A SOIL SURFACE TRAFFIC - CORN YIELD MODEL FOR A SOIL UNDER CERRADO VEGETATION IN BRAZIL WITH LESS THAN 10 YEARS OF CULTIVATION

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Dedicated to my wife, Barbara and to my
children, Rafael and Lucas.

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ABSTRACT

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Due to the rapid expansion of the brazilian agriculture frontier and adoption of mechanization technology, the "Cerrados" area has begun to show some signs of mismanagement. One area of mismanagement is the mechanization process especially how it affects soil compaction.

This study was conducted at the National Research Center for Corn and Sorghum GMBRAPA, Sete Lagoas, Minas Gerais, Brazil, 1983, with the objective to quantify the effect of surface traffic on corn yield in soil with less than 10 years of cultivation and also to model the effect of traffic on Dark Red Latosol soil.

Five compaction levels (0, 1, 5, 10, 10 + subsoiler) and two irrigation levels in a split plot design were tested. The soil's critical moisture content range was 32-35% and was obtained by the Standard and 15-Blow Proctor.

A Ford-6000 tractor carrying a disk harrow in an up position with 4900 Kg weight was used as static force and its front and rear contact pressure was 0.70 and 0.78 Kg/cm^2.

A soil characterization of the plots was performed before and after soil compaction at 0-7.5, 7.5-15, 15-22.5, 22.5-30, 30-37.5 and 37.5-45 cm depth and the parameters studied were: bulk density, particle density, pore size distribution, particle size distribution, aggregate stability and soil strength. Also plant growth, soil moisture content, root weight and grain yield were evaluated under the tested compaction levels.

A stepwise regression program was used and the best set of independent variable was found to establish a regression model.

There was no significant difference among the ten compaction treatments for its effects on corn yield.

INTRODUCTION

The constant increase in the world population is one of the biggest challenges to food production in many countries. The increase in production can be attained in two ways: (1) improving agricultural productivity or (2) increasing the amount of cultivated land. Many countries have been adopting number (1) for a long time like the USA, Canada, France, Japan, etc., and a few others, like Brazil, that still have plenty of land available, are adopting number (2) and at the same time developing more advanced technology to increase productivity.

Many regions in Brasil are in the process of agricultural development and expansion of agricultural lands, like the Northwestern Amazon Region, but one of the great concerns of the Brasilian government is the agricultural use of 180 million hectares of land called "cerrados". These lands extend over part of West-Central, Northern, Northeastern and Southeastern regions of Brasil (Figure 1). According to Goedert et al. (1980), 150 million hectares of "cerrados" are ready for agricultural use, either for crops (annuals and perenials) or forage and commercial forests. The remaining 30 million hectares should be considered as non-agricultural lands, like ecologic parks, urban areas, water reservoirs, etc. Due to intensive attention to "cerrados" given by the Brazilian government in the past four years, 3 million hectares of land

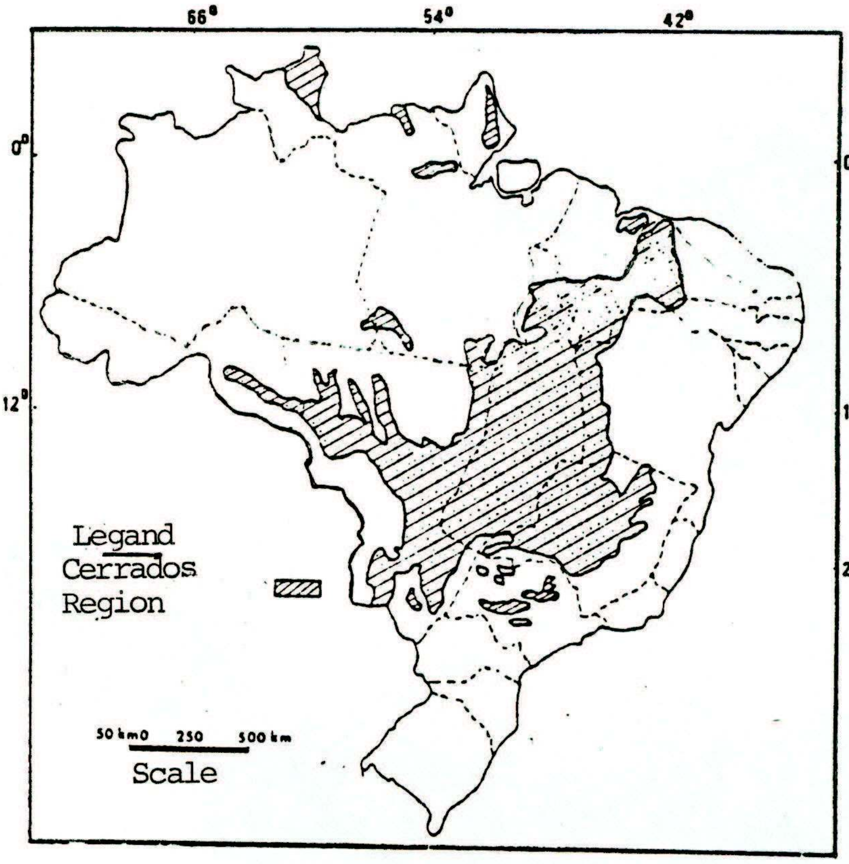


Figure 1. The present stage of knowledge about "cerrados" distribution, including transition areas with other formations. Source: Geodert et al., 1980.

were already incorporated into farms and are in use and it is expected that, an additional 2 million hectares will be annually incorporated.

The current annual production of "cerrados" corresponds to 15% of the Brazilian production (10% of the grain, 25% of the meat, and 50% of the wood) which can be considered very important to the economy.

According to Buol et al. (1980), the past few years have witnessed expanded and intensive use of oxisols in the area between Brasilia and Sao Paulo, Brasil. With a basic understanding that phosphate and lime

Table 1. Present situation of agricultural production in the "cerrados" region.

Activity	Area (million/ha)	Productivity	Annual Production
Grain* (annual crops)	5	1.5 t/ha/yr	7.5 million ton
Meat (cattle)	144	15 kg/ha/yr**	2.2 million ton
Wood (forest)	1	15m^3/ha/yr***	15 million m^3

* The annual crops considered are: rice, beans corn, soybean, sorghum and wheat.
**Obtained productivity, considering 15% of the area with improved grassland, with 0.4 heads/ha and slaughtered at 4 years of age, with 150 kg of meat.
***Data obtained on an annual average increment of 15 m^3/ha/yr.
Source: Goedert et al., 1980.

were vital to the growth of crops of these soils, and of the need for marketing and infrastructure systems, farmers with both technical and business abilities have put thousands of hectares under the plow for the growth of soybeans, wheat, corn and coffee. Taking advantage of the favorable soil structure and nearly level topography, farmers utilize the largest of equipment and most modern of technology in their successful operations.

The Problem

According to Fundacao IBGE (1979), the area of the farms in the "cerrado" region is more than 1000 ha. The annual crops are generally planted in 200 ha. This implies predominance of mechanized agriculture.

The tractors and implements produced by the Brazilian manufacturers are not designed to work under "cerrado" region conditions.

Goedert et al. (1980) characterized these conditions as:

1. There does not exist an efficient implement for the process of root extraction which make the clearing of new frontiers very expensive.

2. The process of lime application is not very good. The disk plow is being used widely but is limited in the incorporation of lime and phosphates at shallow depths.

Due to the rapid expansion of the Brazilian agriculture frontier and adoption of mechanization technology the "cerrados" area has begun to show some signs of mismanagement. One is the mechanization process, especially on soil compaction.

Heavy machinery equipment are being used during clearing with the objective to clean the area under "cerrado" vegetation and to apply soil correctives that neutralize the soil acidity. Usually, rice is cultivated in the first two years, because of its high tolerance to toxic aluminum. After these two years, the soil is ready to be planted with other crops. Light equipment can be used to handle the initial tillage practices. After the first two years the farmers continue to use the equipment they invested in originally instead of changing to more appropriate equipment.

The disk plow is used by almost 100% of the Brazilian farms to plow the land then it is followed by a disc harrow to form a granular seedbed. Also, the heavy disk harrow is being used to plow soils in the "cerrado" because there is no impediment of work by the roots left on the soil after cutting of the "cerrado" vegetation.

Trouse (1954) has found that a disc harrow may create a "harrow sole", particularly if the soil beneath the upper few inches happens to be moist enough to permit compaction. He noted that, beneath about 4 inches of loosened soil there exists about 7 inches of compacted soil which he called the "harrow sole".

Carvalho et al. (1974) noted that a moldboard plow used on Dusky-Red Latosol when compared with disk plow increased the corn productivity 20% in the Triangulo Mineiro region. He noted that the disk plow was compacting the soil beneath the plow layer forming a "plow sole".

OBJECTIVES

The objectives of this research are:

1. To quantify the effect of surface traffic on corn yield in soil with less than 10 years of cultivation.

2. To model the effect of traffic on Dark-Red Latosol.

BACKGROUND AND LITERATURE REVIEW

Because of the complexity and large numbers of variables that can interact during soil compaction problem, the discussion of this section was inserted to include most of the arguments and past work.

Characterization of the Region

Buol et al. (1980) stated that oxisols do occupy the majority part of the landscape in some parts of the intertropical region. The most extensive area easily traversed and observed is the central Brazilian Plateau. The area has an Ustic moisture regime and is vegetatively covered with a savanna suppporting dwarf woody species commonly referred to as "cerrado".

Geodert et al. (1980) gave an approximate distribution of the main soil units under "cerrado" vegetation.

Red-Yellow Latosol	41%
Dark-Red Latosol	11%
Dusky Red Latosol	4%

Goedert et al. (1980) said that during the year, temperature and solar radiation in general do not constitute a problem for the growth of crops (Table 2). If the total annual rainfall is more than enough for any crop, the distribution of this rainfall can be varied. Its distribution is the climatic factor that influences the agriculture use of "cerrado" the most. The rainfall period extends from October to May, occurring around 80% of the total annual rainfall (average of 1580 mm, in Brasilia) in the period of November to March.

Soils Under Cerrado's Vegetation

Geodert et al. (1980) classified the soil under "cerrado" vegetation as deep and well drained with the texture varying from sand to clay. The infiltration rate is very high with recorded values of 14 to 20 cm/hr in Dark-Red Latosol.

Wolf (1977) found the water retention capacity very low, mainly because of the mineralogic and structural compositions. Only 6 to 8% of the water is retained between tensions of zero and one bar and almost nothing under tensions above one bar. This means that the water stored in the plow layer will be enough to maintain the crop growth for a period of only six to 10 days.

Moura and Buol (1972) cited by Buol et al. (1976) studied the effects of 15 years of annual cropping in a Brazilian Eutrustrox and observed that infiltration rates decreased from 82 to 12 cm/hr with intensive cropping (Table 3). The decrease in infiltration was associated with a sharp decrease in macropores greater than 0.05 mm in diameter in both A and B horizons, where the micropores remained essentially

Table 2. Climatic data, obtained from 35 years of observations in Formosa, Goiás Brasil.

Months	Ave. Temp. (°C)	Min. Temp. (°C)	Max. Temp. (°C)	Relative Humidity (%)	Monthly Ave. Precipitation (mm)	Max. Precipitation in 24 hrs. (mm)	Evaporation (mm)	Insolation (hr)	Solar Radiation ($cal/cm^2/day$)
January	22.0	17.8	27.4	80.2	271.9	100.7	73.2	180.5	425.0
February	22.1	18.0	27.8	80.8	204.2	85.0	63.7	159.3	410.1
March	21.9	17.9	27.6	81.5	220.6	92.5	67.1	186.8	380.9
April	21.5	17.0	27.6	77.3	42.7	77.8	75.3	222.2	377.0
May	20.1	14.8	27.0	71.0	17.0	41.8	97.8	270.3	377.9
June	19.0	13.1	26.4	66.0	3.2	18.0	113.0	279.9	376.8
July	18.9	12.6	26.3	59.4	5.5	25.2	141.3	278.0	428.3
August	20.7	13.7	28.4	49.6	2.5	45.8	188.3	303.2	445.1
September	22.8	16.2	30.1	51.7	30.0	63.6	189.2	236.2	423.2
October	22.9	17.8	29.2	66.0	127.1	103.4	138.1	200.7	405.5
November	21.6	18.0	27.4	79.3	255.3	107.5	75.2	142.7	408.4
December	21.9	18.1	26.6	83.0	342.5	124.9	60.8	125.1	409.5
Year	21.3	16.2	27.6	70.6	1,572.5		1,283.0	2,614.9	

Source: Goedert et al., 1980.

unchanged. Compaction by machinery was considered the cause of the decreased macroporosity. They also observed that water-dispersible clay contents decreased in the A horizon with cultivation and increased in parts of the B horizon. Apparently, some clay translocation may have also reduced porosity. A drop in infiltration rate from 82 to 12 cm/hr could be considered beneficial because of reduced percolation and leaching losses.

Table 3. Effects of Cultivation on the Physical Properties of an Extrustox from Minas Gerais, Brasil.

Soil Property	Recently Cleared	Cropping for 15 years
Infiltration rate (cm/hr)	82	12
Pores > 0.05 mm, A horizon (%)	25	11
Pores > 0.05 mm, B horizon (%)	34	13
Pores < 0.05 mm, A horizon (%)	33	32
Pores < 0.05 mm, B horizon (%)	30	33
H_2O - dispersible clay, A horizon (%)	13	7
H_2O - dispersible clay, B horizon (%)	1	7

Source: Sanches, (1976), adapted from Moura Filho and Buol (1972).

Holtz and Kovacs (1981) defines compaction as the densification of soils by the application of mechanical energy. It may also involve a modification of the water content as well as the gradation of the soil.

Harris (1971) defines compaction as a change in the state of compaction of soil resulting from a change in its volume caused by forces that may originate either from natural internal forces or from applied external forces.

Byrnes et al. (1982) describes the process of soil compaction in 14 items.

1. The process of soil compaction altered the equilibrium between solid, liquid and gas components of the soil.

2. Soil tends to compact in two stages; first the loose structure is collapsed, then soil particles are rearranged into dense clods.

3. The degree of compaction from external pressure is influenced by texture, moisture content, structure, and organic matter content of the soil.

4. Agricultural equipment causes compaction of soils by:

   - applying high pressures from tires to the soil surface,

   - applying high pressure from tillage implements to soil beneath the surface in the process of soil working,

   - causing soil to undergo shear deformation at the time that pressures are applied.

5. In equipment operation:

   - the first pass with a particular piece of equipment causes the greatest percent of compaction.

   - The longer a piece of equipment rests on the soil, the greater will be compaction.

- wheel slip in equipment operation may cause further compaction damage.

6. Pressures generated at some depth within the soil are mainly a function of the total weight of the equipment or the weight carried on one wheel or track.

7. Pressures applied to the surface by pneumatic tires are approximately equal to tire inflation pressures, but localized high pressures occur due to pressure concentration by tire lugs and sidewalls.

8. Pressures applied to the surface by crawler tracks are not uniformly distributed, so that peak pressures usually amount to two or three times the computed average ground pressure.

9. For a particular soil and moisture content, a given pressure on the soil will result in a predictable bulk density.

10. Dry soils have more resistance to compaction than do wet soils, i.e., a higher level of pressure is required to compress a dry soil to a given porosity than is required to compress a moist soil to the same porosity. Bulk density changes for a given pressure, increases to a maximum at a moisture content near field capacity.

11. With a given level of pressure, soils with a very broad range of particle sizes can be compacted to a lower porosity than soils of more uniform particle-size distribution.

12. When soils are saturated they are not compacted by short duration pressures applied by agricultural equipment, but they may be greatly disturbed and deformed. Thus, soils wet to the point of saturation are less subject to compression to very low porosity levels than are soils of intermediate moisture content. But, very wet or saturated soils, when subjected to excessive deformation, may become puddled (structural, breakdown); even though they may not be compacted immediately, they can shrink to a highly compacted and cloddy state when drying.

13. The volume of pore space lost from agricultural soil due to compaction by equipment is approximately equal to the volume of ruts produced by that equipment.

14. Ruts with low depth-width ratios tend to be associated with soil compaction near the surface; those with high depth-width ratios cause compaction at comparatively greater depths.

Cohron (1971) found that tractor tires inflated to nominal pressures of 69 to 103 KPa (10 to 15 psi) commonly apply pressures of 138 to 345 KPa (20 to 50 psi) to the soil. Both static and dynamic loads can compress a soil. Most agricultural compaction is caused by dynamic soil loading.

Raghavan et al. (1976) demonstrated that a conventional Proctor compaction soil mechanics test can be used to index and predict with reasonable accuracy, the compaction behavior of agricultural top soils over a wide range of soil moisture contents and single or multiple passes of tires of varying contact pressure. The equivalent cummulative pressure was found to be 17.6 kg/cm^2.

Weaver, H.A. and V.C. Jamison (1951) found that the tractor compaction curves were in general comparable with the laboratory Modified Proctor curves for the moisture ranges tested. Maximum compaction in the bin studies at the U.S. National Tillage Machinery Laboratory were indicated at lower moisture contents than in laboratory tests, probably because of the tendency for soil to flow under pressure when in an unconfined state. Draft-volume-weight relationships indicated that greatest compaction occurred at less than 545 kg per wheel draft when treatments of ten tire passes were imposed. Indicated peak compactions in both soils under the tractor treatments occurred at moisture contents near the lower plastic limits and optimum plowing moistures. The general conformity of test bin and laboratory results suggests that modified Proctor tests may be used with some degree of reliability as guides for field tractor compaction studies. The results indicate that less compaction occurs when operations are performed on dry soil than on soil at or above the optimum moisture content for tillage.

Proctor, R.R. (1930) cited by Holtz and Kovaks (1981) established that compaction is a function of four variables: 1) Dry Density, 2) Water Content, 3) Compactive effort and 4) Soil type (gradation, presence of dry materials etc).

Jamison et al. (1950) studying the compactive effects of a rear wheel pneumatic farm tractor tire on Cecil clay in a test bin at the U.S. Tillage Machinery Laboratory found that track depth, maximum bulk density, and depth of penetration of compactive effects increased with moisture and initial looseness of the soil. The depth to which compaction was observed was nearly as great in the "moist" as in the wet soil condition, being evident to depths varying from 43 cm below the surface in a loose soil to 30 cm in a heavily compacted state.

According to Ellis (1977) the physical measurement of unit ground pressure under a tire in soil is a very difficult chore. Differences in soil composition, moisture content, and other factors uncontrolled in nature as well as differences in the pressure distribution of the tire footprint area create difficulties. Lacking laboratory accuracy in these areas, a rule of thumb can be suggested. As long as tire loads and inflation pressure are reasonably close to the rate values, average unit ground pressure will be equal to approximately the tire inflation pressure from 6.895 to 13.79 KPa.

Chancellor (1975) showed that for every level of soil pressure there is (for each particular soil and moisture content) a corresponding value of soil porosity; and for every level of soil porosity there is the same corresponding level of soil pressure which must be exceeded in order for further soil compaction to take place.

Raghavan et al. (1982) studying soil bulk density versus depths at different number of tractor passes showed that most of the effect of compaction was in the top 0.075 m; that most of the damage in the clay loam field was done by the first pass of the tractor; and that the effect of higher number of passes went deeper in the Clay soil.

Shaw et al. (1942) that soil moisture content is the dominant factor influencing the force required to push a probe into the soil. Under field conditions there is no simple relationship between soil moisture and penetrometer readings. In a small area of apparently uniform soil growing an apparently uniform crop, porosity and root difference are of sufficient magnitude to have large effects on the measurements. In field studies it is not practical to attempt to interpret penetrometer readings in terms of specific soil properties. In spite of the limitations the penetrometer is a useful tool in field investigation. Its correct function is as an aid in soil dignosis. While penetrometer records do not lend themselves to precise descriptions, they often give the clue that makes it possible to discover the correct reasons for noted differences in, say, crop yields or percolation rates.

Buntley, G.I. (1977) found that the size and weight of the tractor and other farm implements has a direct effect on the degree of compaction and the formation of traffic pans. The degree and extent of soil compaction resulting from a single trip through the field increases as the weight of the tractor and implement used increases. Width of tires also has an effect. For a given normal force tires increases the degree of compaction, out the area compacted is relatively narrow. Wide tires decrease the degree of compaction, but the area of compaction is much broader.

