50	2.10
1.5	.5	3.0	12.60
	1.0	1.5	6.30
	1.5	1.0	4.20
	2.0	.75	3.15
	2.5	.60	2.52
	3.0	.50	2.10
	3.5	.43	1.81
	4.0	.38	1.60
	4.5	.33	1.39
	5.0	.30	1.26

Q_0 = tire pressure = 14 psi

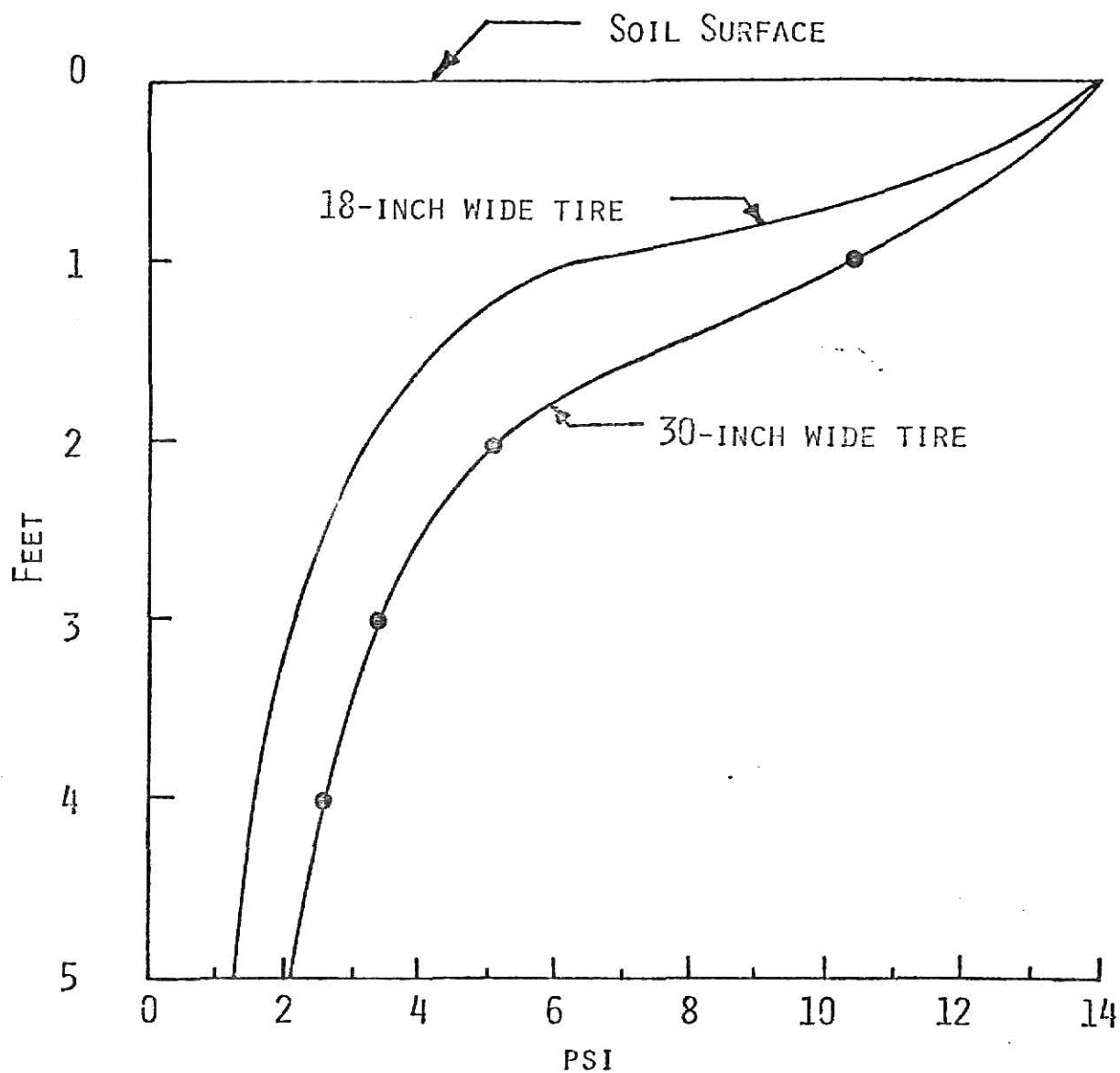


Figure 3. Plot of Vertical Stress versus Depth Under a Loaded Area. The loaded area is considered to be a tractor tire with surface pressure equal to fourteen pounds per square inch. The data was calculated using equation 1 of the thesis text on page 12.

INVESTIGATION

Objectives

The objectives of this research could be divided into initial and secondary objectives. The secondary objectives are secondary only because they were established after seeing the results of the initial research.

The initial objectives of the study were: (1) to determine if a compacted layer is being formed in the soil because of the depth effect of the pressure bulb, and (2) to test for any differences due to tire arrangement.

The secondary objectives were: (1) to check for a compacted layer in a different soil type, (2) to just test between different size tires, and (3) to test the effect of multiple passes.

Materials and Equipment

For the first part of the research, a plot of ground was selected which had never had a tire wider than eighteen inches on the soil. This was thought to be necessary to avoid any possible residual compaction effect from previous traffic of wider tires. Five tractor tire and weight arrangements were used in the tests and are shown in Figures 4 to 8:

1. A 14,200 pound two-wheel drive tractor on 18.4 x 34 single tires.
2. A 14,660 pound two-wheel drive tractor on 18.4 x 34 dual tires.
3. A 26,200 pound four-wheel drive tractor on 30.5 x 32 single tires.
4. A 19,020 pound four-wheel drive tractor on 30.5 x 32 single tires.
5. A 19,660 pound four-wheel drive tractor on 18.4 x 38 dual tires.

After the tests were run, it was necessary to obtain soil core samples for density measurements. Figure 9 shows an overall view of the probe truck borrowed from the Agronomy Department to obtain the samples. Figure 10 shows

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Figure 4. The 14,200 pound tractor on 18.4 x 34 single tires.



Figure 5. A 14,660 pound tractor on 18.4 x 34 dual tires.



Figure 6. A 26,200 pound tractor on 30.5 x 32 single tires.



Figure 7. A 19,020 pound tractor on 30.5 x 32 single tires.

a close-up of the core tube used to pull the samples. A trough and the miter box used for trimming the samples are shown in Figure 11.

The second part of the research was done on a plot of sandy soil which had had wide tires on it. For these tests, the tractors in Figures 4 and 6 were used again. The same probe was used for obtaining the soil samples. A standard 1/2 square inch area cone-type penetrometer was used for penetrometer test readings.

Method of Procedure

This research was divided into two parts. The second part of the research was planned after seeing the results of the first part. For the second part, the soil type was changed, fewer tractor tire arrangements were used, and multiple passes were used.

Part 1 of Research

A site was chosen with a uniform slope and consistent appearing soil type. The soil was a Ladysmith silty clay loam, zero to one percent slopes according to the Soil Survey of Harvey County, Kansas. Test plots were staked off 20 feet wide and 52 feet long on the site. Fifteen plots were staked off side by side thus allowing three replications of each tractor tire arrangement. The tractor tire arrangements were considered as different treatments. The particular position of a treatment plot within each replication was randomly selected by drawing number.

Replication A is shown in Figure 12. Also shown in Figure 12 are the locations of the sample holes in relation to the tracks and to the plot boundaries. The location of a sample refers to whether the sample was taken under a tire track, between the tracks of a set of duals, or outside of the tracks as a control. The location of the samples in relation to the tire tracks and plot boundaries is the same for the individual treatments in all



Figure 8. A 19,660 pound tractor on 18.4 x 38 dual tires.