Frowhlich, O.K. (1934) reports that deep soil compaction is a function of the total load applied to the surface of the soil and the area over which it is applied. It is not a function of the unit pressure applied to the soil alone.

Soehne, W. (1953) concluded that when surface pressures are equal, the pressure bulbs will be larger and will reach deeper as the total load increases.

Soehne, W. (1958) stated that the pressure in the upper layer is determined by the specific pressure at the surface, which depends upon the inflation pressure and the soil deformation. The pressure in deeper soil layer is determined by the amount of the load.

Veihmeyer and Hendrickson (1948) showed that unconfined compressive soil strength greater than 1.75 kg/cm^2, measured at field capacity, impeded penetration of maize roots in coarse-textured soils.

The compaction generated from traction thrust and wheel slip was observed by Raghavan et al. (1978) for all the tires tested in fields. This compaction was found to reach a maximum between 10 and 50 percent wheel slip, and reduced at higher slip rates, with an increase of dry density up to 0.25 g/cm^3 observed due to wheel slip. These results were confirmed in the laboratory shear-box studies.

Raghavan et al. (1976) studies vehicle compaction patterns in clay soil under the tire path cross sections for different soil moisture contents, normal pressure, number of passes and tire configurations. The effect of contact pressure on compaction was less pronounced for small changes, but higher compaction resulted from bigger changes in contact pressure. The maximum change in dry densities up to 0.20 g/cc occurred between 12 to 26 cm under the center of the tires, and this effect lessens at higher depths or distances farther from the center of the tire trace. The effect of the number of passes on compaction of a site was noted in terms of the increase in dry density for several tires. Most of the density increase (70%) occurred within the first five passes, and the density changes leveled off for further increases in the number of passes. The increase in dry density obtained was found to depend on the moisture condition of the field for a given contact pressure and number of tranverses. As the field moisture changed towards the optimum value for worst compaction, the value of maximum change in dry density increased.

Raghavan et al. (1976) observed that the density pattern obtained after 15 passes of machinery in a fresh field show the same effect as that of those seen in Laboratory test (Standard Proctor).

Cooper et al. (1957) using Froechlich's formula found that deep compaction is a function of the total load applied to surface of the soil and the area over which it is applied. It is not a function of the unit pressure applied to the soil. Data reported show that a rear tractor tire containing an air pressure of 110 KPa applied an average pressure of 373 KPa to the soil. Pressure as high as 297 KPa were measured in the soil at approximately 5 cm depth. This soil was very dense and the entire weight on the rear axle of the tractor was carried on the lugs of the rear tires.

Mannering (1972) stated that the higher the bulk density (volume weight) of a soil, the lower the total pore space affecting soil aeration. Finer-textured soils (silts and clays) have more total pore space than coarse-textured soils (sands), although coarse soils have more large pores that promote rapid drainage. With a specific soil, the greater the compaction (higher the bulk density) the less the porosity.

VandenBerg and Gill (1962), Larson and Gill (1973) and Chancellor (1977) has found the pressure at the edges of a tire can be as much as five times as great as the inflation pressure.

According to Chancellor (1977) there is a difference in the pressure under lugs versus the smooth parts of the tire. However, this difference is usually evened out so that at a depth of 15 cm of so, there is little effect from the tire lugs.

Harris (1971) and Chancellor (1971) have reported that for partially saturated soils, the higher the percentage moisture, a greater compaction was produced for a given pressure.

Raghavan et al. (1978) found that soil compaction was affected by dual tires in the sense that distributions of compaction was changed.

Jamison et al. (1950), Harris (1971) and Raghavan et al. (1976) have reported the first pass with a particular piece of equipment causes the greatest percent of compaction.

Reaves and Nichols (1955) and Larson et al. (1980) showed that the first stage of compaction is the elimination of large pores. Cohron (1971) showed that the increasing number of passes increases bulk density to the maximum possible density for that piece of equipment. Despite this emperical relationship, no clear equation is available to predict the amount of compaction under a particular set of conditions.

Aboaba (1969) and Gill and Reaves (1956) have reported that speed of operations is an important factor in determining the amount of soil compaction produced by a given operation.

Heyedus (1965) studying soil compaction by tires showed that not all the pressure producing compaction can be explained by wheel geometry and soil properties alone. The shear force produced by wheel slip has to be included.

Raghavan et al. (1977), Raghavan and McKyes (1978) and Raghavan et al. (1978) showed that a density increase of 0.25 g/cm^3 could be attributed to wheel slip.

Usually the shear strength of soil is estimated by Coulomb's equation:

$$\pi_{max} = \pi_{normal} \tan\theta + C$$

where;

π_{max} = maximum shearing stress during failure

π_{normal} = normal stress on the failure plane

$\tan\theta$ = coefficient of internal friction

C = apparent cohesion

Raghavan et al. (1976) noted that the maximum change in the dry density of a soil occurred at a depth between 20 and 30 centimeters when tires were driven over the soil surface.

Cooper (1971) has reported that disk harrows, the second most used primarily tillage tool in the U.S., compact soil immediately below the depth of operation due to the considerable weight required to hold them in the ground and the transfer of this weight by small contact areas of the disk blades to the soil.

Brady and Bauer (1974 and 1961), reported that a wide range of agricultural soils they had noted compacted layers at the bottom of the zone of plowing. These layers were assumed to originate from a combination of tillage and other farm operations.

Chancellor (1971) states that soil exhibits strength both in resistance to compression and in resistance to deformation of soil structural units. He also indicates that major factors affecting the relationship between soil strength and compaction are soil moisture content and texture.

Chancellor (1977) points out that penetrometer resistance, a secondary expression of soil compaction, is frequently used for comparative measurement of soil strength.

According to Freitag (1971) compaction stresses affect three basic soil characteristics, these are: soil porosity, pore size distribution and soil structure.

Brady (1974) cites examples where large pores were reduced 50%, small pores increased about 30%, and total pore space reduced 10 to 14% in the upper 30 cm of a clay soil in Texas subjected to continuous cropping.

Studies of pore space distribution in relation to compaction pressure conducted on moist, fine-textured soil in Sweden (Erickson et al., 1974) showed that large pore decreased successively with increasing pressure. The large pores were severely reduced at 100 KPa pressure, reached critically low values at 200 KPa and were completely compressed at 800 KPa.

Meredith and Patrick (1961) showed that high compactive effort above 718 kJ/m^3, destroyed almost all large pores, changed bulk density 0.2 to 0.35 g/cm^3, and drastically reduced water permeability in laboratory studies on bulk samples of three Louisiana silt loam and clay soils. Maximum compaction of the silt loams occurred at 18 percent moisture content and of the clay loam soil at 21 percent moisture.

In Quebec, Canada, Raghavan et al. (1977) found that increases in dry bulk density of a clay soil reached levels of 0.35 g/cm^3 after multiple passes of tractor tires with contact pressure up to 0.51 kg/cm^2. The maximum change in density occurred between 12 and 26 cm below the tire path and 70 percent of the density increase occurred during the first five tractor passes. The worst compaction was found at soil moisture contents between 28 and 35 percent, while lower moisture contents, even with higher contact pressures of 0.6 to 1.4 kg/cm^2, produced smaller increases in soil density.

Warkentin (1971) has observed that the field capacity of layered soils is usually increased due to slower drainage through the layer. In an unsaturated soil, the compacted subsoil draws moisture from more porous surface layers until water potentials are equal.

Warkentin (1971) states that a soil with a higher unsaturated conductivity above one with a lower conductivity loses more water through evaporation than a homogeneous soil.

According to Nichols (1932) major factor in the subsoiling operation is the shear value of the soil. Soil moisture content also has a great influence on the effectiveness and permanent nature of the subsoiling operation. If the soil is sufficiently moist to form a small ball and plastic enough to roll out like a wire, Nichols (1955) states that it will flow pastically around the tool compacting instead of shattering the soil. In general this compacting is considered to be detrimental to the soil. However if only small layers of the subsoiled area are plastic and shattering extends into a relatively large area, some benefits will usually result.

Bateman, H.P. (1963) stated that corn growth may be retarded when the air voids at field capacity moisture are near the 10% value. Also, many results have demonstrated that tractor tire traffic can reduce air voids to the critical value of 10% or less in many soil types, and these low values are easier to develop at higher soil moisture contents.

Bauder et al. (1979) observed that during wet years in poorly drained soils, compaction may decrease yields by reducing the soil aeration porosity and slowing soil warming. During dry years and where moisture is limited, crop yields may be increased by a firm seedbed and moderate amounts of compaction that increase temporary water storage and better seed-soil contact.

According to Threadgill (1981) cone index values greater than 2000 KPa frequently reduce crop yield and values above 1500 KPa frequently reduce root growth.

Negi et al. (1981) stated that: 1) all the tillage operations generally reduced the soil dry densities to values below those of the compacted plots up to a depth of about 15 cm, but only the subsoiler reduced the densities below the 15 cm depth provided the soil was relatively dry to the full depth of subsoiling. The cone resistance, unlike dry bulk density, did not depend on soil type for the two fields used, but was affected by the traffic and tillage treatments. 2) Compaction of the soil, if not subsequently loosened by a tillage operation, caused a marked reduction in plant yield. The chiseling and subsoiling operations, caused a marked reduction in plant yield. Also, chiseling and subsoiling operations in a sandy loam soil produced the highest and second highest yield, respectively while the best yields in a clay soil were observed on plowed and chiseled plots. The heavily compacted no-tillage plots displayed the lowest yields in both soil types. 3) A narrow range of average dry bulk density from 1.3 to 1.45 g/cm^3 produced the optimum silage corn yields in the Sta. Amable sandy loam soil tests. Crop yields were significantly diminished when the soil density exceeded 1.5 g/cm^3.

Negi et al. (1980) found that the amount of water available to plants at 30 cm depth was twice as large in the subsoiled and rototilled plots when compared to the compacted-untilled, plowed and chiseled plots. Finally crop yields were proportionally greater in the first two cases.

McKyes et al. (1979) observed that in a relatively dry season, a narrow range of soil dry density produces the optimum silage crop yield in the Ste. Rosalie clay soil tests. Crop yields are reduced up to 30%

when soil density is $0.1 g/cm^3$ above or below the optimum of about $1.2 g/cm^3$. In a wetter year, the change in yield is less pronounced with varying soil density while the optimum density range is lower to below $0.9 g/cm^3$. The lower optimum density reflects a higher availability of rainwater for plants during the season. Therefore less retained water is needed during periods of moisture deficit.

Phillips and Kirkham (1959) showed that compaction increased mechanical impedance to root growth and this mechanical impedance, as measured by a needle penetrometer and bulk density, was much greater in compacted plots than in noncompacted plots. The yield reductions caused by compaction may be said to be due to mechanical impedance if the 10 to 15% level of oxygen in the soil air can be considered adequate for plant growth.

Siemens (ref. 79) indicated that many soil-plant relationships are affected by soil compaction. The factors affected are the proportion of the air voids in the soil, moisture movement, mechanical impedance to root growth, water infiltration rates, and plant growth. Growing crops in a compacted soil reduces yields of nearly all crops if, and perhaps only if, the compaction substantially increases plant stress in terms of obtaining water or nutrients.

Raghavan et al. (1979) observed that during a wet year any amount of compaction reduced plant growth, probably due to water stress and lack of nutrients uptake. A 50 percent reduction in corn yield was recorded on a severely compacted soil in a wet year.

Allmaras (1971) indicated that during periods of sufficient moisture, crop yields do not suffer as much, possibly due to increased root penetration of the pan and because water stress never occurs.

Musik and Dusek (1978) suggested that if planned water deficits on corn must occur during an irrigation season. They should be restricted to the early part of the growing season during the vegetative stage well ahead of tasseling.

Raghavan et al. (1981) studying soil compaction effects on soil productivity concluded that soil dry density can be used on a measure of compaction and it can be expressed as a function of contact pressure at the tire interface, number of passes, moisture content and position relative to the tire.

Iowa State University agronomists (1977) found that corn wilting from water stress over a four day period caused a 10% yield reduction up until a week before tasseling. Up to 50 percent yield loss with the same degree of water stress occurred near the end of the pollination period.

Larson and Allmaras (1971) and Raghavan et al. (1979) have noticed that, in dry years, yield reductions due to compaction, although moderate compaction, give quicker emergence and tasseling in corn.

Trouse (1971) found that excessive moisture due to compaction may reduce seed germination by reducing aeration and increasing seed destruction by disease.

Raghavan et al. (1979) found that soil compaction had varying effects on yield reduction depending on soil moisture availability. In a dry year a maximum of 23 percent reduction in yield resulted from high compaction. In a wet year, reductions of up to 50 percent were attributed to vehicular compaction.

Gaultney (1980) reported up to 50 percent yield reduction on heavy compacted corn plots under water stress.

Baver (1961) suggested that tillage operations should be performed at a soil moisture content below field capacity.

Dumas et al. (1973), in a study done at Auburn, recommended the adoption of a permanent controlled traffic system of tillage in order to spare planted strips from the adversities of compaction. They found that average soil densities in traffic lanes were 1.82 g/cm^3 while in the non-compacted areas the bulk densities average 1.44 g/cm^3.

Danfors (1977) suggests that by improving wheel equipment and increasing total tire volume, inflation pressure can be lowered and stress on the soil will be reduced.

Chaudhary and Prihar (1974), when studying four cultural treatments: 1) control, 2) 5 cm deep postplanting cultivation, 3) 2 cm thick straw mulch, and 4) interrow compaction on sandy loam and sandy soils, found straw mulch and cultivation enhanced root growth in the upper 15 cm of soil and increased the lateral spread of roots. The mulch treatment had less roots than the control below 15 cm. The cultivated plants had more symmetric root distribution. Interrow compaction inhibited lateral square of roots in the surface layers and caused downward growth of roots.

Phillips and Kirkham (1962) found that grain yields were directly proportional to weight of roots in a 60 cm layer of soil whether in compacted or noncompacted plots, fertilized or not fertilized.

Ziemmerman and Kardos (1961) found a significant negative correlation between root weight and bulk density. They reported that bulk density which virtually excluded root penetration were obtained at value of 1.8 g/cm^3 on a silty clay, 1.9 g/cm^3 on sandy loam to sandy clay and 2.0 g/cm^3 on a clay loam texture soil. In Illinois, Edwards et al. (1964) working on a silt loam planosol, reported that a discrete bulk density of about 1.8 g/cm^3 was the threshold bulk density above which were not penetrated by roots in the soils.

According to Larson (1964) a lower limit of bulk density is necessary in order to know the minimum compaction needed to create adequate soil waterseed and soil water-root contact. He suggested critical limits of 1.0-1.4 g/cm^3 for a medial brunizem with a 10% slope and for planosols with less than 1% slope. According to him, the lower value is an estimate from field observations and the upper one is an approximation for satisfactory growth in several corn belt soils.

Barber (1971) measured corn root distribution seven and eight years after starting eight different tillage-residue management-cropping practices with continuous corn. He found that when the soil was plowed annually corn roots developed more extensively to a greater depth than where soil was not tilled. Removal of residues depressed root growth in the 0-10 cm depth. Roots were finer and longer in tilled soil than in notilled soil. The amount of root growth averaged 12 mg/cm^2 in 1968 and 42mg/cm^2 in 1969, although average corn grain yields were 9380 kg/ha in 1968 and 8980 kg/ha in 1969.

Raghavan et al. (1977) performed extensive field investigation to provide information regarding the compaction behavior of a clay agricultural soil when subjected to different external pressures generated by off road power machine wheels. The combination of these results together with the laboratory compaction tests were used to formulate a prediction equation for a clay soil at all moisture contents encountered.

$$Y_{dry} = \frac{0.9622}{1.8579} + \frac{0.0651}{0.0766} \ln(np) + \frac{0.0121}{0.2391} \ln(W), \; W \lessgtr W_{opt.}$$

Y_{dry} = dry density, g/cc

p = contact pressure, kg/cm^2

n = number of passes

W = moisture content, %

W_{opt} = moisture content optimum, %

Miles et al. (____) studied soil compaction during skidding operation over ranges of moisture contents and traffic intercities while also looking at the effect of each component of a machine-load system on soil density. The results were presented in a Stepwise Multiple Linear regression and the conclusions are: 1) Soil compaction is more sensitive to moisture content than any other variable, 2) Soil density increases with the number of trips but much of the compaction occurs on the first trip, 3) Beneath the tracks or wheels of the machine, most compaction is due to the weight of the machine and the shear force required to skid to turn, 4) The tractor caused slightly less compaction than the skidder.

Bergmann (1979) used the following inputs in a compaction modeling study: initial soil density, weight, plasticity index, number of wheel passes, vehicle speed, gravitational constant, and the percent dry weight soil moisture. Some of these parameters are beyond practical control, but others can be beneficially managed.

Amir et al. (1976) and Soehne (1958) developed equations to predict compaction effects on both soil porosity and density based on applied pressure, residual pressure, and volumetric soil moisture content within the range of 0.4 to 0.6 of saturation.

Amir et al. (1976) states that these equations make it possible for a given soil to: 1) predict the amount of soil compaction as a function of soil moisture content and contact pressure, 2) evaluation drainage in terms of work days permissable, and 3) make decisions where a desired applied pressure and operating time are involved.

Raghavan and McKyes (1978) studying the effect of vehicular traffic on soil moisture content in corn plots set up statistical models to predict soil moisture content in terms of the number of machine passes and the contact pressure. The results indicated that heavy machinery traffic alters the internal soil environmental such that higher moisture contents occurred in heavily compacted plots. The altered soil structure in compacted soil contributed to reduce crop yields. The difficulty encountered by roots in penetration compacted subsoils was a concurrent factor.

Raghavan et al. (1979) showed that the reduction in yields were over 35% in non-compacted plots and heavily-compacted plots when compared to the moderately-compacted plots. A second degree equation using traffic as a variable explained the variations of yield. This is different from the results of 1976 wherein the model was an exponential decrease of yield with traffic treatments. The observed changes in the results of these two studies are due to the characteristics of the weather input. In 1976, seasonal average rainfall was about 54 cm as opposed to 36 cm in 1977. In a dry year, uncompacted plots are not as able to retain and supply water to the plants as those which are subjected to moderate compaction, whereas, in heavy compacted plots, the growth of plants is restricted by high root penetration resistance of the soil and insufficient water storage. Therefore, it is evident that when the weather conditions are abnormally dry, a certain amount of machinery traffic on the field can be beneficial.

Raghavan and McKyes (1978), in their compaction modeling, found that soil dry density increases with increase in ground water contact pressure and decreases with an increase in moisture content.

MATERIALS AND METHODS

A field experiment was conducted in Sete Lagoas, Minas Gerais, Brazil, in 1983 on a Dark Red Latosol. This experiment was designed to quantify the effect of subsoil compaction (surface to 45 cm) on corn yield and also to model subsoil compaction on a Dark Red Latosol.

A split-plot design with irrigation as a whole plot treatment and compaction conditions as the split plot were used.

Ten treatments and 3 replications were randomly chosen in an area according to Figure 2.

The experimental area was well adapted to the corn crop. It was chosen according to Brazil's standard for the cerrados area (3 years of leguminose crop and pH above 5.5) where the soils show normal bulk density. A field characterization of the area was done in order to know the soil conditions before and after soil compactions and the parameters studied were:

1. Bulk Density: Volume and weight method - Uhland Probe

2. Particle Size Distribution: Pippete Method

3. Pore Size Distribution: Pressure Plate Method

4. Aggregate Stability: Wet Sieve Method.

These parameters were determined in each one of 10 treatments and all 3 replications at 0-7.5, 7.5-15, 15-22.5, 22.5-30, 30-37.5, 37.5-45 cm depth.

Without Irrigation					With Irrigation				
2	3	4	5	1	8	9	10	7	6
1	5	3	4	2	8	10	6	7	9
3	1	4	5	2	9	6	7	10	8

Plot Size: 18 rows 16 m x 20 m

Soil: Dark Red Latosol

Treatments	Compaction Levels	Irrigation
1	0 Tractor Pass	without
2	1 Tractor Pass	without
3	5 Tractor Passes	without
4	10 Tractor Passes	without
5	10 Tractor Passes + subsoiler	without
6	0 Tractor Pass	with
7	1 Tractor Pass	with
8	5 Tractor Passes	with
9	10 Tractor Passes	with
10	10 Tractor Passes + subsoiler	with

Figure 2. Experimental Field Plot Design for a Soil Compaction-Corn Yield Model for a Dark Red Latosol, Sete Lagoas, Minas Gerais, Brazil, 1983.

Disk plowing at 20 cm depth and two passes of a disk harrow were used as the tillage practice preparation of a uniform soil bed.

A Laboratory compaction curve was obtained by using the Proctor Test, Standard AASHTO (1978), Designation T 99 (see figure 3). Three compactive efforts were used: 15 Blow-Proctor (354 KPa), Standard Proctor (503 KPa) and Modified Proctor (2693 KPa).

The soil moisture content at which the compaction is critical was determined based on values obtained by three compactive curves. The optimum moisture content for maximum density was obtained from the 15-Blow Proctor and the Standard Proctor Curve which gives a value of a compactive effort close to that of a field tractor compactive effort, Cohron (1971). A Ford 6600 tractor carrying a disk harrow on a "up-position", with 4900 kg of weight, was used as static force, to establish compaction levels (see Figure 4). The R-1 tractor tire (18.4/15-30) was used, and its front and rear tire contact pressure was 0.70 kg/cm^2 and 0.78 kg/cm^2 respectively (see Figure 5).

Five compaction levels were chosen for planting maize within the optimum range of soil moisture content (32-35%): zero tractor pass, one tractor pass, five tractor passes, ten tractor passes and ten tractor passes followed by subsoiling. Two irrigation levels were used: zero and sufficient water supply to maintain corn crop under those five different compaction levels without stress. The ten treatments and three replications were compacted on November 7, 8 and 9th and planted on November 9th, 1983. A Turbo-Max 3-row planter was used, with no-till coulter disks, with a 0.90 m row spacing set to plant 120 thousand seeds per hectare for a final stand of 60 thousand plants. Corn crop fertilizer application was made based on soil analysis following "Recommendacoes para uso de Corretivos e Fertilizantes em Minas Gerais" (1978).

Figure 3. Proctor Test

Figure 4. Soil compaction of the plots

Two-hundred kg/ha of the 8-28-16 NPK formulation was used during planting and Nitrogen was applied 45 days after planting with a dosage 40 kg/ha.

Soil moisture content was measured for each of the compaction and water levels for all three replications during the corn crop. Access tubes were placed on the middle row, at least 6 m from the plot border.

The Neutron-Scattering method measured water content using McHenry's (1962) theory.

Also, soil moisture content was measured weekly after planting until the corn reached physiological maturity with the combination Troxler Neutron Probe-Scaler Ratemeter (2600 series) at the following depths: 00-20, 20-40, 40-60, 60-80 and 80-100 cm depths (see Figure 6).

Plant population was programmed to be double at planting to avoid germination losses and corrected to an optimum plant stand of 60,000 plants per hectare 8 weeks after planting (see Figures 7 and 8). Plant height data was obtained by randomly choosing and measuring 10 plants in each of the 10 treatments in all 3 replications during the 4th and 8th weeks after planting.

A soil core was taken around one randomly selected plant in each plot by using a Hammer probe (see Figures 9 and 10). Core dimensions are: 7.0 cm in diameter by 7.5 cm deep. The core sample was taken during the corn tasseling stage at 0-7.5, 7.5-15, 15-22.5, 22.5-30, 30-37.5 and 37.5-45 cm depths. The roots in each core segment were washed free of soil by using a "wet-screening" method.

Figure 5. Contact area measurement.

Figure 6. Soil moisture content measurement.

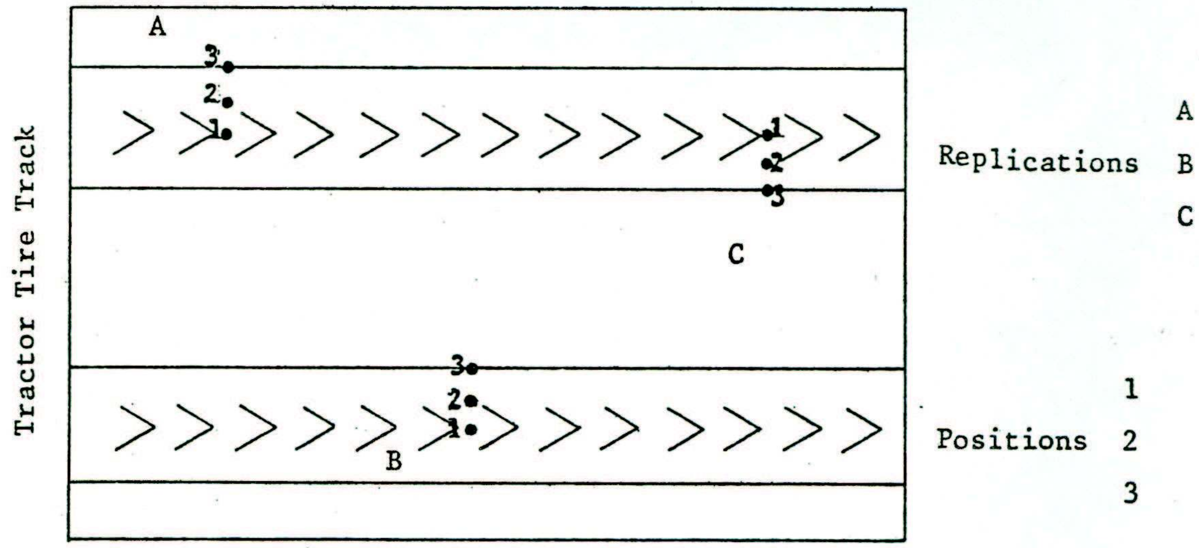
Figure 7. Corn plot in Sete Logoas, Brazil.

Figure 8. Thinning stands to a constant 600 or plot/acre.

Root weight was determined after drying the sample in a forced-air oven at 60^{o}C for a minimum of 48 hours.

Soil bulk density measurements were taken in all ten treatments and three replications by using a hammer-driven soil core sample (Uhland Probe) similar to that described by U.S. Department of Agriculture Handbook 60 (1954). The Bulk densities were determined during tasseling period (maximum root development) at 0-7.5, 7.5-15, 15-22.5, 22.5-30, 30-37.5 and 37.5-45 cm depths, measured between the seventh and nineth rows.

The Cone Penetrometer readings were determined in each plot and all three replications after soil compaction, 3 places/plot, 3 positions/place (5, 10, 15, 20, 25, 30, 35, 40 cm depth), according to the following procedure:



A sprinkler system supplied water at a head rate of 10 mm/hr from January 16 (stress period), 6 hours/week until February 22, for the plots on all three replications. The amount of water applied was

Figure 9. Corn root system of a compaction level (1 tractor pass).

Figure 10. Root sample.

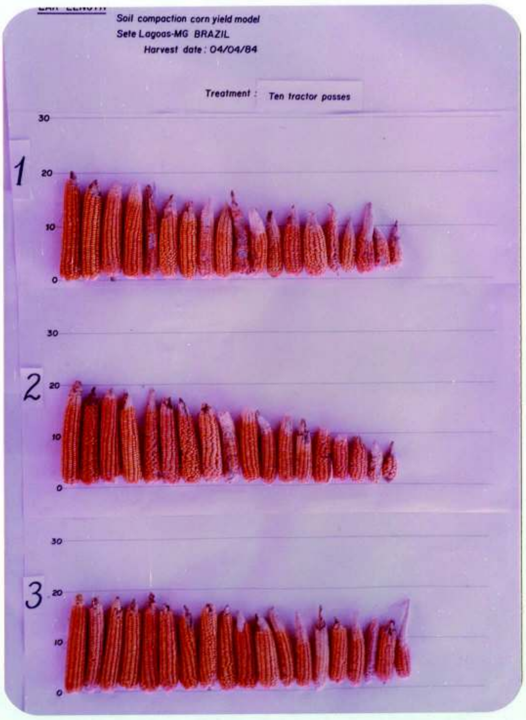


Figure 11. Ear length of a compaction level (zero tractor pass) with irrigation.

Figure 12. Ear length of compaction level (zero tractor pass) without irrigation.

calculated according to the evapotranspiration of the area during these two months (6.0 mm/day).

Nine rows in corn plots 10 m long were harvested by hand to obtain the yield data (see Figures 11 and 12).

RESULTS AND DISCUSSION

The compaction curve is shown on Figure 13 and Appendix Table 1. There are 16 points for each one of the three compactive levels. The maximum dry density versus optimum moisture content is given as:

	Maximum Dry Density (g/cc)	Optimum Moisture Content (%)
Modified Proctor	1.47	28
Standard Proctor	1.32	32
15-Blows Proctor	1.29	35

The plots were compacted at the 30-32% moisture content range determined by the standard proctor curve for maximum dry density. In Figure 14, the water retention curve shows 30-32% moisture content for field capacity. Therefore the soil compaction was performed at the critical moisture content for Dark Red Latosol.

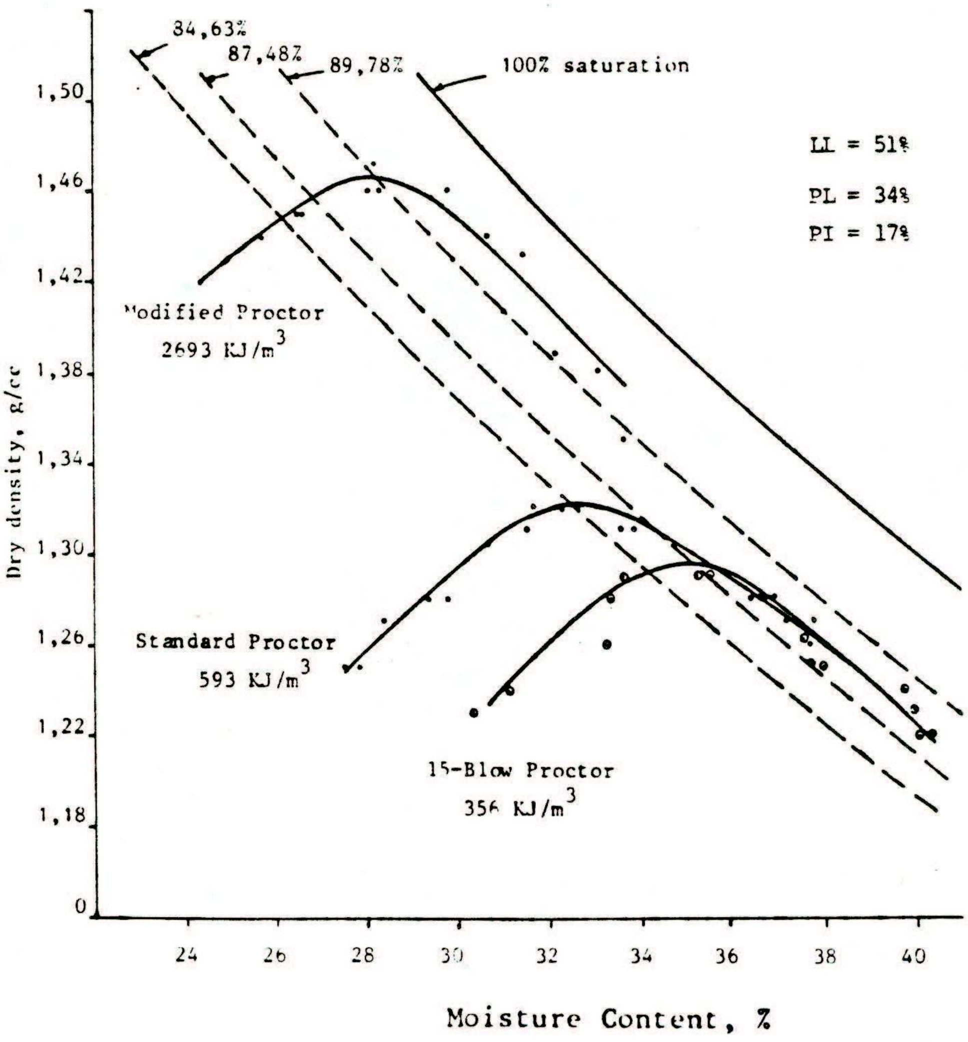


Figure 13. Dark red latosol compaction curve

Cone penetrometer readings were taken after soil compaction and the results are shown in Figures 15, 16 and 17.

The analysis of variance of penetrometer resistance is given on Table 4. There is significant difference among the treatments (number of tractor passes). The tukey test, 5% probability level was used to separate the means and the results are shown in Table 5, 6 and 7.

The compaction levels (number of tractor passes) were evident until a depth soil layer of 15 cm. Also the soil compaction in the plot area was very uniform, as shown in Figure 15, 16 and 17. In Figure 5 the soil layer below 15 cm depth, treatments: 0, 1 and 5 tractor passes become (appendix table 5) even and ten tractor passes continued to show higher values of penetrometer resistance (1055-2391 KPa) with the tendency to level off at a constant value compared with the other three treatments at depths below 40 cm. Ten tractor passes + subsoiler showed significant difference among the five treatments and the lowest penetrometer resistance values (2-793 KPa) in all nine soil depths, as can be seen in Figure 15.

The soil characterization before compaction shown in Table 8 depicts pore size distribution for the Dark Red Latosol with 60% total pore space (22% macropores and 38% micropores) at all 6 depths (0-7.5, 7.5-15, 15-22.5, 22.5-30, 30-37.5 and 37.5-45 cm).

After soil compaction, the results showed substantial reduction in percentage of macropores and increase on the percentage of micropores without modifications on the total pore space. Byrnes (1982) showed that the volume of pore space lost from agricultural soil due to

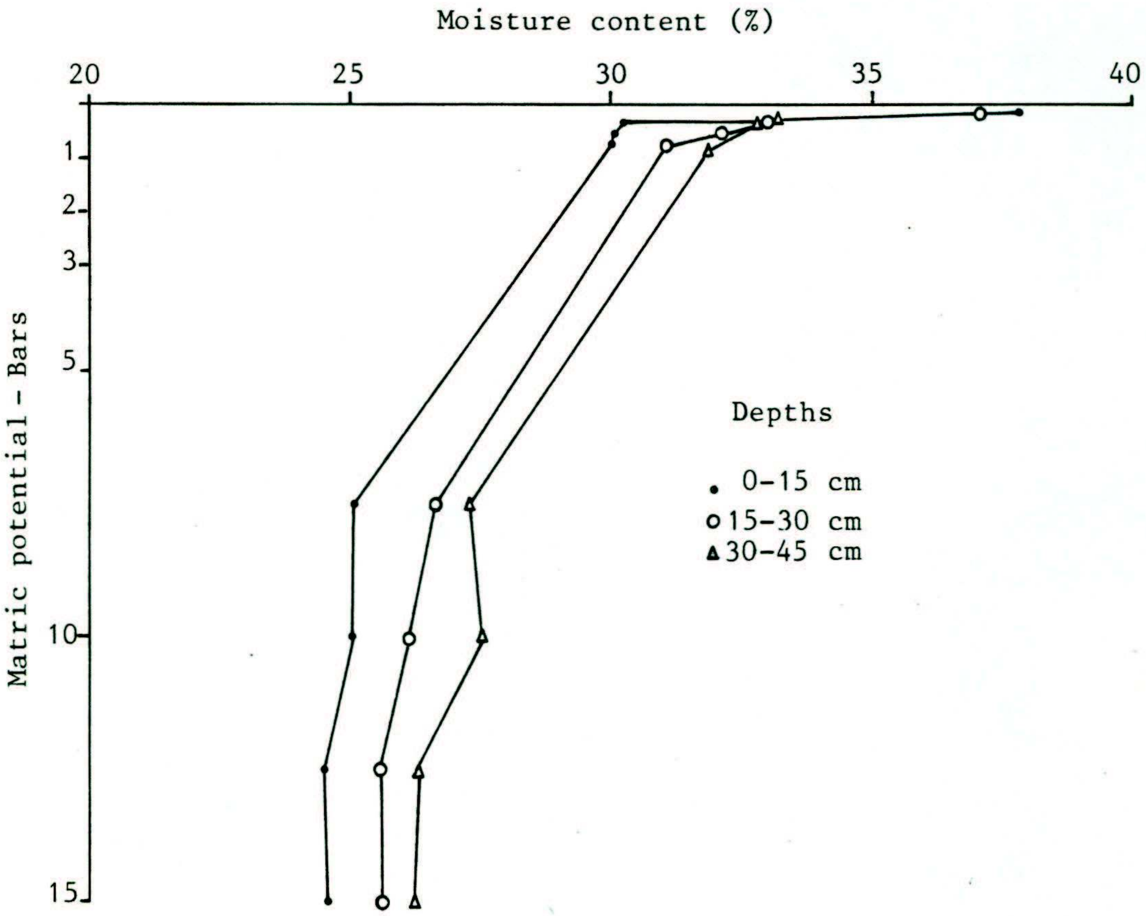


Figure 14. Dark red latosol water retentions curve.

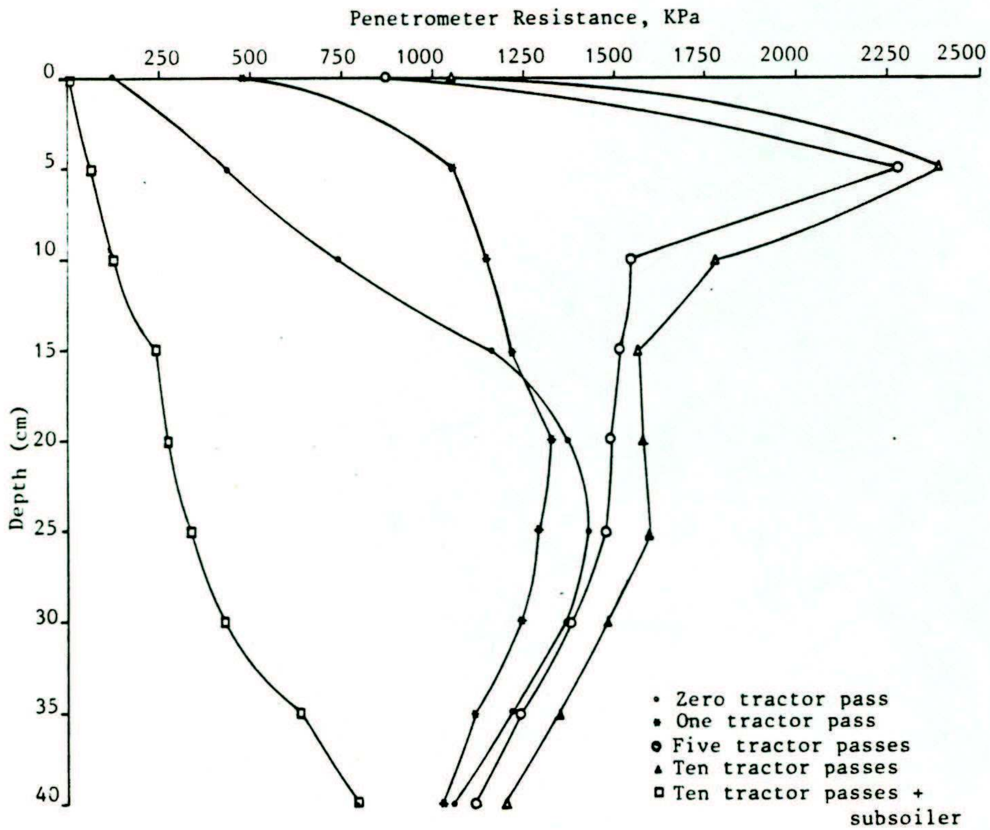


Figure 15. Dark red latosol penetrometer resistance curve at five compaction levels (number of tractor passes) at nine depths.