Figure 9. Overall view of probe truck used for obtaining samples.



Figure 10. Closeup of probe.



Figure 11. Trough and miter box for trimming samples.

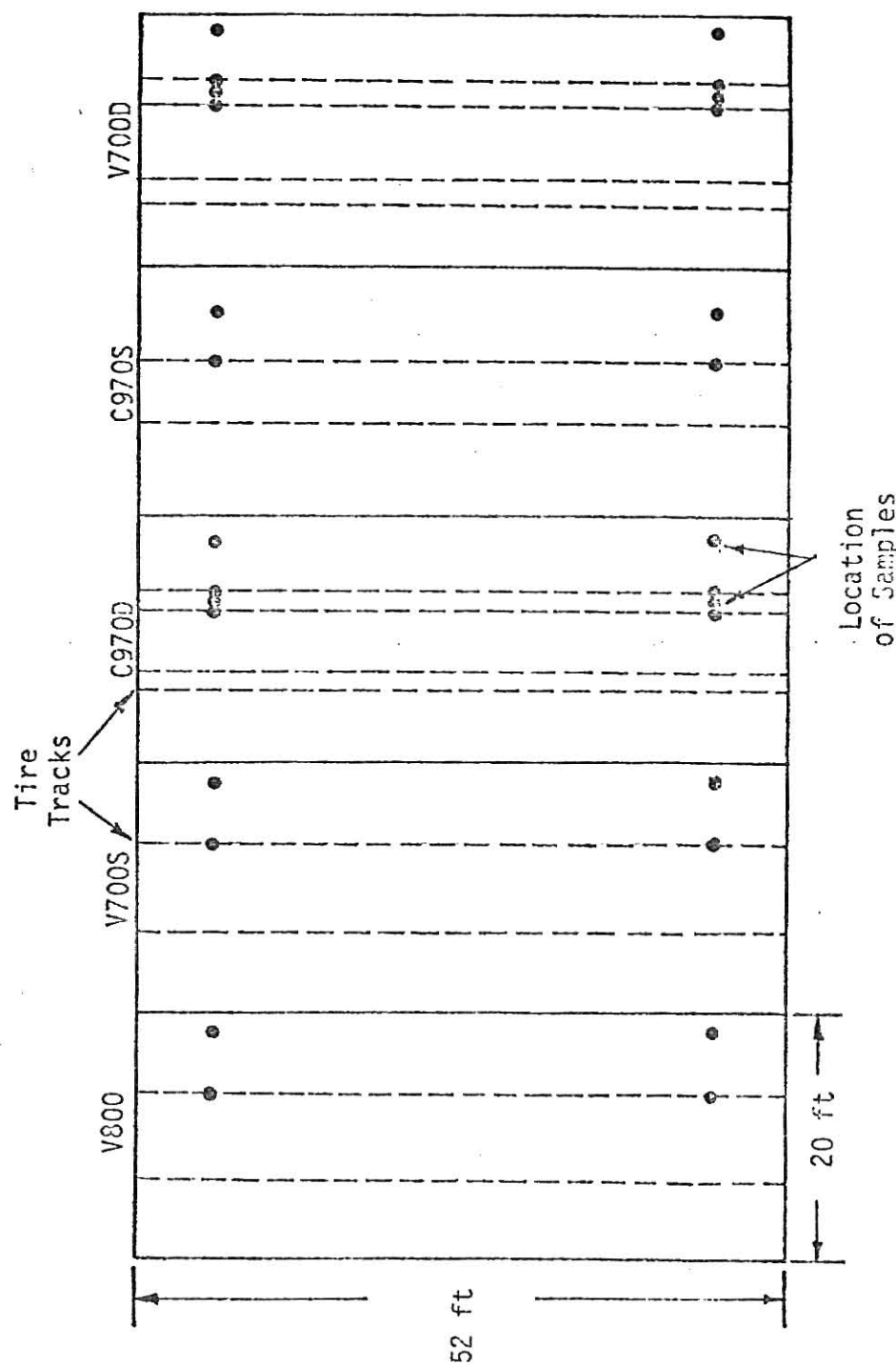


Figure 12. Replication A

V800 - Treatment I - 26,200 pound, four-wheel drive on 30.5 x 32 single tires.
 V700S - Treatment II - 19,020 pound, four-wheel drive on 30.5 x 32 single tires.
 V700D - Treatment III - 19,660 pound, four-wheel drive on 18.4 x 38 dual tires.
 C970D - Treatment IV - 14,660 pound, two-wheel drive on 18.4 x 34 dual tires.
 C970S - Treatment V - 14,200 pound, two-wheel drive on 18.4 x 34 single tires.

replications. The only difference in the replications is the position of the treatments within a replication.

The next step was actually running the tests. The tractors were run through the respective plots pulling a chisel so that the test conditions would be similar to actual field conditions. All the four-wheel drive tractors pulled the same chisel at the same depth. The two-wheel drive tractor pulled a smaller chisel but at the same depth for both treatments. All tractors were run at approximately 4.5 miles per hour. After the tractors were run, the location of the soil samples were marked with flags because the probe truck wasn't available for taking the soil samples at that time. Soil samples were taken for moisture content determination at the time the tests were run. The moisture content was compared with the optimum moisture content for compaction as determined by the Standard Proctor Density Test.

The test samples used for density determination were taken approximately three weeks after the tests had been run. Approximately 1/2 inch of rain fell between the time the tests were run and the time the samples were taken. The sample cores were pulled using the probe truck. These cores were laid out in the trough shown in Figure 11. A short section of the core was cut and trimmed at each foot level down to a depth of six feet. This gave six samples of a given volume from each core. The samples were placed in marked cans and the cans were sealed with tape. Samples were taken six feet in from each end of the plots for all treatments and replications. This gave two sets of samples for each location in each plot. For treatments I and II, a set of samples was taken from under the track in each plot and a set of samples was taken five feet to the side of the samples taken in the track. For treatments III and IV, a set of samples was taken under each tire track, between the tire tracks, and

four feet to the side of the outside tire track. A set of samples was taken under the tire track and four feet to the side for Treatment V.

The samples were then taken into the lab, weighed and dried. From the weights, the moisture content was determined using the gravimetric method. Wet and dry densities were calculated. Void ratio was calculated using the specific gravity determined from the samples. A grain size analysis by the hydrometer method was used to classify the soil.

Part 2 of Research

The second part of the research started with selection of a site on sandy soil due to sandy soil being more sensitive to compaction effects of short duration loads. The soil was a Farnum loam, one to three percent slopes according to the Soil Survey of Harvey County, Kansas. Each plot within a replication had a different treatment. The difference among the treatments was a difference in the number of passes made by each tractor through a plot. Only the tractors in Figures 4 and 6 were used for the second part of the research. Both tractors were run in each plot without any load. The position of the treatments within each replication was determined by a random drawing. The respective side of the plot where the different tractors ran was also randomly selected. Figure 13 shows the first replication.

For the sandy soils a set of samples consists of a sample from 15-inch depth and a sample from 30-inch depth. The three sets of samples running lengthwise in the center of each plot were taken before the tractors were run. One wheel of each tractor then ran over these sample locations as the tests were run. The tractors were run through each plot up to eight times in the same track. After the tractors were run, the other samples were taken from under the tracks. The samples were trimmed to the same size as in part 1

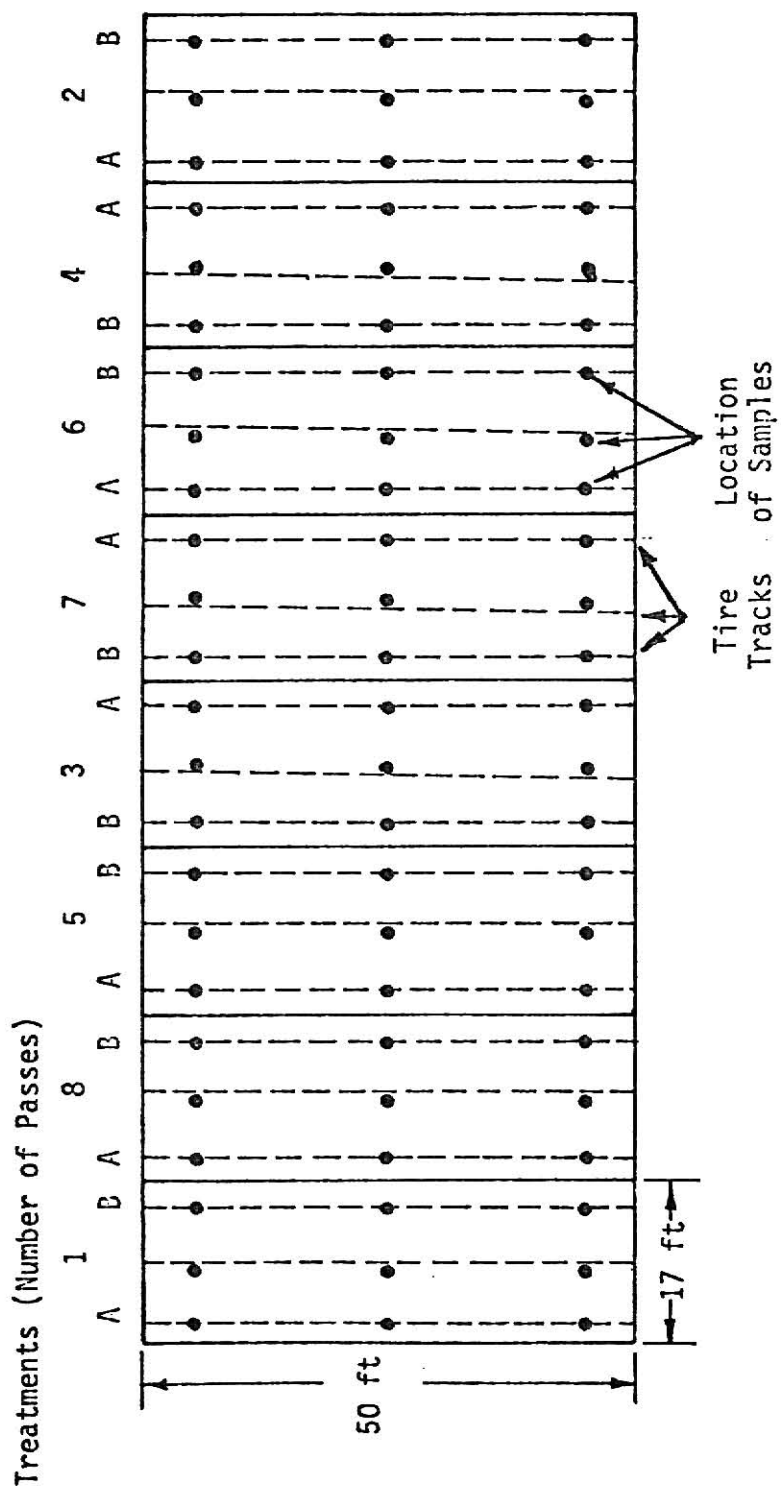


Figure 13. Replication 1
 Tractor A - V800
 Tractor B - C970S

of the research and sealed in cans. These samples were taken back to the lab and subjected to the same tests as in part 1 of the research.

After the samples were taken, penetrometer readings were taken near each sample location to see if there was any difference in the depth of the maximum penetrometer reading. Penetrometer readings were also taken at each sample location on the site of the first part of the research. These readings were taken to see if any differences could be detected using a different method especially after a winter of freezing and thawing. The loose surface soil caused by the chisel at the time of running the initial tests was removed so the penetrometer started on more solid soil.

RESULTS

Part 1 of Research

Soil Properties Tests

Identification of the soil used for the tests was an important factor in the results. A hydrometer analysis for grain size distribution was run on samples from the one-foot, three-foot, and six-foot depths (Table 3). The one-foot depth soil was on the dividing line between clay and silty clay. The other two depths of soil were classified as silty clay. This indicates that the soil gradation was fairly uniform through the depth tested.

The specific gravity test was run on the samples from the one-foot, three-foot, and six-foot depths. They were as follows:

(1) 1 foot	2.67
(2) 3 foot	2.73
(3) 6 foot	2.75

The Atterberg limits test were run on a three-foot depth sample and showed:

(1) Liquid Limit	46.4%
(2) Plastic Limit	22.8%
(3) Plasticity Index	23.6

These indicate a plastic soil. A standard Proctor density test was run on a sample from the two-foot depth. The maximum dry density obtained was 92.5 pounds per cubic foot at a moisture content of 23 percent. The Proctor density test is used to evaluate the maximum dry density which can be obtained with a reasonable amount of compaction energy. The test also gives the moisture content during compaction which will result in the maximum density for a given amount of compaction energy.

The soil moisture content was determined the day the tests were run as well as the day the samples were taken, hereafter referred to as W_a and W_b respectively, (Table 4). The degree of saturation was calculated using Equation 2 for nine samples for each depth and averaged (Table 4).

$$Se = Gw \quad (2)$$

where: S = degree of saturation

e = void ratio

G = specific gravity

w = water content, dry weight basis

Moisture contents W_a and W_b varied some at the different depths but the variations weren't too large except for the six-foot depth where the moisture content varied by four percent. The moisture content W_a figures are the averages of three samples at each depth. The moisture content W_b figures are the averages calculated from the 84 samples at each depth. Part of the variation between the moisture content W_a and W_b figures could be due to the differences in the number of samples in the averages. At several sample locations, it was impossible to pull a sample at the one-foot level because of soil disturbance from the chisel plow. Because the samples weren't complete for the one-foot depth, that depth was not included in the Aardvark statistical analysis.

The degree of saturation values were calculated using nine randomly selected samples from each depth. These degree of saturation values indicate that almost all of the soil pore space was filled with water. This would make water movement in the soil more difficult and in turn the soil would be harder to compact.

Table 3. Hydrometer analysis of clay soil (percent finer than given grain size).

Depth (ft)	Grain Size in Millimeters			*Classification
	0.05	0.01	0.005	
1	91	60	50	Clay or Silty Clay
3	89	58	49	Silty Clay
6	83	53	46	Silty Clay

*Classification by the triangular classification chart.

Table 4. Moisture contents and degree of saturation at different depths in the clay soil.

Depth (ft)	*Moisture Content W_a (percent)	Moisture Content W_b (percent)	Degree of Saturation (percent)
1	29.15	-	88.2
2	27.90	28.29	92.3
3	25.16	24.33	93.2
4	26.52	24.55	94.0
5	25.39	25.04	94.3
6	27.94	23.94	87.1

* W_a = moisture content the day the tests were run.

W_b = moisture content the day the samples were taken.

Results from Compaction Tests

All of the four-wheel drive tractors used a tire inflation pressure of 14 pounds per square inch. The two-wheel drive tractor had an inflation pressure of 16 pounds per square inch in the single tires and the inside dual and a pressure of 13 pounds per square inch in the outside dual. The tire print areas for each tractor were measured the day of the tests and the apparent soil pressure calculated (Table 5). The tire print area was calculated using Equation 3.

$$A = 0.78bl \quad (3)$$

where: A = area in square inches

b = width of the tire print in inches

l = length of the tire print in inches

None of the apparent surface pressures were as high as the tire inflation pressures. This would probably be due to the effect of the lugs, other tire characteristics, and possible inaccuracies in measurement of the areas. The areas were measured with the tractors stationary. Also, four of the five treatments resulted in apparent pressures within a range of two pounds per square inch.