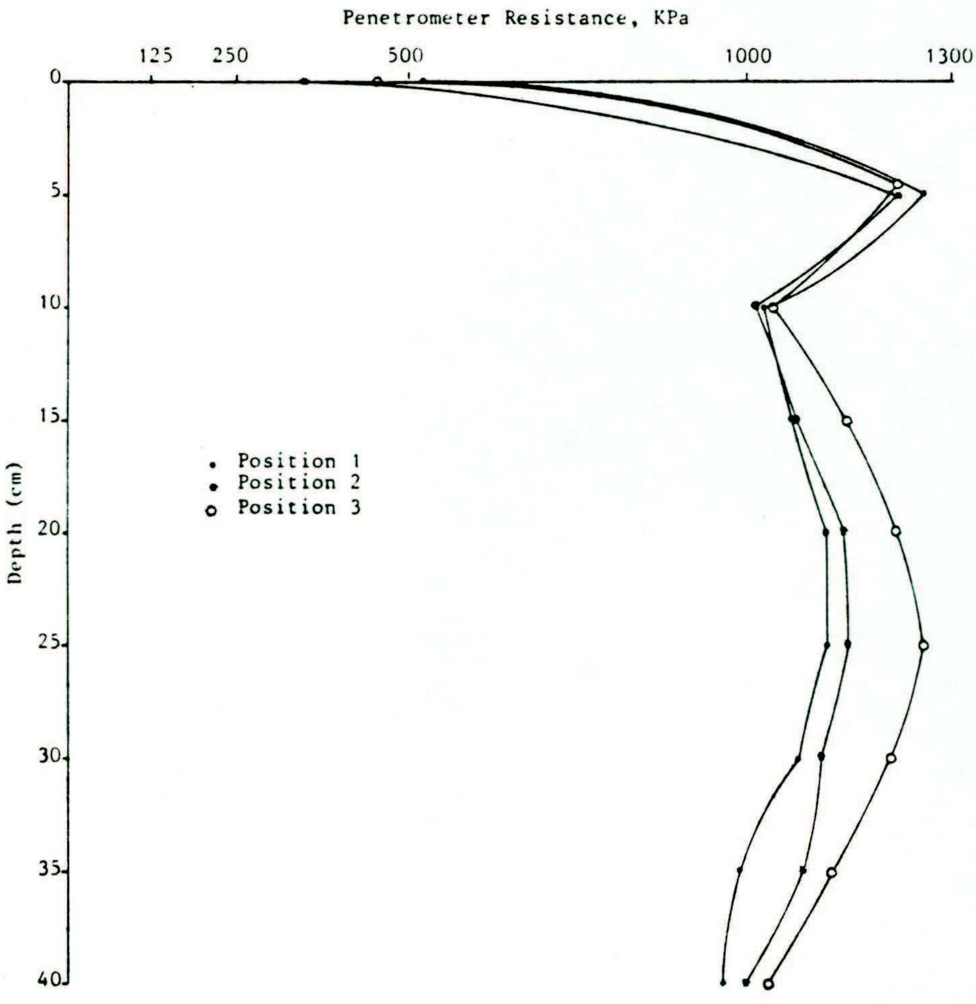


Figure 16. Dark red latosol penetrometer resistance curve of three positions, of the same tire track at nine depths.

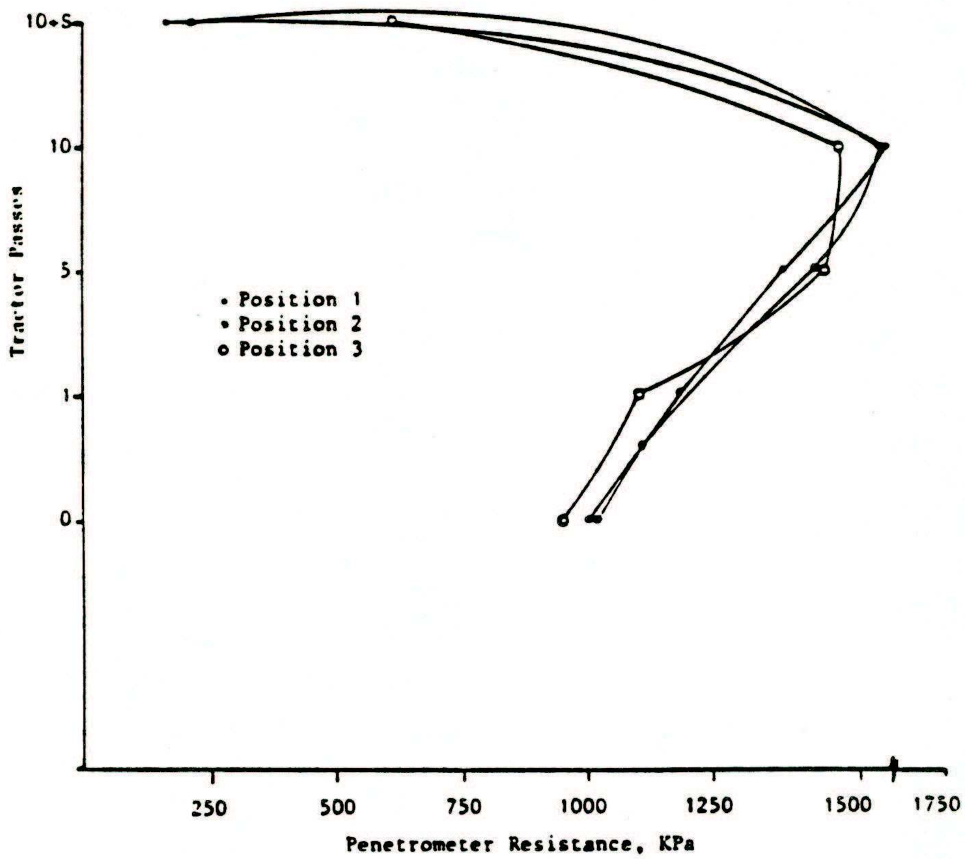


Figure 17. Dark red latosol penetrometer resistance curve of three positions of the same tire track under five compaction levels (Number of tractor passes).

Table 4. Analysis of variance of penetrometer resistance.

Source of Variation	Degree of Freedom	Sum of Squares	Mean Squares	F
Replication (R)	17	17107724.8124	1006336.7537	11.62
Position (P)	2	1826939.7513	913469.8757	10.55 **
Tractor Passes (TP)	4	454880922.6874	113720230.6719	1313.14 **
Depth (D)	8	115558317.6431	14444789.7054	166.80 **
P x TP	8	19901484.3186	2487685.5398	28.73 **
P x D	16	2600610.0334	162538.1271	1.88 *
TP x D	32	162209049.8206	5069032.8069	58.53 **
L x TP x D	64	7392032.5479	115500.5086	1.33 *
Error	2278	197278109.4924	86601.4528	
Total	2429	978755191.1071		

Mean = 1087.1246 C.V. = 27.07%

** significant difference at 1% probability level
* significant difference at 5% probability level

Table 5. Dark red latosol penetrometer resistance (KPa) at five compaction levels (number of tractor passes) at nine depths (average of 18 replications).

Number of Tractor Passes	Depth (cm)									Average
	0	5	10	15	20	25	30	35	40	
0	122 d	438 c	741 d	1165 b	1372 bc	1429 bc	1374 ab	1217 ab	1056 ab	990 D
1	482 c	1265 b	1152 c	1219 b	1327 c	1304 c	1249 b	1123 b	1036 b	1129 C
5	867 b	2272 a	1551 b	1517 a	1490 ab	1476 ab	1384 ab	1239 ab	1121 ab	1435 B
10	1055 a	2392 a	1781 a	1568 a	1585 a	1597 a	1482 a	1351 a	1205 a	1557 A
10+S	2 d	64 d	130 c	239 c	272 d	338 d	434 c	642 c	793 c	324 E
Average	506 g	1286 a	1071 e	1142 cde	1209 abc	1229 ab	1185 bcd	1114 def	1047 f	

*Same letter denotes no significant difference among treatments.

**Averages followed by the same low case letter in the column and by the same capital letter in line are not statistically different at the 5% probability level by the Tukey test.

Table 6. Dark red penetrometer resistance (KPa) of three positions of the same tire track under five levels (Number of tractor passes).

Position	Tractor Passes					Average
	0	1	5	10	10+S	
1	1001 a	1177 a	1383 b	1586 a	160 b	1062 B
2	1020 a	1111 ab	1453 ab	1583 a	206 b	1075 B
3	950 a	1098 b	1470 a	1503 b	605 a	1125 A
Average	990 d	1129 c	1435 b	1557 a	323 c	

* Same letter denotes no significant difference among treatments.

**Averages followed by the same low case letter in the column and by the same capital letter in line are not statistically different at the 5% probability level by the Tukey test.

Table 7. Dark red latosol penetrometer resistance (KPa) of three positions of same tire track at nine depths.

Position	Depth (cm)									Average
	0	5	10	15	20	25	30	35	40	
1	541 a	1319 a	1073 a	1111 a	1169 a	1170 b	1128 b	1034 b	1008 a	1062 B
2	500 a	1269 a	1056 a	1116 a	1194 a	1200 b	1160 b	1133 ab	1043 a	1075 B
3	476 a	1269 a	1084 a	1199 a	1265 a	1316 a	1265 a	1176 a	1076 a	1125 A
Average	506 g	1286 a	1071 ef	1142 cde	1209 abc	1229 ab	1185 bcd	1114 def	1042 f	

* Same letter denotes no significant difference among treatments.

**Averages followed by the same low case letter in the column and by the same capital letter in line are not statistically different at the 5% probability level by the Tukey test.

Table 8. Dark red latosol pore size distribution (%) for all ten treatments at six depths after soil compaction (Average of 3 replications).

Depth (cm)	Pore Size	Treatments (Number of tractor passes) w/o irrigation					w/irrigaton				
		0	1	5	10	10+S	0	1	5	10	10+S
7.5	Micro	41	43	43	42	39	42	44	46	46	42
	Macro	22	18	19	17	24	25	17	13	13	21
	Total	53	62	62	59	63	67	61	58	58	62
15	Micro	41	43	42	43	42	44	43	44	48	45
	Macro	18	19	18	17	18	21	21	15	15	14
	Total	59	61	60	60	70	54	64	69	62	59
22.5	Micro	38	42	42	42	41	41	43	43	43	45
	Macro	21	19	17	18	19	24	19	19	18	14
	Total	59	61	60	60	60	64	61	62	61	59
3.0	Micro	40	40	39	40	38	38	38	42	45	42
	Macro	22	20	24	22	22	25	23	19	16	18
	Total	62	60	63	62	60	63	61	61	61	60
37.5	Micro	39	36	40	41	39	44	40	41	41	43
	Macro	22	29	22	21	23	18	23	20	21	17
	Total	62	65	62	62	62	63	64	61	62	61
45	Micro	38	41	38	39	39	40	37	41	41	41
	Macro	24	23	26	25	25	25	21	21	22	22
	Total	62	63	64	63	63	64	58	62	63	62

compaction by equipment is approximately equal to the volume of ruts produced by that equipment and those with high depth-width the ratios cause compaction at comparatively greater depths. This change in pore space didn't occur on the Dark Red Latosol soil and the expected changes in the soil density didn't happen, as one can see in Table 9. Note that the soil density was 1.08g/cm^3 compared to Gaultney's compaction silt loam soil of 1.80 g/cm^3. Also, total pore space for 1 tractor pass was 60% with additional 10 tractor passes the value was the same, 59% at 22.5 cm depth.

Soil density was measured 70 days after planting (maximum root development) as shown in Table 9. Also, the rainfall distribution was above the normal (around 550 mm) during this study. Two points are made. First, after compaction, the penetrometer resistance showed a high soil strength with a 32% moisture content soil. This depicts that the soil absorbed the compression exerted by the tractor and disk harrow weight for the different number of tractor passes. The second point is related to density. The soil density results did not show compaction problems in the plots with high penetrometer resistance seventy days after planting. Either the Dark Red Latosol reacted during the rainfall period or the compression applied by the tractor and Disk Harrow weight was not enough to change density to values considered detrimental to the corn crop. It is clear that there was modification on soil particle rearrangements as shown on the pore size distribution data after compaction (Table 8). As one decreases the size particle, the exposure area

Table 9. Dark red latosol bulk density (g/cm^3) for all ten treatments at six depths after soil compaction taken 70 days after planting (maximum root development).

Treatment Number of tractor passes		Replication	Depth (cm) 0-7.5	7.5-15	15-22.5	22.5-30	30-37.5	37.5-45
0		1	1.05	1.08	1.08	1.00	1.12	0.98
		2	0.97	1.04	1.07	1.07	0.98	1.05
		3	0.94	0.97	1.07	1.03	1.03	0.99
		AVG.	0.99	1.03	1.07	1.03	1.04	1.01
1		1	0.98	1.06	1.06	1.11	0.97	1.03
		2	1.11	1.06	1.05	1.09	0.98	1.05
		3	0.98	1.01	1.01	1.02	1.01	0.96
		AVG.	1.02	1.04	1.04	1.07	0.99	1.01
5	w/o irrigation	1	1.05	1.04	1.07	1.00	0.96	0.95
		2	1.15	1.13	1.11	1.04	1.12	0.99
		3	1.00	1.01	1.06	1.00	1.04	1.06
		AVG.	1.07	1.06	1.08	1.01	1.04	1.00
10		1	1.11	1.11	1.06	0.99	0.97	0.95
		2	1.13	1.07	1.13	1.07	1.13	1.07
		3	1.15	1.08	1.09	1.04	1.03	0.98
		AVG.	1.13	1.08	1.09	1.06	1.04	1.00
10+S		1	0.97	1.08	1.12	1.04	0.98	1.00
		2	0.96	1.06	1.04	1.12	1.03	1.06
		3	0.98	1.09	1.10	1.06	1.02	1.02
		AVG.	0.97	1.08	1.09	1.07	1.01	1.03
0		1	0.84	1.04	0.98	0.97	1.03	0.95
		2	1.09	1.00	0.98	1.06	1.04	0.99
		3	1.10	1.07	1.04	1.01	1.01	1.03
		AVG.	1.01	1.04	1.00	1.01	1.03	0.99
1		1	1.03	0.96	1.08	0.95	0.98	1.03
		2	1.03	1.06	0.97	1.02	1.03	0.91
		3	1.07	1.13	1.08	0.98	0.99	1.01
		AVG.	1.04	1.05	1.04	0.98	1.00	0.98
5	w/irrigation	1	1.10	1.06	1.00	1.01	0.98	1.00
		2	1.12	1.07	1.10	1.10	1.04	1.02
		3	1.15	1.11	1.08	1.04	1.10	1.05
		AVG.	1.12	1.08	1.06	1.05	1.04	1.02
10		1	1.12	1.13	1.05	1.04	1.02	1.03
		2	1.03	1.06	1.10	1.05	1.01	0.96
		3	1.08	1.07	1.02	1.05	1.02	1.00
		AVG.	1.08	1.07	1.02	1.05	1.02	1.00
10+S		1	0.90	1.02	1.09	1.01	1.05	0.99
		2	1.09	1.15	1.12	1.12	1.07	1.04
		3	1.07	1.17	1.15	1.10	1.05	1.02
		AVG.	1.02	1.11	1.12	1.08	1.06	1.02

**Volume and weight method - Uhland probe increases. According to Rezende (1981) in temperate regions having soil containing 2.1 silicate clay type, presents small particle size and consequently high contact surface. In tropical regions, like Brazil, the silicate clays type presents a big particle size and consequently small contact surface.

This implies, that the bigger the contact surface, the bigger the forces between particles. When compression force is applied to the soil, particle reorganization could be a result. In the case of American soils, particle reorganization when submitted to compression forces occurs readily due to the absence of Fe_2O_3 and high contact surface.

In the specific case of the Dark Red Latosol, there is more difficulty in organizing soil particles due to mineralogic composition.

$$\underset{\text{Gibbsite}}{AL(OH_3)} + \underset{\text{Goethite}}{FeOOH + H_2O} + \underset{\text{Hematite}}{Fe_2O_3} + \text{organic matter}$$

These iron oxides and aluminum hyroxides work as a wedge between the clay layers. Therefore, it is necessary to have higher compression force to break these "wedges" and compress these layers together, and to increase the contact surface.

The analysis of variance (ANOVA) on Table 10 and 11 showed no significant difference among the treatments for plant height at 4th and 8th weeks after planting. Irrigation level in the ANOVA showed significance in affecting plant height 8 weeks after planting. The plants with irrigation showed better growth compared with the plants without irrigation. In Table 10 an F value of greater than 3 for the irrigations level and greater than 2.28 for the treatment means statistical difference at 90% significant level.

Table 10. Analysis of variance of plant height four weeks after planting.

Source of Variation	Degree of Freedom	Sum of Square	Mean Square	F	
Block	2	678.746	339.373		
Irrigation Level (IL)	1	28.0333	28.0333	2.57	ns
Treatment (T)	4	70.4313	17.6078	1.62	ns
IL x T	4	13.5767	3.3949	0.31	ns
Error	18	195.9406	10.8856		
Total	29	986.7279			

Mean = 50.92 C.V. = 6.48%

ns = no significant difference

Table 11. Analysis of variance of plant height eight weeks after planting.

Source of Variation	Degree of Freedom	Sum of Square	Mean Square	F	
Block	2	2103.6167	1051.8083		
Irrigation Level (IL)	1	5964.3000	5964.3000	24.34	**
Treatment (T)	4	1884.2500	471.0625	1.92	ns
IL x T	4	1042.2833	260.5708	1.06	ns
Error	18	4410.2167	245.0120		
Total	29				

Mean = 165.1667 C.V. = 9.48%

ns = no significant difference

Comparing penetrometer resistance on Figure 15, with corn root distribution, on Figures 18 and 19 and rainfall variation during the growth period gives an understanding of what happened to the corn root distribution in this study (see Figures 20 and 21). The results show that all

10 treatments followed the same pattern and are not different. The soil strength showed on the penetrometer resistance data (as shown in Figure 15) disappeared, during rainfall period (60 days). The precipitation average was 300 mm/month which is above the average during the 60 days of rainfall when maximum corn root development takes place. That is the reason why the treatments that received additional irrigation water did not show difference in terms of root distribution.

The analysis of variance of root distribution on Table 12 showed no significant difference among the ten treatments at six different depths (0-7.5, 7.5-15, 15-22.5, 22.5-30, 30-37.5, 37.5-45 cm).

Table 13 shows the analysis of variance of soil moisture content. There was significant difference among the ten treatments and five depths during the nineteen weeks.

The treatments did not show significant difference until the 9th week after planting when the rainfall variation was high. Treatments 1 to 5 started to loose water right after a dry period. Treatments 6 to 10 gained water with irrigation as seen in Figures 22 and 23. At this time (9th week) significant difference can be detected among the ten treatments and is shown in Table 14. One interesting result in Table 14 and Figure 22 and 23 is related to the wet period. Again on weeks 11, 12 and 13 the ten treatments showed the same pattern and a significant difference did not happen. But, during the dry period, weeks 14, 15 and 16, the treatments 1 to 5, with low moisture content for a long time did not show significant difference among themselves but showed significant

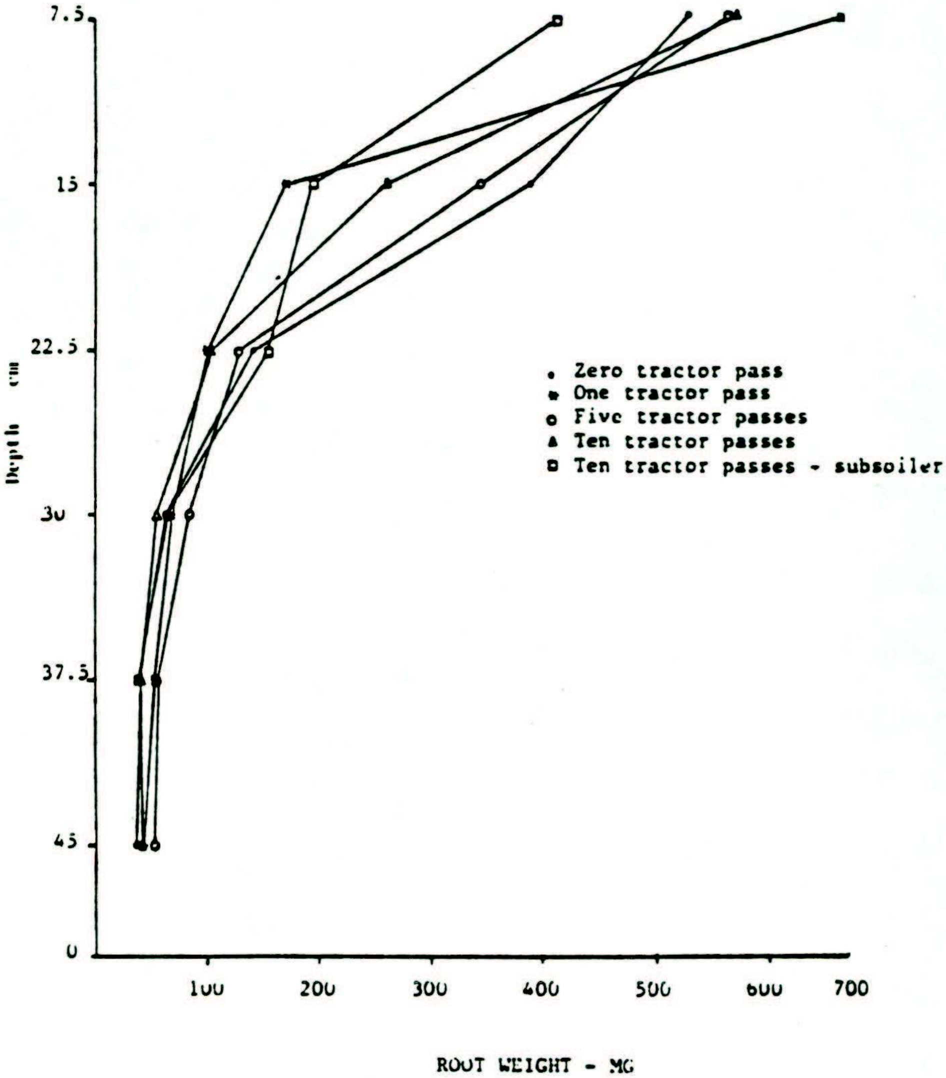


Figure 13. Mean corn root distribution as affected by compaction levels w/o irrigation measured in row (1984).