After the laboratory tests on the samples were performed, a statistical analysis by the Aardvark program was run on the data. The Aardvark program was run twice using two different models. The first model calculated the means for the different replications, treatments, positions, depths, and the interactions among these variables. For the dual-wheel treatments, the samples under each tire track were averaged together before the statistical analysis. The dry density, void ratio, and moisture content were the parameters used in the analysis. The dry density was of primary interest. The void ratio would show the same result because it was calculated from the same

weights as the dry density. The moisture content was included to help explain any differences that might be found.

The density means for the treatments, depths, and position are shown in Table 6. The moisture content means for the different depths are also shown. The important figures to compare in Table 6 are the densities in position 1 versus position 2. The greatest difference between position densities was 2.06 pounds per cubic foot. In ten of the twenty-five cases the density was higher where the tractors didn't run than where they did run. Another important thing shown is that at the two-foot depth the densities range between 90.72 and 93.30 pounds per cubic foot. For the three-foot to six-foot depths the densities ranged from 96.92 to 101.04 pounds per cubic foot. The moisture content mean for the two-foot depth was 28.29 percent and for the three to six-foot depths ranged from 23.94 to 25.04 percent. The density data is shown graphically in Figures 14 and 15.

The F and α values (Table 7) show the statistical significance of the differences in density means. The F values are a test of the equality of two variances. The α values give the chance of being wrong when the two variances are said to be unequal. In other words, an α value of 0.05 means that five percent of the time when two variances are said to be unequal, they are in actuality equal. For significance, α must be less than 0.05. Using an α of 0.05 to define the level of significance, there is only one source of variation which led to a significant difference in dry density or moisture content. The significant source of variation was depth. The reason depth was significant was the increase in dry density and decrease in moisture content between the two and three-foot depths for all treatments and both positions. The increase in dry density would probably be explained by a change in horizons at that

Table 5. Tractor tire print areas and apparent pressures.

Treatment		b (in.)	l (in.)	A (in. ²)	Weight (lbs)	Apparent Surface Pressure (psi)
I	V800	29.5	42	966	8650	9.0
II	V700S	30	32	749	6120	8.2
III	V700D Inside	18	31	858	6020	7.0
	Outside	17.5	31			
IV	C970D Inside	17	24	627	5400	8.6
	Outside	16.5	24			
V	C970S	18.5	27	390	5170	13.3

Table 6. Moisture content and dry density* means for treatment, depth, and position for the clay samples.

Depth (ft)	Moisture Content (%)	Treatment				
		I-V800	II-V700S	III-V700D	IV-C970D	V-C970S
2	28.29	92.38 (92.32)	92.41 (93.05)	93.14 (93.30)	91.79 (90.72)	92.90 (92.46)
3	24.33	100.28 (99.58)	98.82 (100.41)	99.04 (100.01)	98.98 (96.92)	99.21 (98.29)
4	24.55	99.42 (99.10)	100.15 (100.40)	100.24 (100.05)	99.33 (98.46)	100.13 (100.49)
5	25.04	98.69 (97.87)	99.00 (99.48)	98.59 (98.09)	99.05 (99.24)	99.76 (99.21)
6	23.94	99.19 (99.16)	101.04 (99.60)	99.55 (98.62)	98.71 (99.13)	98.78 (100.33)

*Pounds per cubic foot

Position 1 was a set of samples under the tire track.

(Position 2) was a set of samples outside the tire track.

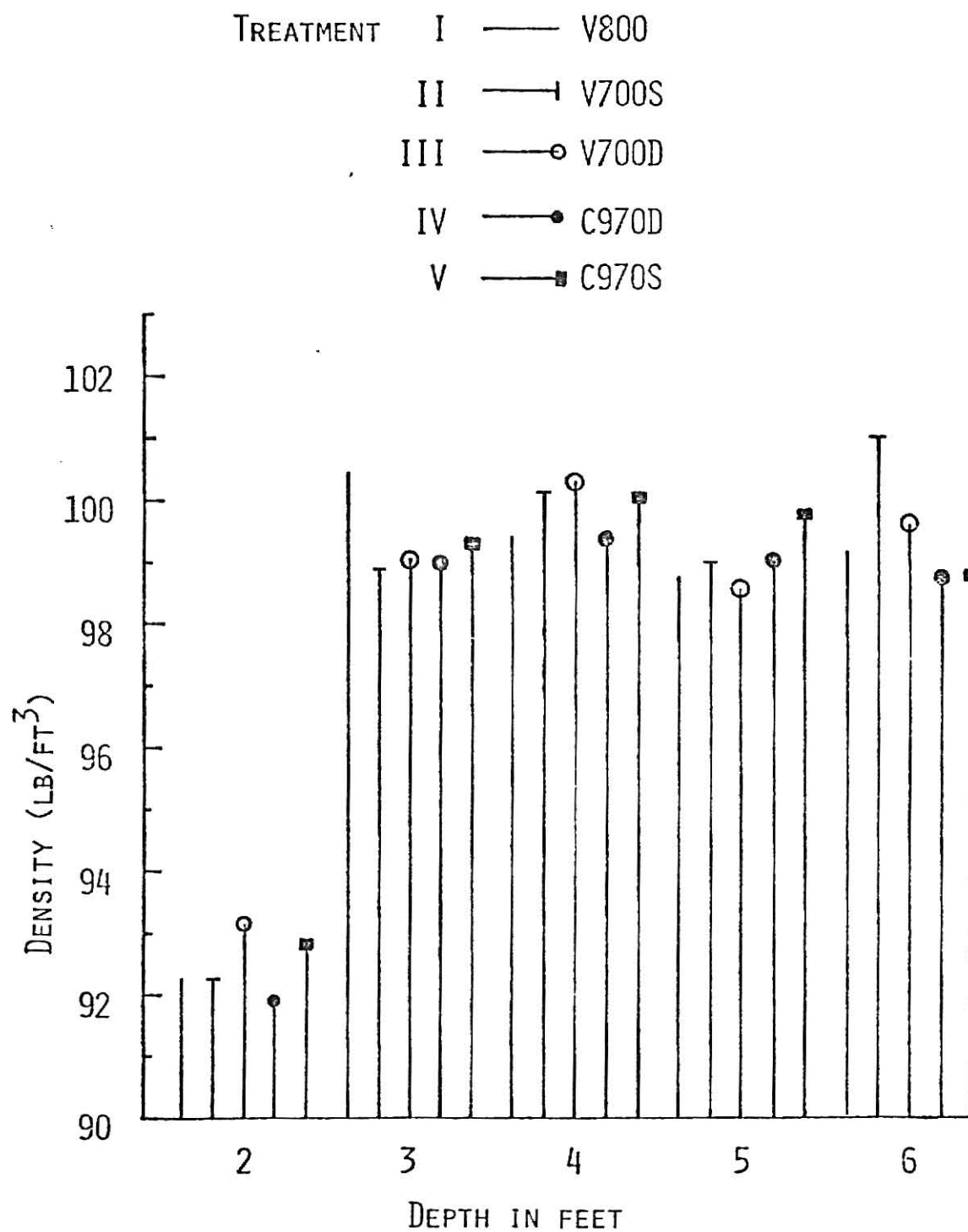


Figure 14. Density Means for Treatment versus Depth Under the Track.

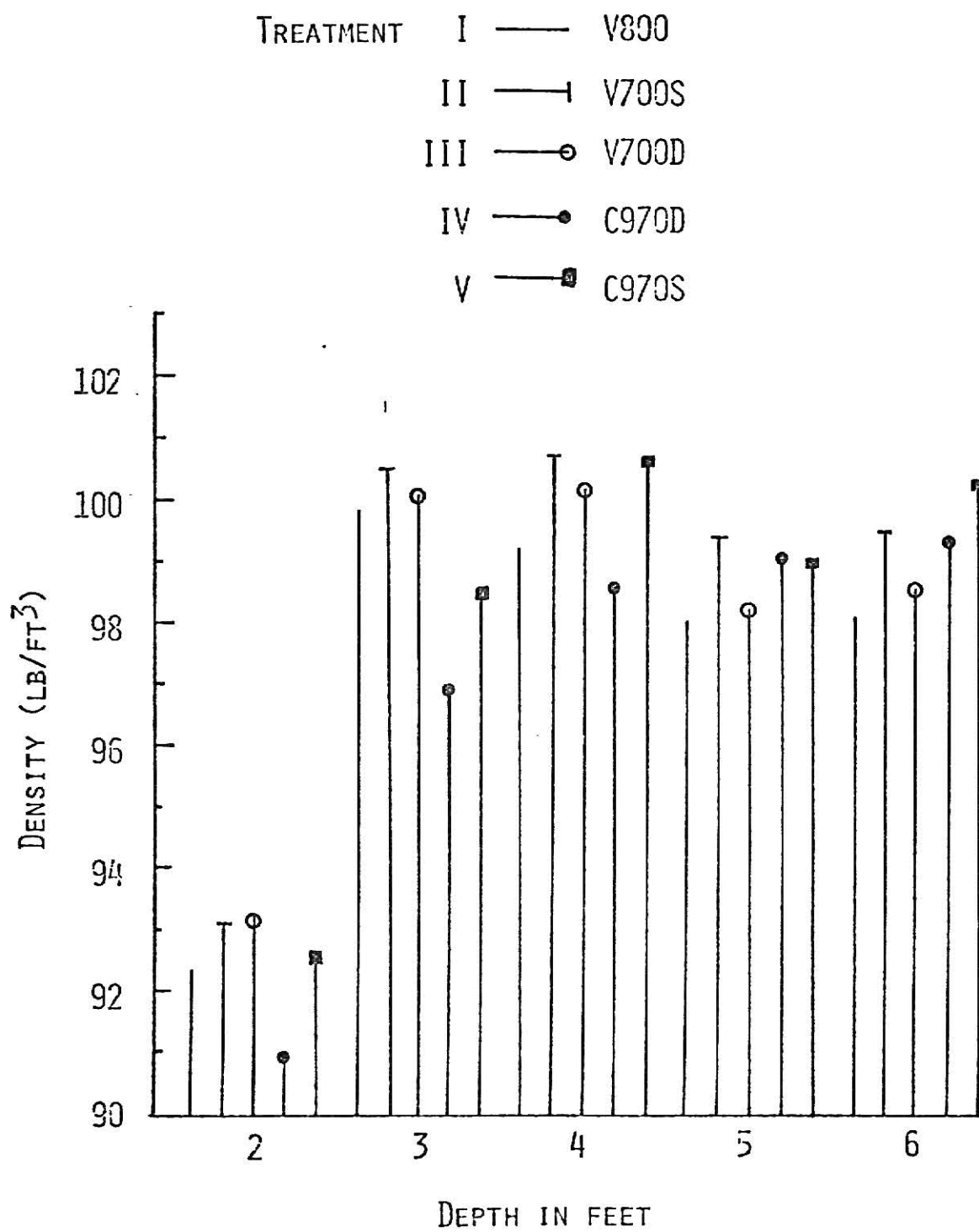


Figure 15. Density Means for Treatment versus Depth Outside of Track.

depth. The change in moisture content between the two-foot and three-foot depths could also have some effect on dry density if the clay is expansive.

The second model used in the Aardvark program was based on the difference between the dry density means under a track and the corresponding dry density means outside the track. It was thought that this model might point out some significant difference not apparent from the other model.

The density difference means (Table 8) are shown in a graphical form in Figure 16. This shows that many of these density differences are small and several are negative. One thing to note here is that treatment I was the only treatment which had all positive density differences. Also, 15 of the 25 treatment-depth combinations had positive differences which indicates possible compaction. However the F and α values (Table 9) don't show any significant differences due to any source of variation. The treatment was the source of variation which was the closest to significance. The significance would be between treatment II with a density difference mean of -0.306 pounds per cubic foot and treatment IV with a density difference mean of 0.679 pounds per cubic foot.

The last tests run on the clay soil were penetrometer tests. The maximum penetrometer reading and the depth of that reading were recorded for analysis (Table 10). The important thing in this analysis was to compare the maximum pressure readings for the two positions within each treatment. Three of the five treatments showed larger maximum penetrometer readings outside the track than under the track. This does not indicate compaction for those treatments. Treatment II had lower maximum penetrometer readings for both positions than any other treatment, even though the penetrometer reading

Table 7. F and α values for the first statistical analysis of the clay samples.

Source of Variation	Dry Density		Moisture Content	
	F	α	F	α
Replication	1.91	0.21	1.76	0.23
Treatment	1.70	0.24	0.88	0.51
Position	0.47	0.49	0.30	0.59
Depth	122.59	0.00	69.25	0.00
Interactions:				
Treatment & Position	0.46	0.77	0.15	0.96
Treatment & Depth	0.77	0.72	0.71	0.78
Position & Depth	0.01	1.00	0.23	0.92
Treatment, Position & Depth	0.61	0.86	0.52	0.92

Table 8. Dry density difference* means for treatments and depths of clay samples.

Depth (ft)	Treatment				
	I-V800	II-V700S	III-V700D	IV-C970D	V-C970S
2	0.06	-0.64	- 0.16	1.07	0.44
3	0.70	-1.59	- 0.98	2.06	0.92
4	0.31	-0.25	0.19	0.87	- 0.37
5	0.82	-0.48	0.50	- 0.19	0.55
6	0.04	1.44	0.93	- 0.42	- 1.55

*Dry density in pounds per cubic foot.