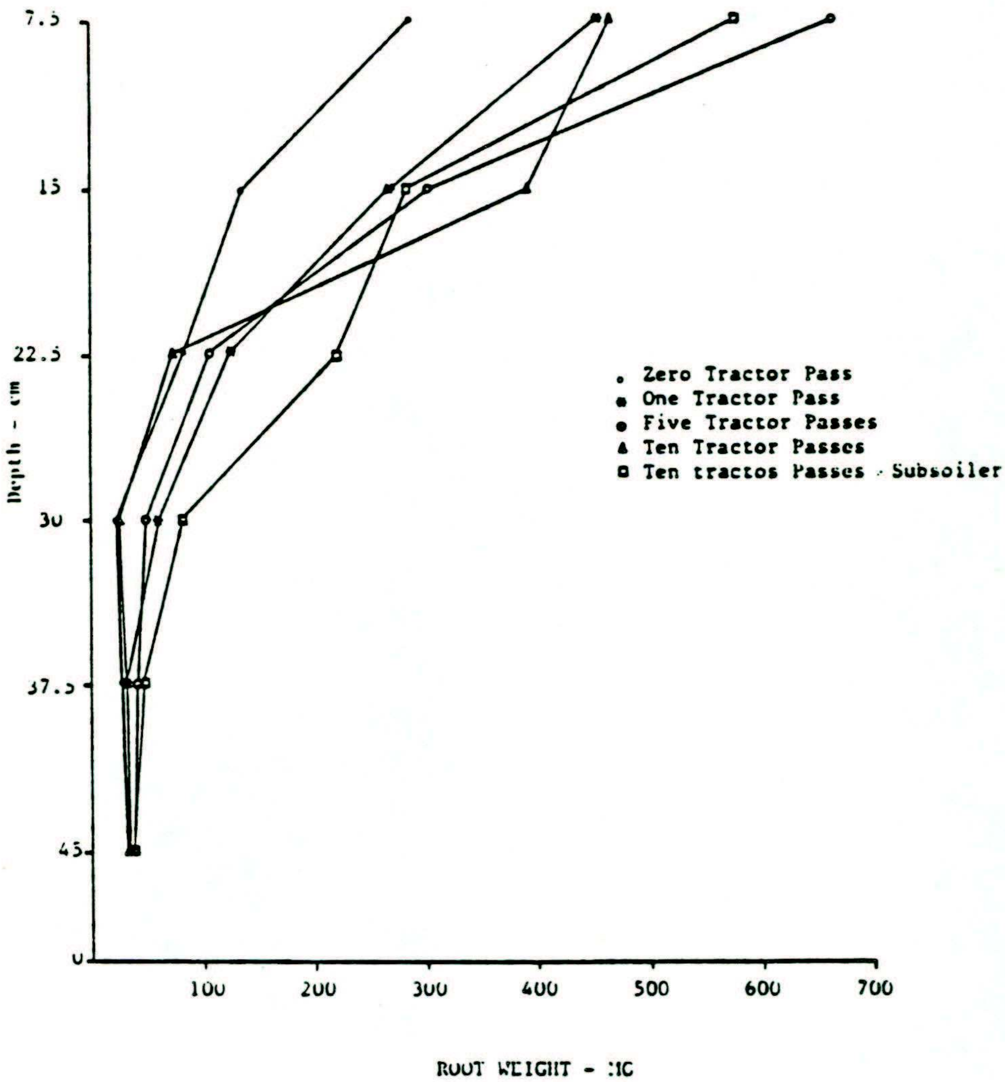


Figure 19. Mean corn root distribution as affected by compaction levels w/irrigation measured in row (1984).

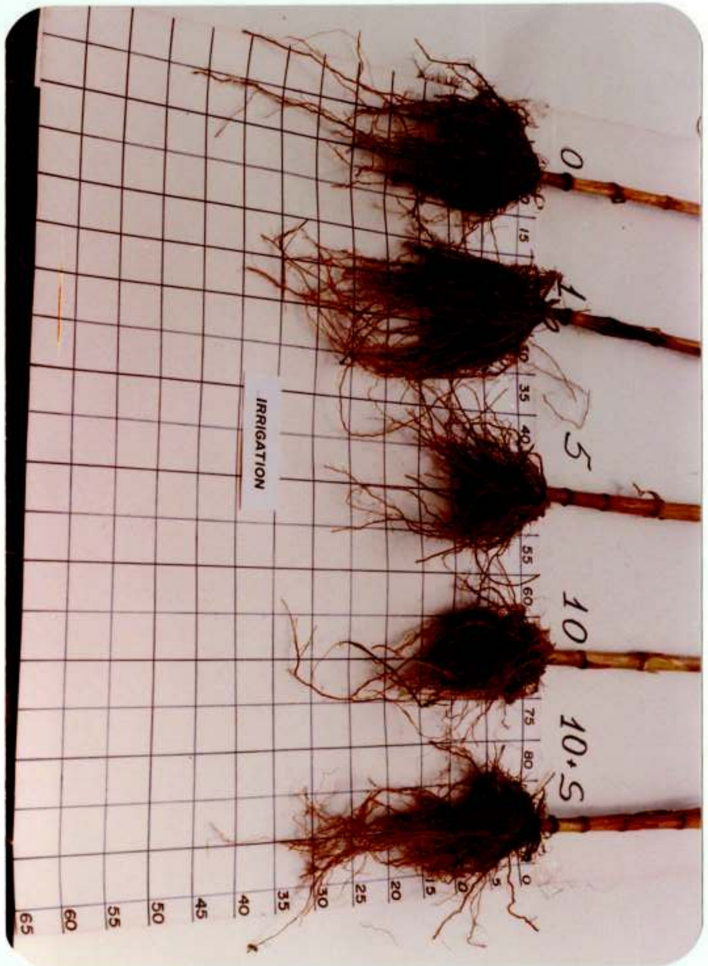


Figure 20. Root system of the compaction levels w/irrigation.

Figure 21. Root system of the compaction levels w/o irrigation.

Table 12. Mean square from analysis of variance of root weight at six different depths.

Source of Variation	Degree of Freedom	Mean Square Depth (cm)					
		0-7.5	7.5-15	15-22.5	22.5-30	30-37.5	37.5-45
Block	2	0.0459	0.0421	0.0006	0.0024	0.0000	0.0002
Irrigation Level (IL)	1	0.0014	0.0571	0.0005	0.0026	0.0000	0.0001
Treatment (T)*	4	0.0307	0.0245	0.0083	0.0013	0.0001	0.0000
IL x T	4	0.0886	0.0536	0.0043	0.0009	0.0004	0.0001
Error	18	0.0396	0.0412	0.0071	0.0018	0.0002	0.0002
CV		40.28	39.54	69.24	74.73	69.29	68.64
Average		0.4941	0.3029	0.1214	0.0566	0.0246	0.0244

*No significant difference among the six depths for each of the ten treatments.

Table 13. Analysis of variance of soil moisture content of the ten treatments, six depths and nineteen weeks after planting.

Source of Variation	Degree of Freedom	Sum of Squares	Mean Squares	F
Replication	2	2.7411	0.3706	8.07 **
Treatment (T)	9	68.6936	7.6326	44.95 **
Depth (D)	4	321.1945	80.2986	472.89 **
Week (W)	18	1618.4978	89.9165	529.53 **
T x D	36	26.6361	0.7399	4.36 **
T x W	162	196.7608	1.2146	7.15 **
D x W	72	131.1575	1.8215	10.73 **
T x D x W	648	77.4871	0.1196	0.70 ns
Error	1898	322.2900	0.1698	
Total	2849	2765.4586		

Mean = 6.6385 C.V. = 6.21%

** Significant difference at 5% level.
ns No significant difference.

Table 14. Interaction effect of treatment (number of tractor passes) x weeks after planting on soil moisture content by volume.

Treatments Number of tractor passes		Weeks 1	2	3	4	5
1) 0	w/o irrigation	7.61 a AB	7.84 a A	7.43 a ABC	7.63 a AB	7.57 a AB
2) 1	w/o irrigation	7.63 a A	7.83 a A	7.61 a A	7.65 a A	7.55 a AB
3) 5	w/o irrigation	7.71 a AB	7.98 a A	7.69 a AB	7.89 a AB	7.84 a A
4) 10	w/o irrigation	7.83 a AB	8.07 a A	7.59 a ABC	8.01 a A	7.82 a AB
5) 10+S		7.81 a AB	8.03 a A	7.59 a ABC	7.77 a AB	7.81 a AB
6) 0	w/irrigation	7.57 a A	7.66 a A	7.35 a AB	7.55 a A	7.57 a A
7) 1	w/irrigation	7.59 a A	7.71 a A	7.28 a AB	7.62 a A	7.51 a A
8) 5	w/irrigation	7.50 a A	7.84 a A	7.41 a AB	7.55 a A	7.58 a A
9) 10	w/irrigation	7.62 a AB	7.93 a A	7.39 a BC	7.71 a AB	7.58 a AB
10) 10+S		7.65 a AB	7.80 a A	7.43 a ABC	7.55 a AB	7.55 a AB
Average		b	a	a	b	b

**Averages followed by the same low case letter in the column and by the same capital letter in the line are not statistically different at the 5% probability level by the Tukey test.

Table 14 (cont).

Treatments Number of tractor passes		Weeks 6	7	8	9	10
1) 0	w/o irrigation	6.75 a DEF	7.21 abc BCD	6.38 a FG	6.27 ab FG	5.65 bcd HIJ
2) 1		6.75 a CDE	6.85 c CD	6.28 a EFT	6.03 b FGH	5.42 d IJK
3) 5		7.01 a CD	7.33 abc BC	6.41 a EF	6.17 ab EFG	5.59 cd HIJ
4) 10		7.16 a CD	7.31 abc BCD	6.62 a EF	6.38 ab FG	5.63 bcd HI
5) 10+S		7.11 a CD	6.47 a BC	6.73 a DE	6.58 a E	5.74 bcd FGH
6) 0	w/irrigation	6.74 a CDE	7.02 abc BC	6.50 a CDEF	6.21 ab EF	6.50 a CDEF
7) 1		6.82 a BCDE	7.21 abc ABC	6.42 a EFG	6.29 ab FG	6.02 bc G
8) 5		6.81 a CD	6.97 bc BC	6.36 a DEF	6.11 ab EFG	6.10 ab EFG
9) 10		6.85 a DE	6.38 ab BCD	6.44 a EFGH	6.10 b GH	5.99 bc H
10) 10+S		6.94 a CD	7.17 a c BC	6.48 a DEFG	6.29 ab EFG	5.99 bc GH
Average		e	d	f	g	i

Table 14 (cont).

Treatments Number of tractor passes		Weeks 11	12	13	14	15
1) 0	w/o irrigation	6.93 cd CDE	6.60 a EF	6.03 ab CH	5.48 d IJ	5.44 de IJ
2) 1		7.07 bcd BC	6.47 a DEF	5.93 ab GHI	5.36 d JK	5.32 e JK
3) 5		7.14 bcd C	6.62 a DE	5.88 b GHI	5.57 cd HIJ	5.39 e IJ
4) 10		6.97 cd DE	6.51 a EF	5.87 b GH	5.44 d HI	5.36 e HI
5) 10+S		7.67 a AB	6.56 a E	6.22 ab EF	5.56 d GH	5.43 e HEF
6) 0	w/irrigation	7.49 ab AB	6.64 a CDE	6.10 ab F	6.31 ab DEF	6.45 a DEF
7) 1		7.50 ab A	6.76 a BCDEF	6.37 a EFG	6.54 a DEFG	6.43 ab DEFG
8) 5		6.80 d CD	6.59 a CDE	6.10 ab EFG	6.23 ab EFG	5.90 cd FGH
9) 10		6.87 cd CDE	6.57 a EFG	5.87 b CDE	6.11 ab FGH	6.03 abc H
10) 10+S		7.28 abc ABC	6.59 a DE	6.11 ab EFGH	6.04 bc FGH	5.96 bc
Average		d	f	h	i	ij

Table 14 (cont).

Treatments Number of tractor passes		Weeks 16			17			18			19			Average	
1) 0	w/o irrigation	5.27	ef	J	5.32	c	J	5.46	d	IJ	5.93	cd	GHI	6.46	d DE
2) 1		5.23	ef	JK	5.17	c	K	5.38	d	JK	5.71	d	HIS	6.38	E
3) 5		5.29	ef	J	5.32	c	J	5.48	d	HIJ	5.97	cd	FGH	6.54	CD
4) 10		5.20	f	I	5.23	c	I	5.46	d	HI	5.86	cd	GH	6.54	CD
5) 10+S		5.36	def	H	5.24	c	H	5.61	d	GH	6.01	cd	FG	6.65	BC
6) 0	w/irrigation	6.64	a	CDE	6.78	a	CD	6.99	a	BC	6.81	a	CD	6.89	A
7) 1		6.17	b	G	6.34	ab	EFH	6.96	a	BCD	6.70	a	CDEF	6.85	A
8) 5		5.80	bcd	GH	5.45	c	H	6.13	c	EFG	6.20	bc	EFG	6.60	C
9) 10		5.95	b	H	6.11	b	FGH	6.64	ab	EF	6.57	ab	EFG	6.72	B
10) 10+S		5.69	cde	H	6.31	ab	EFG	6.47	bc	DEFG	6.55	ab	DEF	6.73	B
Average			j			ij			h			g			

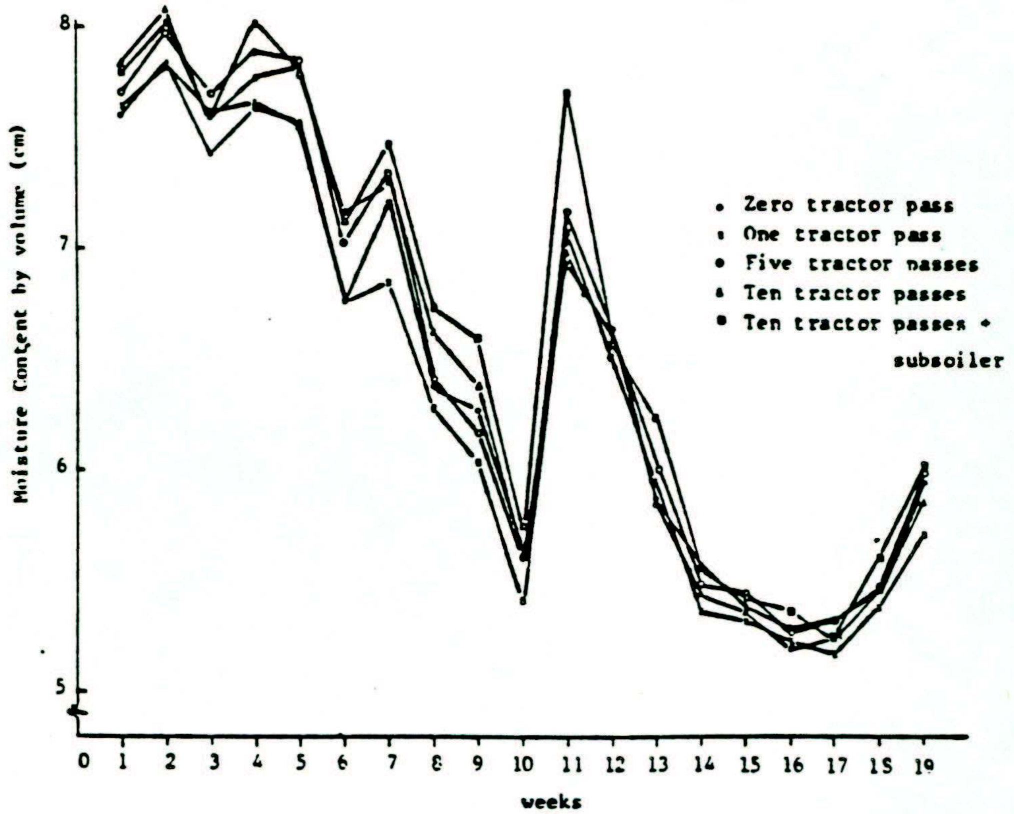


Figure 22. Interaction effect of treatments (number of tractor passes) x weeks after planting without irrigation on soil moisture content.

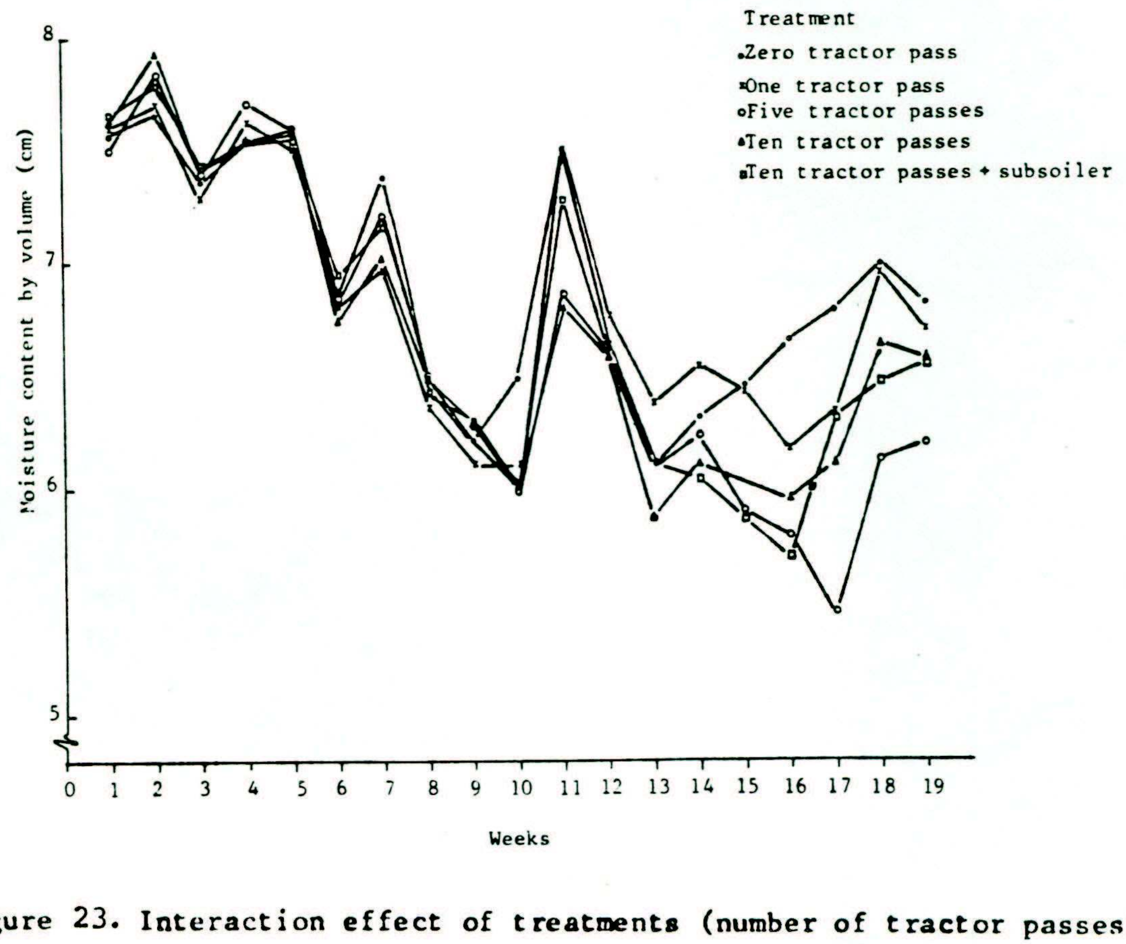


Figure 23. Interaction effect of treatments (number of tractor passes) x weeks after planting with irrigation on soil moisture content.