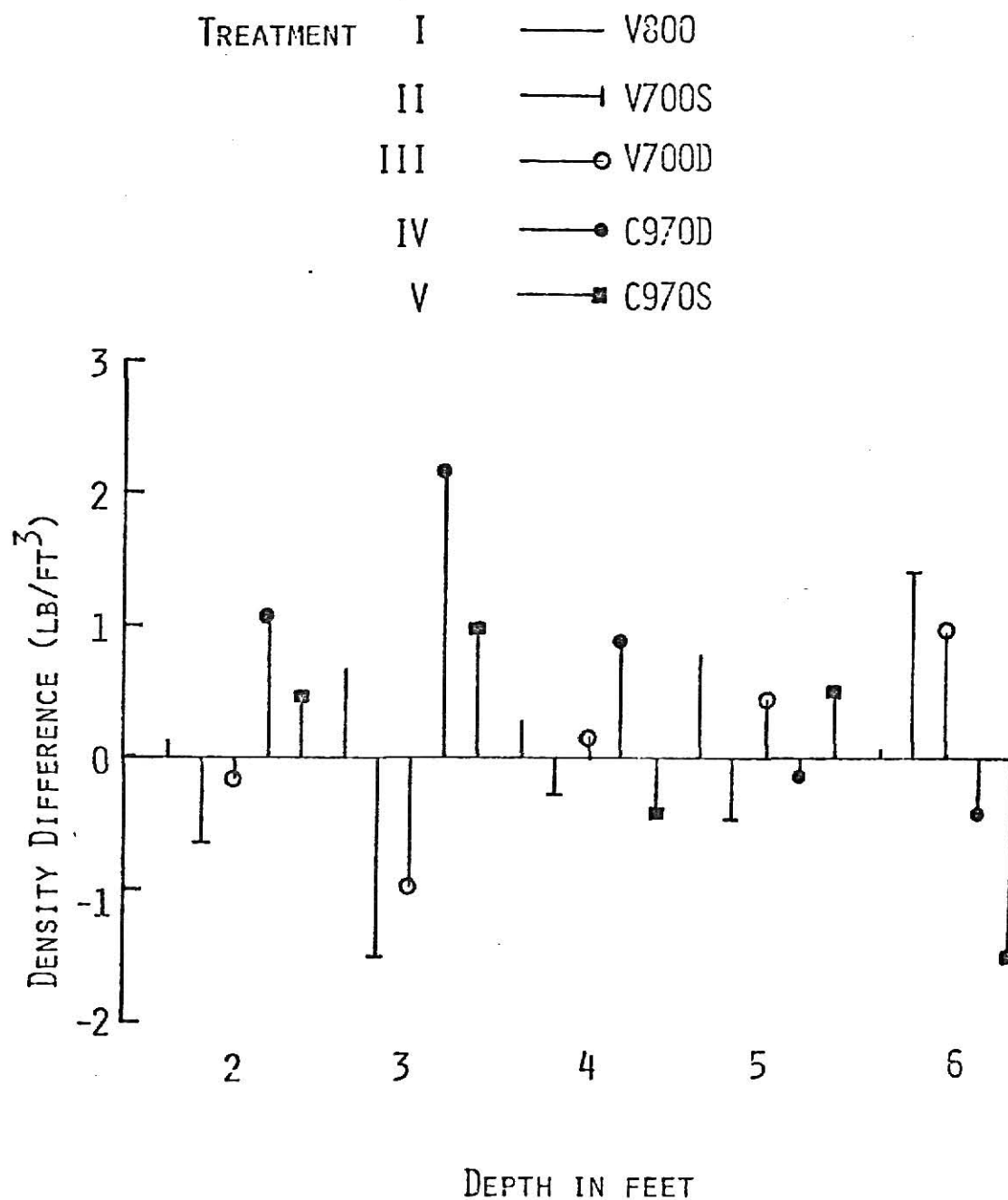


Figure 16. Differences in Density Means of Treatment versus Depth.
 Difference = Density Under Track - Density Outside of Track.

Table 9. F and α values for second statistical analysis of the clay samples.

Source of Variation	Dry Density	
	F	α
Replication	0.68	0.53
Treatment	2.56	0.12
Depth	0.02	1.00
Interaction:		
Treatment & Depth	1.13	0.36

Table 10. Means of maximum penetrometer readings and the depth of these readings for the clay soil.

Position *	Treatment				
	I-V800	II-V700S	III-V700D	IV-C970D	V-C970S
Pressure (psi)					
Position 1	231.7	201.0	230.0	224.7	233.3
Position 2	218.3	191.7	250.0	232.7	235.0
Depth (in.)					
Position 1	14.5	13.5	13.4	14.9	14.0
Position 2	15.5	11.3	13.0	15.7	10.7

*Position 1 is under the tire track.
 Position 2 is outside the tire track.

was higher in position 1 than position 2. Since the penetrometer readings for both positions were lower, it was probably due to a soil condition. The results of the statistical analysis (Table 11) show that the only significant source of variation is the replication. The replication is only significant for the maximum penetrometer readings. This means that the means of all the penetrometer readings within each replication are not equal.

Part 2 of Research

Soil Properties Tests

The second part of the research started with a sieve and hydrometer analysis of a sandy soil sample. The analysis was run for a 15-inch and a 30-inch deep sample (Table 12). Both depths classified as sand.

The specific gravity and standard Proctor density tests were run on the 15 and 30-inch depth samples (Table 13). The samples had almost the same specific gravity and did compact to a higher dry density than the clay samples. Atterberg limits tests weren't run because the sand wouldn't be plastic.

Results from Compaction Tests

Only two tractors were used in this part of the research. One two-wheel drive on 18-inch wide tires and one four-wheel drive on 30-inch wide tires. The tire print areas were measured and the apparent surface pressure calculated (Table 14). Again, neither of the apparent surface pressures were as high as the tire inflation pressures. The apparent surface pressures were slightly higher than for the clay soil.

Laboratory tests were run on the samples. The results from the laboratory tests were then statistically analyzed by the Aardvark program. The

Table 11. F and α values for the penetrometer tests on the clay soil.

Source of Variation	Maximum Penetrometer Reading		Depth of Maximum Reading	
	F	α	F	α
Replication	5.30	0.03	0.43	0.67
Treatment	3.48	0.06	1.35	0.33
Position	0.03	0.87	1.27	0.29
Interaction:				
Treatment & Position	0.56	0.70	1.30	0.33

Table 12. Sieve and hydrometer analysis for the sandy soil (percent finer than given grain size).

Depth (in.)	Grain Size in Millimeters			*Classification
	2.0	0.05	0.005	
15	97	15	5	Sand
30	96	5	2	Sand

*Classification by the triangular classification chart.

Table 13. Specific gravity and Proctor density test results for the sandy soil.

Depth (in.)	Specific Gravity	Maximum Dry Density (lbs/cu ft)	Moisture Content for Maximum Dry Density (%)
15	2.61	115	12
30	2.62	119	11

Table 14. Tire print areas and apparent surface pressure for tractors used on sandy soil tests.

Tire Width (in.)	Tire Pressure (psi)	Width b (in.)	Length l (in.)	Area* (in. ²)	Weight (lbs)	Apparent Surface Pressure (psi)
18	14	19	24	356	5170	14.5
30	16	29.5	38	874	8650	9.9

*A $\approx$ 0.78bl

program was run twice, once for the 15-inch depth data and once for the 30-inch depth data. The model was the same for both runs. The model used the dry density, void ratio, and moisture content as the input test parameters. The dry density and moisture content were of primary interest. The actual means for the treatments and tire widths were calculated (Table 15) as well as the means of the difference between the samples under a track and the corresponding control samples (Table 16). The treatments in this research were the number of passes over a certain track.

There is no trend of increasing density with increasing number of passes for either tire size or depth. There is no discernable difference in density due to tire size or depth under the track. The control densities do appear higher for the 30-inch depth than for the 15-inch depth. This indicates the possibility of some compaction taking place even though the statistical analysis didn't show the difference as being significant. The samples pulled for testing under the tracks did seem to hold together better and were less fragile than the control samples. This was a soil characteristic which was noticeable as the samples were taken. The only pattern in the moisture contents means was that the 30-inch depth samples were drier than the 15-inch depth samples. The moisture content at the 15-inch depth was slightly above optimum for compaction and at the 30-inch depth was below optimum. The density difference means did show a trend in that all but one of the differences were positive for the 15-inch depth. Four of the differences are negative at the 30-inch depth. In general, the differences are larger in magnitude at the 15-inch depth than the 30-inch depth.

Table 15. Dry density and moisture content means for the sand samples.