Table 15. Interaction effect of soil depth (cm) x weeks after planning on soil moisture content.

Depth (cm)	Weeks				
	1	2	3	4	5
0–20	8.10 a BC	8.44 a AB	7.81 a C	8.59 a A	8.28 a AB
20–40	8.25 a AB	8.33 a A	7.83 a CD	8.10 b ABC	7.94 b BC
40–60	7.61 b AB	7.70 b A	7.41 b AB	7.57 c AB	7.44 c AB
60–80	7.29 c A	7.47 bc A	7.24 bc A	7.19 d A	7.26 c A
80–100	7.04 c AB	7.40 c A	7.09 c A	7.09 d A	7.28 c A
Average	b	a	c	b	b

Table 15. (Cont.)

Depth (cm)	Weeks				
	6	7	8	9	10
0-20	7.10 ab D	8.13 a AB	6.73 a EF	6.74 a DEF	6.47 a FG
20-40	7.13 a E	7.54 b D	6.61 ab F	6.41 b FGH	6.036 HIJ
40-60	6.82 bc C	6.84 c C	6.29 c DE	5.95 c EFG	5.51 c H
60-80	67.2 c B	6.60 cd BC	6.27 c CD	5.97 c DE	5.53 c F
80-100	6.70 c BC	6.54 d C	6.42 bc CD	6.14 bc DE	5.78 bc EFG
Average	e	d	f	g	I

Table 15. (Cont.)

Depth (cm)	Weeks				
	11	12	13	14	15
0–20	8.25 a AB	6.90 a DE	6.40 a FG	6.21 a GH	6.16 a GH
20–40	7.76 b CD	6.77 ab EF	6.17 ab GHI	5.87 b IJK	5.75 b JK
40–60	7.27 b B	6.58 bc CD	5.87 c FGH	5.67 e FGH	5.60 b GH
60–80	6.51 bc BC	6.35 c BC	5.86 c EF	5.74 d EF	5.65 b EF
80–100	6.08 d DEF	6.36 c CD	5.94 bc EFG	5.82 c EFG	5.70 b FG
Average	d	f	h	i	ij

Table 15. (Cont.)

Depth (cm)	Weeks				
	16	17	18	19	Average
0-20	5.92 a H	6.14 a GH	6.70 a EF	7.08 a DE	7.18 A
20-40	5.65 ab K	5.76 b JK	6.06 a HIJ	6.53 b FG	6.87 B
40-60	5.53 b H	5.55 b H	5.87 a FGH	6.01 c EF	6.48 C
60-80	5.51 b F	5.59 b F	5.77 a EF	5.81 c EF	5.33 D
80-100	5.68 a G	5.61 b G	5.87 a EFG	5.74 c FG	6.33 D
Average	j	ij	h	g	

Table 16. Interaction effect of treatment (number of tractor passes) x soil depth on soil moisture content.

Treatment: Number of tractor passes		Depth (cm): 0–20	20–40	40–60	60–80	80–100	Average
1) 0	w/o irrigation	7.03 cd A	6.78 bc B	6.38 bcd C	6.00 b D	6.13 de D	6.46 DE
2) 1	w/o irrigation	6.82 d A	6.50 d B	6.20 d CD	6.30 a C	6.08 e D	6.38 E
3) 5	w/o irrigation	7.30 ab A	6.81 bc B	6.37 cd CC	6.04 b D	6.18 de D	6.54 CD
4) 10	w/o irrigation	7.10 cd A	6.72 bcd B	6.43 bcd C	6.41 a C	6.16 de D	6.54 CD
5) 10+S		7.05 cd A	6.86 bc A	6.58 abc B	6.44 a BC	6.31 cde C	6.65 BC
6) 0		7.31 ab A	7.22 a A	6.77 a B	6.53 a C	6.63 a BC	6.89 A
7) 1	w/irrigation	7.34 a A	7.24 a A	6.62 ab B	6.51 a B	6.56 ab B	6.85 A
8) 5	w/irrigation	7.14 bc A	6.72 cd B	6.35 cd C	6.43 a C	6.37 bcd C	6.60 C
9) 10	w/irrigation	7.45 a A	6.87 bc B	6.51 bc C	6.32 a C	6.46 abc C	6.72 B
10) 10+S		7.36 ab A	6.96 b B	6.55 abc C	6.35 a C	6.43 abc C	6.73 B
Average		7.18 a	6.87 b	6.48 c	6.33 d	6.33 d	

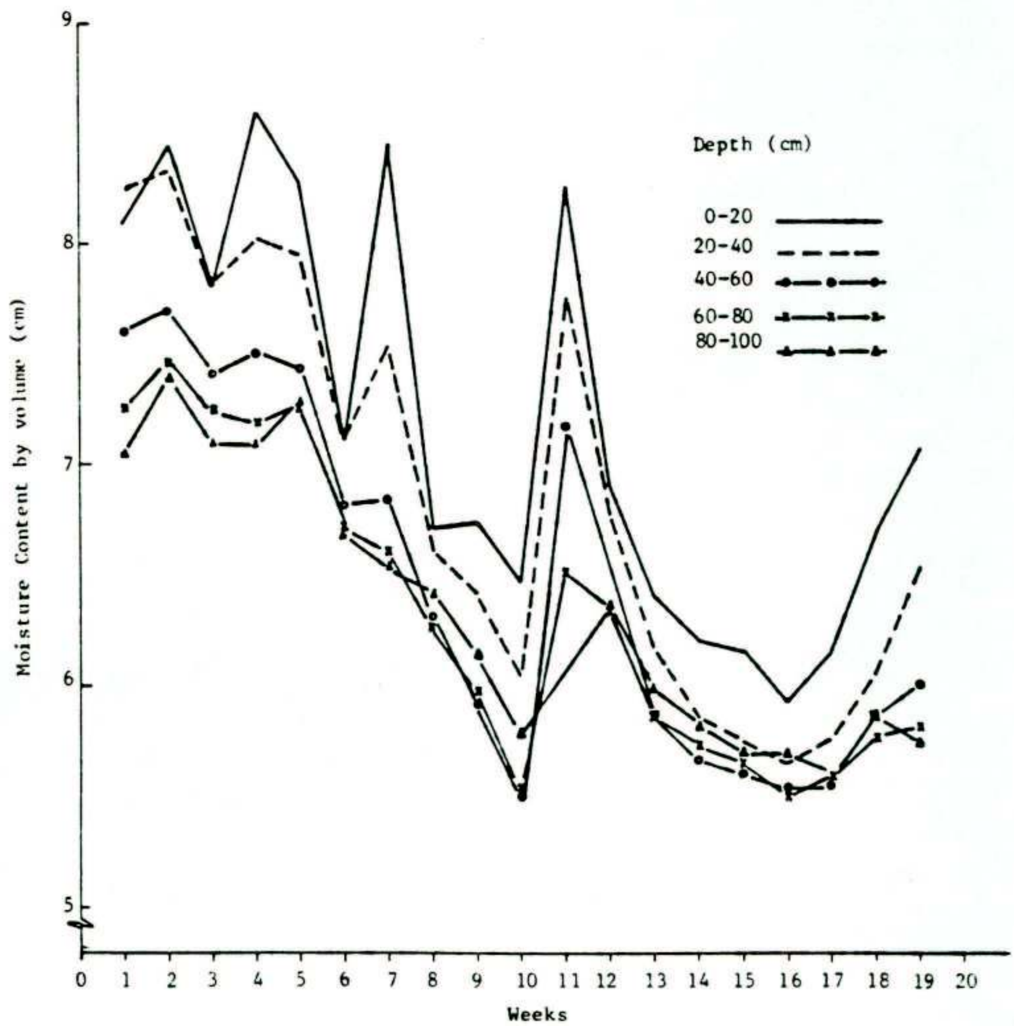


Figure 24. Interaction effect of weeks x soil depths x weeks after planting on soil moisture content.

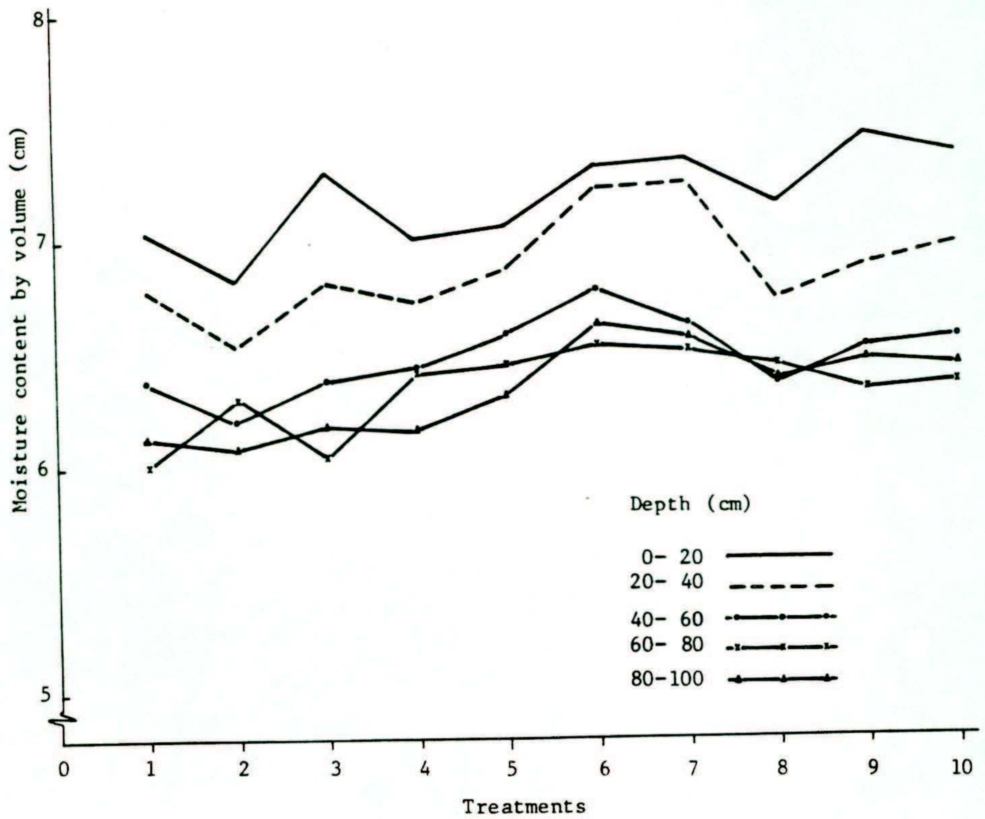


Figure 25. Interaction effect treatments (number of tractor passes) x soil depths on soil moisture content.

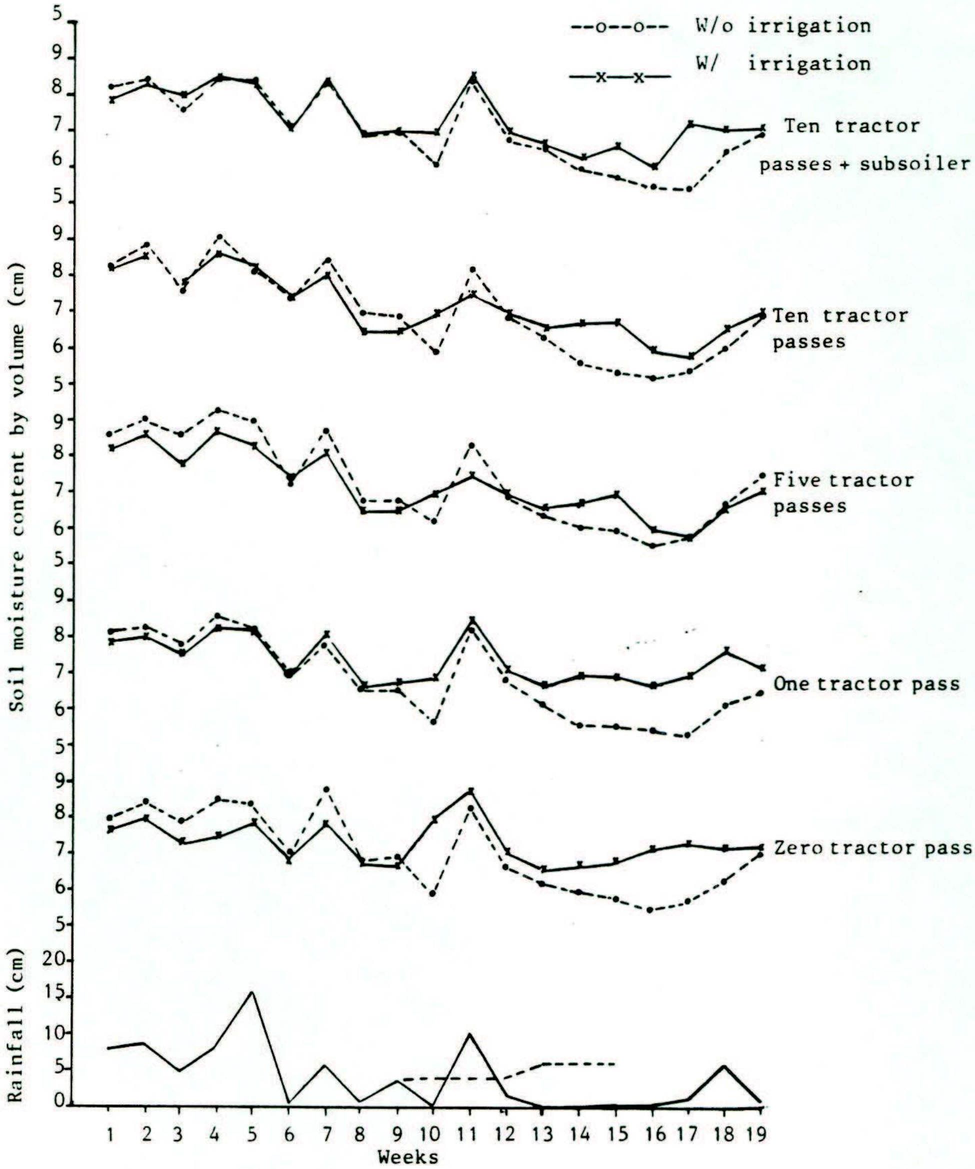


Figure 26. Rainfall distribution (cm) and soil moisture content by volume (cm at the depth of 20cm for each of the ten treatments (1983).

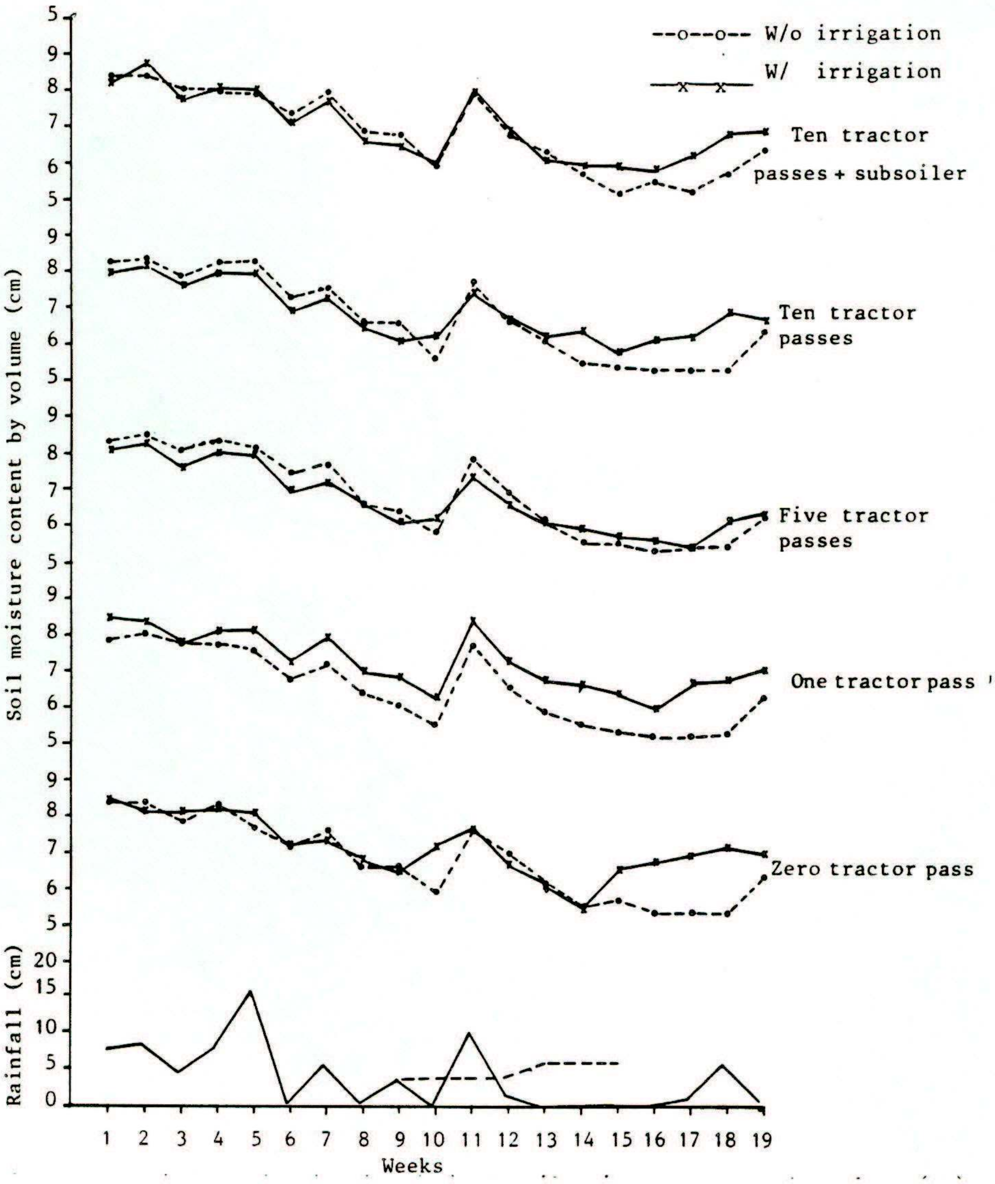


Figure 27. Rainfall distribution (cm) and soil moisture content by volume (cm) at the depth of 40 cm for each of the ten treatments (1983).

difference with the irrigation treatments irrigation 6, 7, 8, 9 and 10. The treatments 6, 7, 8, 9 and 10 after irrigation showed significant difference (see Figure 23) reinforcing the discussion by Rezende (1981) about some aspects of pore size distribution with respect to water retention. The soil moisture content results show most compaction levels have an average intake of water and others are somewhat below average. Therefore, water retention curve will be needed for each compaction level to clarify the changes. More investigation will be needed to certify about the range of pore size diameter in each of these five treatments.

In Tables 15 and 16, and Figures 24 and 25 it is shown that at depths of 0-20 and 20-40 cm the highest amount of water exists during all nineteen weeks and for the ten treatments.

The data on rainfall variation and soil moisture content by volume through the entire season for all ten treatments at the depths 20, 40, 60 and 100 cm is shown in figures 26, 27, 28, 29 and 30. All compaction levels are about 7 cm of water with no difference. The figures 31 and 32 show the total moisture content by volume throughout the season for the top 100 cm layer of the soil for each of the ten treatments.

Corn yield for all ten treatments is shown in Table 17. The Analysis of Variance of corn yield (in Table 18) showed no significant difference among the ten treatments.

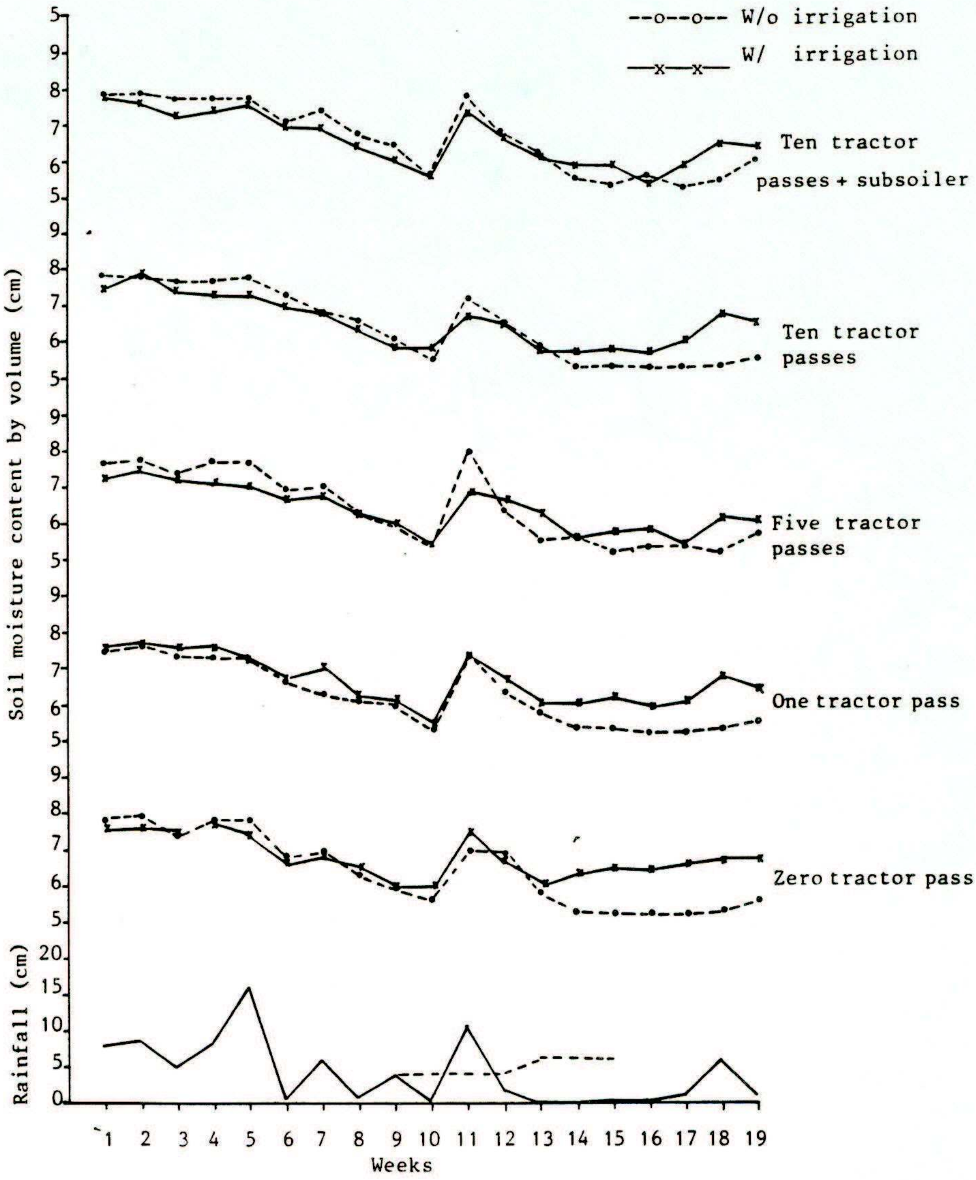


Figure 28. Rainfall distribution (cm) and soil moisture content by volume (cm) at the depth of 60cm for each of the ten treatments (1983).

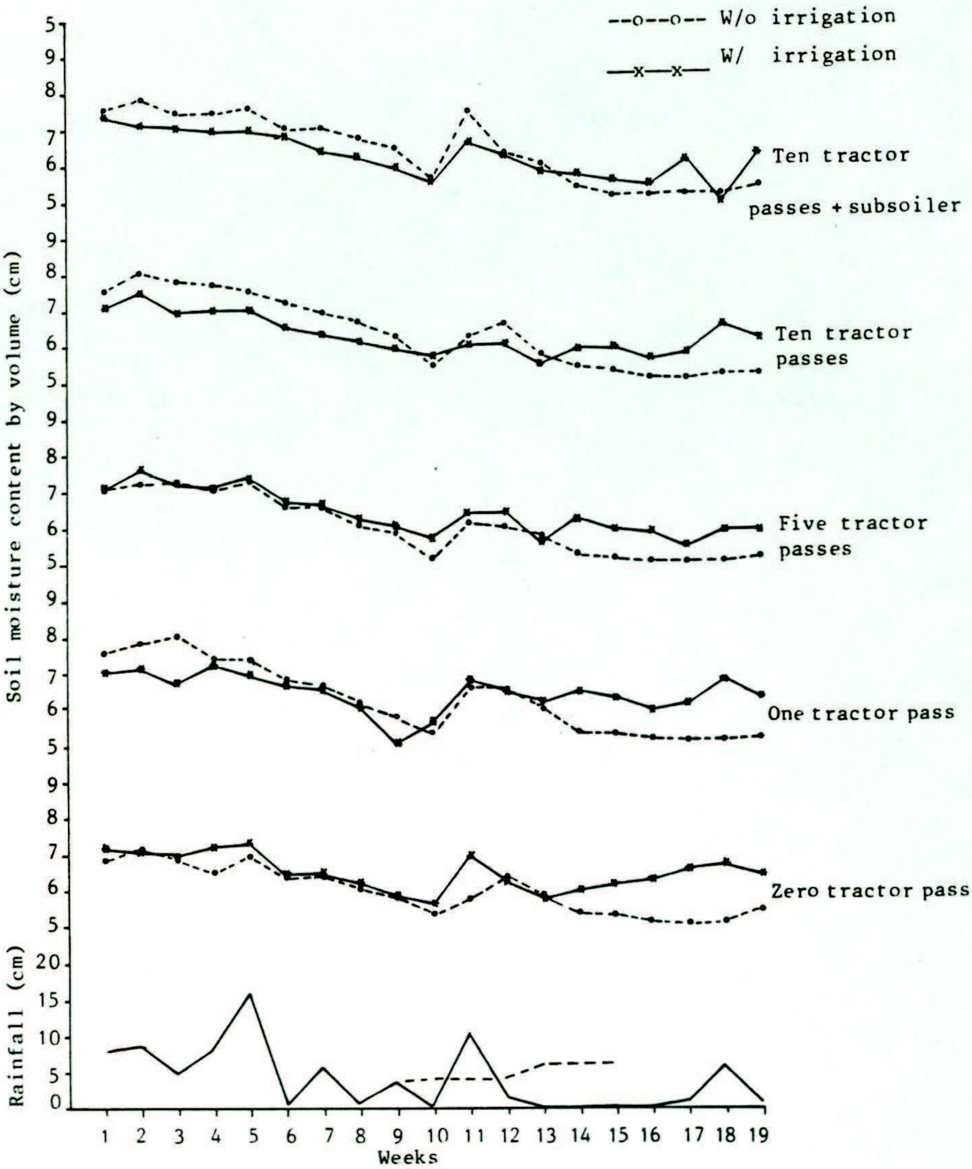


Figure 29. Rainfall distribution (cm) and soil moisture content by volume (cm) at the depth of 80cm for each of the ten treatments (1983).

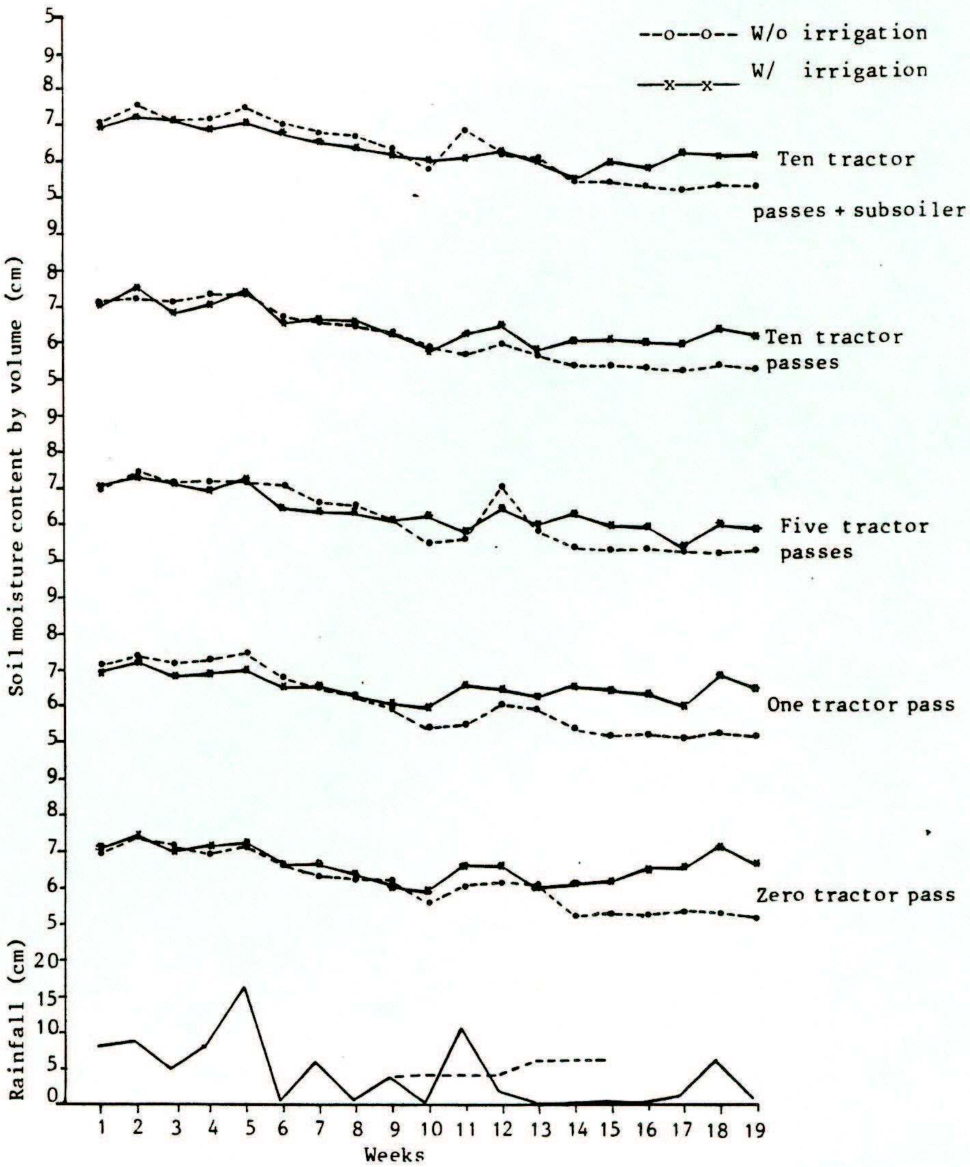


Figure 30. Rainfall distribution (cm) and soil moisture content by volume (cm) at the depth of 100cm for each of the ten treatments (1983).

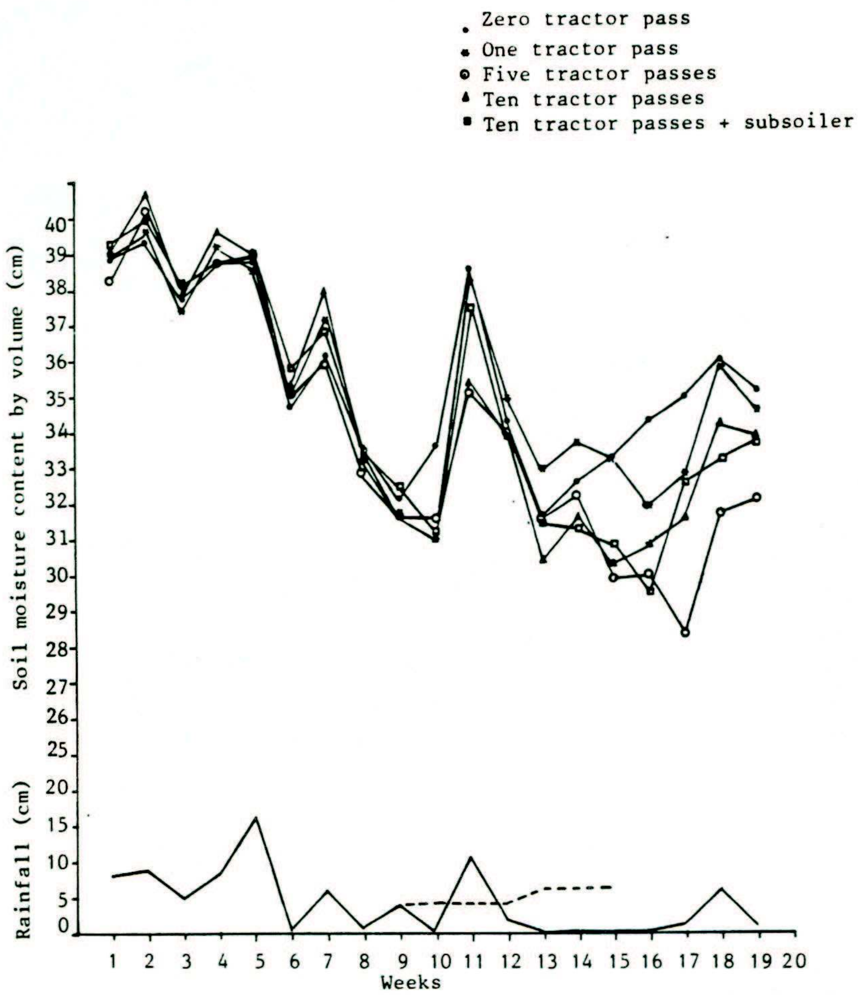


Figure 31. Rainfall distribution (cm) and total soil moisture content by volume (cm) throughout the season for the top 100 cm layer of soil for each of the five treatments with irrigation (1983).

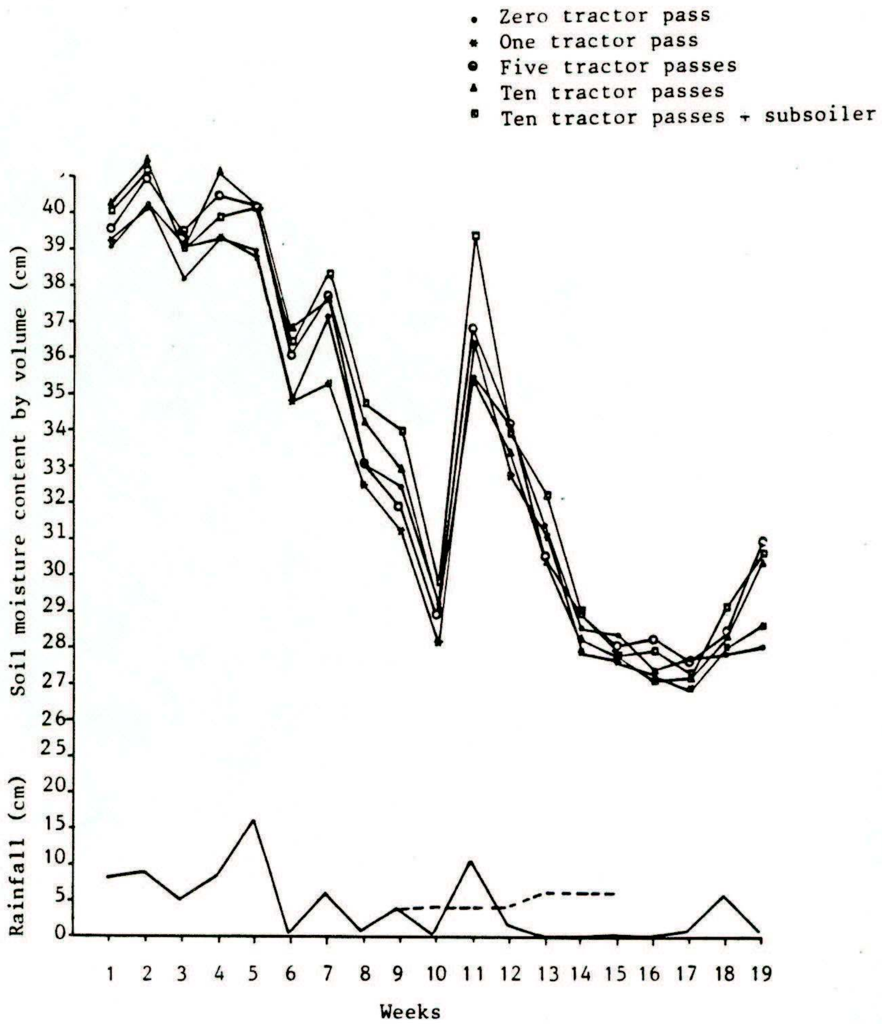


Figure 32. Rainfall distribution (cm) and total soil moisture content (cm) throughout the season for the top 100cm layer of soil for each of the five treatments without irrigation (1983).

Table 17. Corn yield, kg/ha (harvest date: 04/04/84).

Replications	Treatments (Number of Tractor Passes)									
	w/o irrigation					w/irrigation				
	0	1	5	10	10+S	0	1	5	10	10+S
1	2144	2922	3116	2308	2786	5050	5269	5732	4977	5331
2	3392	4022	2828	2645	3329	6294	5181	6982	5207	5636
3	2361	2548	3515	2201	2890	4810	3828	4308	4344	3830
AVG.	2632	3164	3153	2385	3002	5385	4759	5674	4843	4932

Table 18. Analysis of variance of corn yield.

Source of Variation	Degree of Freedom	Sum of Square	Mean Square Square	F
Block	2	5932744.0667	2966372.0333	10.5417
Irrigation Level (IL)	1	38018266.1333	38018266.1333	135.106 **
Treatment (T)	4	1935671.8000	483917.9500	1.797
IL x T	4	1349392.8667	337348.2167	1.1988
Residue	18	5065113.6000	281395.2000	
Total	29	52301188.4667		
Average = 3993		C.V. = 13,29%		

** Means significant difference.

The data showed some tendency for increase in corn yield with the increase of the compaction level. The production increased from zero tractor pass to 5 tractor passes, and decreased on 10 and 10+S tractor passes in both cases with and without irrigation.

Rezende (1981) made some considerations about the Latosols as follow:

1. All clay soil have high microporosity, although it can have high macroporosity due to its aggregation (structure).

2. The roots grow better across macropores.

3. The agents which aggregate the primary particles (clay, silt and sand), like organic matter, Ca, and Fe and Al oxides, promote aeration and water infiltration, while the agent which destroys the aggregate like Na, compaction and puddling have an inverse effect thus affecting root growth.

4. The small pores retain water with greater force than big pores. Soil with big pores had the water removed by gravity and with small pores the water is not available to the plants. Between these extremes there is intermediate structure of pores in sizes.

The small pores conduct water by capillary action, but decrease irrigation and aeration (gas exchange).

5. The granular structure, when well development, like in B horizon of the latosol has two populations of pores: the macropores (between granules) and the micropores (inside of the aggregates). These soils have the tendency to retain water in two distinct classes: one which occupies the big pores, around 1 µm (3 bars) and secondly water which corresponds to a pore diameter smaller than 0.2 µm (15 bars). This means that there are no pores in between these two sizes. This is also true for the sandy soils. The soil which does not have granular structure has the tendency to have big pores (equivalent diameter) between 1 and 2,0 µm. Realizing that a great amount of available water is between 30 to 1 µm of diameter, that, in some soils, compaction can be beneficial. Increasing the amount of pores of 30 to 1 µm it is possible in some latosols, to increase

the available water by transforming part of pores greater than 30 μm (1/10 bar) into small pores. It is important that contact between root and soil be developed for optional crop growth. As always happens in natural systems, it is necessary caution doesn't have contrary effect. If compaction to be very intense, infiltration decrease, increase erosion, decrease root growth, etc.

Based on Rezende's consideration and pore size distribution regarding corn yield results we can understand what happened with our project corn yield. We believe that there is a compaction level or in other words, a bulk density more adequate for corn production than the one considered normal for the Dark Red Latosol.