Treatment (Number of Passes)	Depth (in.)	Dry Density (lbs/cu ft)		Moisture Content (%)		
		18-inch wide tire	30-inch wide tire	Control	18-inch wide tire	30-inch wide tire
1	15	112.87	112.54	110.18	12.09	13.41
2		111.86	111.57	111.52	12.06	12.53
3		116.51	112.48	108.37	12.05	13.08
4		112.08	115.01	108.64	13.19	10.75
5		112.57	111.93	109.72	12.55	13.26
6		112.34	113.20	107.85	12.74	12.76
7		113.98	111.29	105.83	12.46	13.04
8		114.62	114.10	114.42	11.42	11.23
1	30	115.20	112.48	113.32	8.84	8.53
2		112.25	113.02	111.61	8.64	7.89
3		111.56	111.25	111.46	8.19	7.70
4		112.23	112.97	111.45	8.27	8.15
5		112.27	111.75	111.58	9.98	9.68
6		112.87	112.92	111.41	8.61	8.84
7		114.29	114.46	111.62	9.26	9.02
8		114.14	112.19	115.31	8.61	10.58
						8.95
						8.10
						8.12
						9.22
						10.14
						8.95
						9.14
						8.62

Table 16. Density difference* means for the sandy soil samples.

Depth (in.)	Treatment	Density Difference (lbs/ft ³)	
		18-inch wide tire	30-inch wide tire
15	1	2.68	2.36
	2	0.33	0.05
	3	8.13	4.10
	4	3.43	6.36
	5	2.85	2.21
	6	4.49	5.35
	7	8.14	5.45
	8	0.20	-0.32
30	1	1.88	-0.84
	2	0.64	1.42
	3	0.10	-0.21
	4	0.78	1.52
	5	0.69	0.17
	6	1.47	1.51
	7	2.67	2.84
	8	-1.17	-3.12

*Density under tracks - density of controls = density difference.

The F and α values (Table 17) of the dry density and moisture content means show some significant sources of variation. The significant sources of variation were location for both dry density and moisture content and replication for dry density. The location being significant means that the plots showed different results on one side from the other side for the same treatment. The replication being significant means that the results of one replication weren't repeated in the other replication. Both the above statements indicate faults in the research due to site nonuniformities rather than effects of treatment or tire size.

The F and α values of the density differences are shown in Table 18. The replication and location were almost significant for the 15-inch depth. The location and interaction between treatment and location were significant at the 30-inch depth. However, this doesn't show anything important in terms of treatment or tire size.

The maximum penetrometer readings and the depth of the maximum readings were recorded and then analyzed. The means of the penetrometer readings and depths (Table 19) don't really show any trends. The penetrometer reading difference means and depth difference means were calculated and analyzed (Table 20). The only trends were that the penetrometer reading differences appeared higher for the 18-inch tire than for the 30-inch tire and all but four of the depth differences were negative. The mean of the maximum penetrometer reading differences for the 18-inch wide tire was 19.8 pounds per square inch and for the 30-inch wide tire was 9.0 pounds per square inch. This possibly indicates greater compaction under the 18-inch wide tire which also had the highest apparent surface pressure. The depth

Table 17. F and α values for the statistical analysis of the sandy samples.

Depth (in.)	Source of Variation	Dry Density		Moisture Content	
		F	α	F	α
15	Replication	29.41	0.001	2.20	0.18
	Treatment	0.93	0.54	0.49	0.82
	Tire Size	0.74	0.41	0.15	0.71
	Location	8.50	0.001	4.33	0.02
	Interactions:				
	Treatment & Tire Size	1.19	0.40	0.76	0.63
	Treatment & Location	0.30	0.99	0.56	0.87
	Tire Size & Location	0.01	0.99	0.68	0.51
	Treatment, Tire Size & Location	0.90	0.57	0.86	0.60
30	Replication	0.34	0.58	0.69	0.43
	Treatment	2.66	0.11	0.93	0.54
	Tire Size	0.60	0.46	0.00	1.00
	Location	1.97	0.16	0.46	0.64
	Interactions:				
	Treatment & Tire Size	0.53	0.79	1.08	0.45
	Treatment & Location	1.44	0.19	1.26	0.28
	Tire Size & Location	0.58	0.57	0.90	0.42
	Treatment, Tire Size & Location	1.05	0.43	0.83	0.64

Table 18. F and α values for the statistical analysis of the sandy samples.

Source of Variation	Density Difference Fifteen inch depth		Density Difference Thirty inch depth	
	F	α	F	α
Replication	5.10	0.06	0.49	0.51
Treatment	0.96	0.52	0.47	0.83
Tire Size	0.74	0.41	0.60	0.46
Location	2.82	0.07	4.20	0.02
Interactions:				
Treatment & Tire Size	1.19	0.40	0.53	0.79
Treatment & Location	1.61	0.13	4.13	0.00
Tire Size & Location	0.01	1.00	0.48	0.62
Treatment, Tire Size & Location	0.45	0.94	0.88	0.59

Table 19. Means of maximum penetrometer readings and depth of maximum readings for sandy soil.

Treatment	18-inch wide tire		30-inch wide tire	
	Maximum Penetrometer Reading (psi)	Depth of Maximum Reading (in.)	Maximum Penetrometer Reading (psi)	Depth of Maximum Reading (in.)
1	296.7	14.2	286.7	13.3
2	300.0	14.8	283.3	12.8
3	293.3	14.8	275.0	13.3
4	286.7	13.7	270.0	16.3
5	276.7	13.0	293.3	13.3
6	273.3	12.3	263.3	16.3
7	290.0	15.3	265.0	14.0
8	290.0	12.7	283.3	11.3

Table 20. Means of maximum penetrometer reading differences and depth differences* for sandy soil.

Treatment	18-inch wide tire		30-inch wide tire	
	Penetrometer Reading Differences (psi)	Depth Differences (in.)	Penetrometer Reading Differences (psi)	Depth Differences (in.)
1	50.0	0.5	40.0	-0.3
2	16.7	-0.5	0.0	-2.5
3	3.3	-1.3	15.0	-2.8
4	36.7	-4.2	20.0	-1.5
5	-23.3	-3.0	-6.7	-2.7
6	21.7	-3.5	11.7	0.5
7	43.3	1.3	18.3	0.0
8	10.0	-2.3	3.3	-3.7

*The differences were calculated by subtracting the values in the control locations from their corresponding values in the tracks.

differences being negative indicates that the maximum penetrometer reading was reached at a shallower depth under the track than in the control.

The F and α values for the maximum penetrometer readings and the depths (Table 21) showed only one significant source of variation. The location was significant for the depth. The tire size was almost significant for the penetrometer readings. The location and the interaction between the treatment and location were significant for the penetrometer reading differences. Again, none of the significant sources of variation were of importance in terms of treatment or tire size.

Considering the magnitudes of the calculated vertical soil stress in Tables 1 and 2, it seems reasonable that possibly no compaction could be detected especially at the greater depths. These soil pressures are not large when compared to the pressures a soil is capable of supporting as demonstrated by loaded trucks moving through fields. The loads from the tractors were also very short duration which probably wouldn't cause any water movement. Most compaction would be in the form of soil particle rearrangement.

The porosity of some samples was calculated (Table 22) using Equation 4.

$$n = \frac{e}{1 + e} \quad (4)$$

where: n = porosity

e = void ratio

These porosities were calculated to determine whether any of the densities found were large or small enough to affect plant growth. The optimum porosity is 40-50 percent as stated on page 3. Maximum and minimum density means for each soil type and the corresponding void ratios were used in the calculations. All of the porosities calculated for the clay soil were in the

Table 21. F and α values for the penetrometer readings, depths, penetrometer reading differences, and depth differences on the sandy soil.

Source of Variation	Maximum Penetrometer Readings		Depth of Maximum Readings		Penetrometer Reading Differences		Depth Differences	
	F	α	F	α	F	α	F	α
Replication	0.02	0.89	0.14	0.72	0.01	0.92	0.08	0.78
Treatment	0.95	0.53	1.45	0.32	0.52	0.80	0.44	0.85
Tire Size	4.32	0.07	0.00	1.00	4.32	0.07	0.00	1.00
Location	0.45	0.64	6.67	0.00	7.68	0.00	2.56	0.09
Interactions:								
Treatment & Tire Size	0.72	0.66	1.22	0.39	0.72	0.66	1.22	0.39
Treatment & Location	0.36	0.98	0.50	0.92	3.80	0.00	1.19	0.33
Tire Size & Location	0.03	0.97	0.57	0.57	0.05	0.95	0.30	0.74
Treatment, Tire Size & Location	0.60	0.84	1.31	0.25	1.02	0.45	0.69	0.76

Table 22. Porosity calculation for both soil types.

Soil Type	Depth (ft)	Density (lbs /ft ³)	Void Ratio	Porosity
Clay	2	93.30	0.787	0.440
		90.72	0.837	0.456
	4	100.40	0.696	0.410
		98.46	0.730	0.422
	6	101.04	0.699	0.411
		98.62	0.740	0.425
Sand	1.25	116.51	0.397	0.284
		105.83	0.538	0.350
	2.5	115.31	0.420	0.296
		111.25	0.471	0.320

optimum range but none of the sand soil samples were in the optimum range. To be in the optimum porosity range the void ratio must be between 0.667 and 1.0. The minimum dry density used for the sandy soil was from a control sample so the natural soil state is not in the optimum porosity range. This is probably partially compensated for by the larger pores in a sandy soil.

DISCUSSION

The problem of soil compaction due to vehicular traffic is one which may change as the vehicle types and traction devices change. The emphasis in this research was to test for a depth effect of soil compaction due to the increased size of the pressure bulb under the new wider tires.

The clay soil used for testing was found to be denser in situ than in the standard Proctor density test. This would make it extremely difficult to further compact this soil without expending a great amount of compaction energy. The soil was also almost saturated which would make water movement and further compaction more difficult. No soil compaction was detectable due to any tire arrangement at any depth. A difference in soil compactness was detected at the two to three-foot depth but it wasn't due to the tests. However, this did cause more confidence in the sampling method.

The sandy soil was not as dense in situ as could be obtained with the standard Proctor density test. The moisture content was fairly close to optimum for compaction. No soil compaction was detectable due to either tire size or number of passes. There was a difference in soil compactness in different areas of the plots. This again gave more confidence in the sampling method because a difference was found.

Compaction wasn't detected by either density measurements or penetrometer readings. No depth effect of compaction due to wide tires was detectable possibly due to the magnitude of the surface pressures applied or possibly due to the sensitivity of measurement.

CONCLUSIONS

Results from this study indicate:

1. Soil compaction due to vehicular traffic was not detectable with the methods used in this study on either soil.
2. Differences in compactness were detectable with the methods used.
The differences were due to nonuniformities in the plots rather than due to treatments used.
3. There was no apparent depth effect of compaction due to tire width.

SUGGESTIONS FOR FUTURE RESEARCH

Further research in this area could be done in the lab where the soil conditions and properties could be controlled. This might help in setting up further field tests. Other field tests could be run using fewer treatments and possibly more samples could be taken from each treatment. A non-destructive type of density measurement would also be useful as this would allow multiple passes over the same soil and eliminate the soil variation. The nondestructive measurement would also allow returning after time had passed to see if any detectable compaction was permanent.

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APPENDIX

Appendix A: Computer program for calculation of densities, void ratio, and moisture content from raw data.

```

Write (6,100)
100 Format ('1', 2X, 'Sample', 5X, 'Wet', 7X, 'Dry', 7X, 'Can', 6X, 'Water',
15X, 'Soil', 7X, 'Wet', 7X, 'Dry', 5X, 'Solids', 5X, 'Void', 6X, 'Void',
25X, 'Water')

Write (6,101)
101 Format (' ', 11X, 'Weight', 4X, 'Weight', 4X, 'Weight', 4X, 'Weight',
14X, 'Weight', 4X, 'Density', 3X, 'Density', 3X, 'Volume', 4X, 'Volume',
24X, 'Ratio', 4X, 'Content')

Write (6,102)
102 Format (' ', 11X, '(Lbs.)', 4X, '(Lbs.)', 4X, '(Lbs.)', 4X, '(Lbs.)',
14X, '(Lbs.)', 2X, '(Lbs/Cuft) (Lbs/Cuft)', 2X, '(Cuft)', 4X, '(Cuft)')

Write (6,103)
103 Format (' ', ' ')

CC = .0022046226
V = .00315
DO 400 I = 1,504

Read, X, WW, DW, CW

If (X) 200, 201, 202

200 SPG = 2.670

Go to 300

201 SPG = 2.728

Go to 300

202 SPG = 2.749

Go to 300

```

```
300 WW = WW*CC
    DW = DW*CC
    CW = CW*CC
    WWW = WW - DW
    SW = DW-CW
    WD = (WW-CW)/V
    DD = SW/V
    SV = SW/(SPG*62.4)
    VV = V-SV
    VR = VV/SV
    WC = (WWW/SW)*100.0
400 Write (6,500) I, WW, DW, CW, WWW, SW, WD, DD, SV, VV, VR, WC
500 Format (' ', 3X, 13, 5X, F7.5, 3X, F7.5, 3X, F7.5, 3X, F7.5, 3X, F7.5, 4X,
    F6.2, 14X, F6.2, 3X, F7.5, 3X, F7.5, 4X, F5.3, 5X, F5.2)
    Stop
    End
```

DEPTH EFFECT OF SOIL
COMPACTION FROM WIDE TIRES

by

Ray A. Dilts

B.S., Kansas State University, 1974

AN ABSTRACT OF A MASTER'S THESIS

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requirements for the degree

MASTER OF SCIENCE

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1976

ABSTRACT

As related to agricultural production, soil compaction is both beneficial and harmful. For good plant growth, soil must have a certain amount of compactness but beyond this, soil compaction becomes harmful. Vehicular traffic is one source of soil compaction. As tractors and implements become larger and heavier, wider tires are being used to support the loads. According to the pressure bulb theory, a surface load transmits pressure into the soil to a depth approximately equal to twice the width of the loaded area.

This study was undertaken to determine whether or not these wider tires were transmitting pressure to a depth in the soil which would cause compaction. If at a great enough depth, this compaction might be irreversible by tillage methods or natural forces such as freezing and thawing.

The first part of this research was done on clay soil with five different tractor tire arrangements. There were two tractors on 30-inch wide tires but of different weights. There were two tractors on 18-inch wide dual tires and one tractor on 18-inch wide single tires. Soil samples were taken for density measurements. The only significant source of variation was due to the depth of the sample both in the control samples and test samples. This was evidently due to a change in the soil horizon. Penetrometer readings were also taken and the only significant source of variation in the readings was the replication.

Based on the results of the first part of the research, a second group of tests was set up. For these tests, one tractor on 18-inch wide tires and one tractor on 30-inch wide tires were used. The tests were set up on a sandy soil. A sandy soil was used because it should be more sensitive to

compaction than a clay soil. From one to eight passes were made over the same track by each tractor. Soil samples were taken and density measurements made. The significant sources of variation were the sample location within a plot and the replication. Maximum penetrometer readings and the depth of the maximum readings were recorded. The location of the reading in a plot was significant for the depth of the maximum penetrometer readings.

There was no detectable difference in compaction due to the tire size or number of passes for either soil type. The methods of measuring compaction did reveal some differences but these differences in compaction weren't due to the effect of any treatment.