SOIL COMPACTION AND YIELD MODELS

To understand soil compaction it is necessary to study the soil's different variables like: bulk density, particle size distribution, pore size distribution, aggregate stability, ect. and also to know the effects on plant growth and production. An individual analysis is important to know the modifications and effects of each variable but does not explain the soil compaction process as a whole. A stepwise linear regression model was used to model soil compaction and corn-yield and the results are as follows:

Soil Compaction Model

Depth: 7.5 cm

$$y = 704.032 - 3.91255 \times 10^{-4}\ CL^2 + 0.0371051\ LnCl - \quad [1]$$

$$0.0130211\ SMC - 0.767076\ SMC^2 + 8.50692\ Ln\ SMC - 4.30324 \times 10^{-4}\ MA^2 +$$

$$0.105783\ MI - 1.43256 \times 10^{-3}\ MI^2 \qquad R^2 = 57.91\%$$

See Table 19 for F statistics and appendix tables 18, 19, 20, 21 and 22 for shorter model with higher significance in each variable.

Table 19. Stepwise regression for the compaction model (Equation 1).

Variables	Coefficient	F-test for Ho: Variable = 0	Prob>F	Standard Error
Intercept	704.032			
CL2	-3.91256E-04	.648862	43.17%	4.85793E-04
LCL	.0371051	1.57797	22.5	.0295382
SMC	-.0130211	.916198	35.18%	.0136036
SMC2	-.767076	.871023	36.37%	.821909
LSMC	8.50692	4.1957	5.63%	4.15413
PSDMA2	-4.30324E-04	6.611309	1.98%	1.67338E-04
PSDMI	.105783	1.07105	31.52%	.102214
PSDMI2	-1.43256E-03	1.44547	24.57%	1.19154E-03

Analysis of variance

Source	Sum of square	Degrees of freedom	Mean square	F-value	Prob >F	R-square	Standard deviation	Coefficient variation
Regres-• sion	.0792115	6	.0132019	3.89764	1.24%	.57906	.0581993	5.51%
Residuals	.0575817	17	3.38716E-03					
TOTAL	.136793	23						

Depth: 15 cm

$$Y = 1.47947 + 1.43897 \times 10^{-4}\ CL^2 - 0.0117962\ MA - \qquad [2]$$

$$- 1.14659 \times 10^{-4}\ MI^2 \qquad R^2 = 34.73\%$$

Depth: 22.5 cm

$$Y = 460.527 + 0.0117716\ CL - 7.58957 \times 10^{-4}\ CL^2 \qquad [3]$$

$$-8.44308 \times 10^{-3}\ SMC - 0.497864\ SMC^2 + 5.09276\ Ln(SMC) + 0.019416\ MA -$$

$$0.0010204\ MA^2 - 0.0145785\ MI \qquad R^2 = 74.71\%$$

Depth: 30 cm

$$Y = 0.617594 - 9.5753 \times 10^{-5}\ SMC + 5.60825 \times 10^{-4}\ SMC^2 - \quad [4]$$

$$0.01488097\ MA - 7.599 \times 10^{-5}\ MA^2 - 2.11987 \times 10^{-4}\ MI^2 + 0.178553\ AS_2 -$$

$$1.47132\ AS_2^2 \qquad R^2 = 82.58\%$$

Depth: 37.5 cm

$$Y = 1.37128 - 0.045316\ MA + 5.72797 \times 10^{-4}\ MA^2 + 0.0382527\ MI - \quad [5]$$

$$7.21236 \times 10^{-4}\ MI^2 \qquad R_2 = 64.53\%$$

Depth: 45 cm

$$Y = 4.09263 - 1.3674 \times 10^{-3}\ CL^2 - 9.88236 \times 10^{-4}\ SMC^2 + 3.0429 \quad [6]$$

$$\times 10^{-4}\ MA^2 - 0.074091\ AS_2 + 6.15881 \times 10^{-4}\ AS_2^2 \qquad R_2 = 31.54\%$$

Variables

Y = Bulk Density, g/cm^3

CL = Number of tractor passes at contact pressure of 0.70 kg/cm^2 and 0.78 kg/cm^2 for front and rear tires respectively

SMC = Soil moisture content by volume during soil compaction, cm

MA = Macropores, %, by pressure plate method

MI = Micropores, %, by pressure plate method

AS_2 = Aggregate stability, < 1 mm by wet sieve method

Example table for numbers of the variables.

Y Bulk density g/cm^3	CL Compaction level number of tractor passes	SMC Soil moisture content %	MA Macro pores %	MI Micro pores %	AS_2 Aggregate stability > 1 mm %
1.05	0	30.8	22	38	26
0.97	0	31.0	24	36	28
0.94	0	30.5	24	37	37
0.98	1	30.8	24	39	49
1.11	1	31.1	14	44	38
0.98	1	30.9	17	47	62
1.05	5	30.8	20	41	47
1.15	5	31.1	12	45	47
1.00	5	30.9	24	41	66
1.11	10	30.8	17	41	46
1.13	10	31.0	20	40	42
1.15	10	30.9	13	46	58

Corn Yield Model

$$y\ (\text{kg/ha}) = -\ 3438.3 + 2645.09(IL) - 108.856(PH4) + 923.67(SMC_{13}) + \quad [7]$$

$$27.99(PH_{8}) \qquad R^2 = 85.44$$

Variables

Y = Corn yield, kg/ha

IL = Irrigation levels

CL = Number of tractor passes at contact pressure of 0.70 Kg/cm^2 and 0.78 Kg/km^2 for front and rear tire respectively

PH_4 = Plant height 4th week after planting, cm

PH_8 = Plant height 8th week after planting, cm

SMC_{13} = Average of soil moisture content by volume (cm) during the first 13 weeks after planting by the radiation method (Neutron Probe).

The model variables were selected based on a F value of 0.47 and best R^2 that predicts soil compaction and corn yield (see Table 20).

The literature has reported the following variables influence soil compaction: soil moisture content, tractor weight and soil type. Changes in soil compaction or soil bulk density were dependent on soil type (pore size distribution, aggregate stability, particle size distribution, organic matter, etc).

This soil compaction model was developed for the Dark Red Latosol, and its behavior or its reaction when submitted to compression forces is different from one that would be developed for American soils.

The signs (+ and -) of the independent variables (CL, SMC, MA, MI, AS_1, AS_2, IL, PH_4, PH_8, SMC_8, SMC_{13}, SMC_{19}) indicates positive or negative correlation with the dependent variable (y = bulk density or y = corn yield).

Soil compaction can be described as the change of soil bulk density resulting by mechanical energy or sometimes by natural process (fragipans). Usually, the tillage operations contribute to the compaction process the most when used during critical soil conditions. Soil moisture content is one very important variable to consider when doing tillage work. There is a critical range for soil moisture content which gives maximum soil compaction for each soil. Based on Proctor's curves,

Table 20. Stepwise regression for the corn yield model.

Step Number 4.
Variable entering into the model: SMC13

Variables	Coefficient	F-test for Ho: Variable = 0	Prob>F	Standard Error
Intercept	-3438.3			
IL	2645.09	77.1633	.01 %	301.117
PH4	-108.856	17.9576	.04 %	25.6879
SMC13	923.67	4.08945	5.74%	456.756
PH8	27.9881	10.8962	.37%	8.47882

Analysis of variance

Source	Sum of square	Degrees of freedom	Mean square	F-value	Prob >F	R-square	Standard deviation	Coefficient variation
Regression	3.3132E+07	4	8.28299E+06	27.8734	.01%	.854399	545.128	13.66%
Residual	5.64612E+06	19	297164					
TOTAL	3.87781E+07	23						

32-35% moisture content range was a variable researched in this project and in most of six compactions equations, a negative effect was found for moisture content with the compaction levels tested. Other variables such as Macro and Micro porosity reflect the changes in soil bulk density and had a direct effect. The changes in soil bulk density was shown by the decrease in soil macropores, the increase in soil micropores and decrease of total pore space.

The particle size distribution and aggregate stability were very good indications of the vulnerability of soil to becoming compacted. Small soil particles and clay soils are the type which are vulnerable to soil compaction. The model shows this effect at 30 and 45 cm depth (equations 5 and 6).

Rainfall period during corn growth period was not normal in 1984. The total amount of water was enough for corn crops but it had fallen mainly at the beginning of corn growth. During the tasseling and silk period (two most important times for corn yield), low rainfall was experienced.

Irrigation was applied and became the only factor affecting corn yield because of water stress during this period. Irrigation treatment showed a positive correlation on the corn yield model (see Equation 7). Because this study lacked water during tasseling and the soil had low water retention capacity, irrigation was crucial for increasing corn yield under water stress.

The soil compaction effects on corn yield for American soils has been evident during dry years more so than during wet years. The reduction in total soil porosity reduced aeration when surface water increased during wet years. Also during dry years root systems had impediments to penetrate down to the water table.

On the Dark Red Latosols, 80% of the retained water is around 1/10 and 3 bars as seen in Figure 4. A good way to increase the available water range of the water retention curve (from 1/10 bar, Field capacity, and 15 bars, wilting point) is by changing pore size distribution to an optimal pore size which would have the best diameter range (macro and micro pores).

A good indication of optimal soil conditions and weather (moisture and temperature) for a corn crop is the corn growth rate. The plant height reflects the best combination of these two parameters and also plant yield. The negative correlation of plant height in the yield model at 4 weeks after planting (PH_4) may show the excess of water during this early period which logically can have a negative effect on yield. Rainfall after the 2nd 4 weeks after planting started to normalize and during the 8th week after planting significant differences in plant height were found. Therefore, PH_8 showed positive correlation with yield in the regression model.

In the corn yield model the soil moisture content average 13 weeks after planting (which was coincident with a dry period) had a high positive effect compared with the average at 8 (SMC_8) and 19 (SMC_{19}) weeks after planting. During this period, irrigation water was applied on 5 compaction levels and the other 5 treatments had no irrigation. The supplied water gave a very positive effect on plant yield and also available water to the plants as we can see in the regression model.

The variables discussion as shown in Equation 8 are 90% significant in predicting corn yield.

These models will be good indications for subsequent studies on Dark Red Latosol. Additional plot studies of over five years will be needed in order for the model to verify these positive and negative correlations with the independent variables. Also, different weather conditions could affect corn yield models.

CONCLUSIONS

Based on the results obtained, the following conclusions can be drawn:

1. The Dark Red Latosol can be compacted to $1.32 g/cm^3$ in standard Proctor Laboratory test.

2. Root distribution did not show impediment by compacted soils at a compacted level of $1.12 g/cm^3$.

3. There was no significant difference among the ten treatments for corn yield.

4. Corn Crop production on a Dark Red Latosol soil under high rainfall during the growth period was not affected by the compaction levels tested (zero to 10 tractor passes).

5. The soil compaction - corn yield model predicts relationships for Dark Red Latosol soil with 95% significance level but was limited to a one year study.

RECOMMENDATIONS FOR FURTHER STUDY

1. Another soil density method should be studied to characterize soil compaction for this brazilian soil since this project reported no correlation with surface traffic compaction levels.

2. The soil water retention curve should be studied with different soil compaction levels to determine the effect on water retention as a result of pore size.

3. A mineralogic study is needed to find the behavior of clay layer with iron oxides at different levels of soil compression during a wetting and drying cycle.

4. The soil compaction and corn yield model should be field tested at least 6 years to determine its reliability. Also, long term effects as indicated by Moura and Buol (1972) showing pore size changes might result in figure compaction problems.

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APPENDIX

Appendix Table A1. Dark red latosol compaction date for modified proctor, standard proctor and 15-blows proctor.

Observation Number	Modified Proctor		standard Proctor		15-Blows Proctor	
	Dry Density g/cc	Moisture Content %	Dry Density g/cc	Moisture Content %	Dry Density g/cc	Moisture Content %
1	1.42	24.25	1.25	27.52	1.23	30.36
2	1.44	25.68	1.25	27.82	1.24	31.19
3	1.45	26.51	1.27	28.36	1.26	33.28
4	1.45	26.54	1.28	29.34	1.27	33.34
5	1.45	26.81	1.28	29.75	1.29	33.63
6	1.46	28.06	1.31	31.44	1.29	35.23
7	1.46	28.16	1.32	31.67	1.29	35.51
8	1.47	28.26	1.32	32.49	1.27	36.64
9	1.46	29.77	1.31	33.52	1.27	36.82
10	1.43	30.03	1.31	33.81	1.26	37.59
11	1.44	30.58	1.31	34.27	1.25	37.74
12	1.41	31.16	1.28	36.39	1.25	37.87
13	1.43	31.38	1.28	36.71	1.24	39.72
14	1.39	32.26	1.27	37.19	1.23	39.90
15	1.38	33.10	1.26	37.62	1.22	40.10
16	1.35	33.72	1.27	37.75	1.22	40.30

Appendix Table A2. Dark red latosol bulk density (g/cc) after 6 years of cultivation.

Replications	Depth (cm)		
	0-15	15-30	30-45
1	1.08	1.07	1.02
2	1.07	1.08	1.03
3	1.10	1.06	1.05
4	1.12	1.10	1.03
5	1.08	1.09	1.08
6	1.13	1.11	1.11
7	0.98	1.09	1.10
8	1.01	1.09	0.97
9	1.06	1.07	1.06
10	1.01	1.00	1.05
11	1.04	1.14	1.13
12	1.07	1.12	1.03
13	1.02	1.05	1.04
14	1.00	1.09	1.06
15	1.00	1.09	1.06
16	1.01	0.99	1.01
Average	1.06	1.08	1.05

Appendix Table A3. Dark red latosol bulk density (g/cc) under cerrado's vegetation.

Replications	Depth (cm)		
	0-15	15-30	30-45
1	0.86	0.89	0.91
2	0.93	1.00	0.93
3	0.86	0.88	0.95
4	0.91	0.92	0.96
5	0.94	0.84	0.92
Average	0.90	0.92	0.93

Appendix Table A4. Dark red latosol retention curve (%)

Depth (cm)	Replications	Matric Potential - (Bars)							
		0.1	0.2	0.5	0.8	7.5	10.0	12.5	15
0-15	1	37.3	32.2	31.5	29.6	25.3	24.8	24.3	24.2
	2	37.7	32.5	32.0	30.1	25.1	25.0	24.4	24.5
	3	39.3	32.5	32.3	30.5	25.1	25.3	24.5	24.4
	4	38.0	33.1	31.6	30.6	24.8	25.1	24.7	24.9
	5	37.0	33.2	32.2	30.8	25.0	25.2	24.6	24.8
	AVG.	37.86	32.7	31.92	30.32	25.06	25.08	24.5	24.58
15-30	1	35.6	33.9	32.4	30.5	26.7	27.2	24.9	25.4
	2	36.0	32.8	31.1	30.6	26.7	27.0	27.4	25.3
	3	36.7	32.5	33.4	30.8	26.0	25.5	25.2	25.0
	4	39.7	34.5	33.1	31.3	25.8	25.5	25.6	25.2
	5	39.3	34.5	31.6	31.5	27.2	25.8	25.6	25.3
	AVG.	37.07	33.64	32.32	30.94	26.48	26.20	25.58	25.24
30-45	1	32.6	32.6	34.3	31.7	27.3	27.0	25.7	24.6
	2	32.5	32.2	34.0	32.0	27.5	27.6	25.9	24.8
	3	33.4	32.4	33.2	30.8	27.2	26.8	26.5	25.4
	4	34.1	33.3	33.5	31.5	27.0	27.7	26.8	25.7
	5	33.2	33.4	33.9	31.3	27.4	28.0	26.8	25.1
	AVG.	33.16	32.78	33.78	31.46	27.28	27.42	26.34	25.12

Appendix Table A5. Dark red latosol characterization before compaction.

Depth (cm)	Replication	Pore size distribution (%) Micro	Macro	Total	Particle size distribution (%) Sand Coarse	Fine	Silt	Clay	Aggregate stability Sieve size (mm) >2	2-1	1-0.5	0.5-0.25	0.25-0.105	<0.105	Particle Density (g/cc)
0-7.5	1	41.0	19.0	60.0	4.6	6.5	5.3	83.6	73.8	3.44	3.08	1.32	1.32	16.48	2.5
	2	39.0	22.0	61.0	4.8	8.3	11.1	75.8	7.03	4.04	4.24	2.72	2.16	16.56	2.7
	3	36.0	24.0	61.0	4.3	6.8	7.2	81.7	50.08	9.36	11.24	7.60	5.56	16.16	2.6
	4	37.0	24.0	61.0	4.9	8.2	8.3	87.6	67.06	5.06	5.19	3.93	2.99	15.77	2.7
	5	38.0	22.0	61.0	5.8	8.0	14.3	70.9	57.48	5.24	7.12	5.68	5.16	19.32	2.7
	AVG.	38.0	22.0	60.0	5.08	7.56	9.24	78.12	63.74	5.43	6.17	4.36	3.44	16.86	2.66
7.5-15	1	44.0	17.0	61.0	3.9	6.4	6.7	83.0	73.04	3.40	3.00	1.96	1.84	16.76	2.7
	2	36.0	24.0	61.0	4.9	6.1	9.9	79.1	56.12	7.12	8.04	6.08	4.36	18.28	2.7
	3	34.0	27.0	61.0	7.9	5.2	7.1	79.8	39.92	8.24	11.72	10.96	9.76	19.40	2.7
	4	38.0	22.0	61.0	6.7	7.5	15.3	70.4	51.36	6.24	9.48	6.64	4.96	19.32	2.7
	AVG.	38.0	22.0	60.0	5.66	6.44	9.54	78.36	53.38	7.02	8.46	6.89	5.53	18.68	2.7
15-22.5	1	41.0	19.0	60.0	3.3	6.8	5.5	84.4	60.54	5.66	5.95	4.58	3.58	16.69	2.7
	2	26.0	34.0	60.0	4.6	7.3	11.6	76.5	58.68	8.84	7.72	3.80	2.12	18.84	2.7
	3	37.0	23.0	60.0	4.6	7.3	9.5	78.6	50.52	8.80	10.52	6.88	4.84	18.44	2.7
	4	40.0	20.0	60.0	4.7	6.2	8.6	80.5	48.80	7.68	9.26	8.80	6.28	18.48	2.7
	5	42.0	18.0	60.0	5.8	5.9	13.5	74.8	48.64	9.08	11.40	7.52	4.88	18.48	2.7
	AVG.	37.0	23.0	60.0	4.6	6.7	9.74	78.95	63.44	8.01	8.97	6.32	4.34	18.79	2.7

Appendix Table A5 (cont.)

Depth (cm)	Repli-cation	Pore size distribution (%)			Particle size distribution (%)				Aggregate stability						Particle
		Micro	Macro	Total	Sand		Silt	Clay	Sieve size (mm)						Density
					Coarse	Fine			>2	2-1	1-0.5	0.5-0.25	0.25-0.105	<0.105	(g/cc)
22.5-30	1	40.0	20.0	60.0	3.7	5.9	6.6	83.8	43.68	10.48	11.68	9.20	6.44	18.52	2.7
	2	31.0	29.0	60.0	4.7	8.5	8.8	78.0	28.84	12.60	17.36	12.72	8.20	20.28	2.7
	3	34.0	26.0	60.0	4.9	9.4	7.7	78.0	32.56	11.96	15.44	12.40	7.72	19.92	2.8
	4	37.0	23.0	60.0	3.9	8.2	8.4	79.5	48.96	10.00	10.52	7.16	4.80	18.56	2.8
	5	31.0	29.0	60.0	4.2	8.2	12.0	75.6	53.35	8.70	8.60	6.05	3.95	19.35	2.7
	AVG.	34.0	26.0	60.0	4.28	8.04	8.70	78.98	41.48	10.75	12.72	9.51	6.22	19.33	2.7
30-37.5	1	37.0	24.0	61.0	5.2	5.4	4.9	84.5	36.64	11.36	14.64	10.72	7.12	19.52	2.6
	2	27.0	32.0	61.0	6.1	6.6	8.4	78.9	38.44	12.76	14.88	8.84	5.32	19.76	2.7
	3	45.0	16.0	61.0	4.7	5.9	6.4	83.0	22.28	11.04	18.08	19.28	12.16	17.16	2.7
	4	37.0	24.0	61.0	4.2	5.6	7.8	82.4	31.00	11.44	17.00	15.12	9.24	16.20	2.7
	5	33.0	28.0	61.0	4.6	6.7	12.4	76.3	38.45	9.33	13.87	12.12	7.12	19.11	2.7
	AVG.	36.0	25.0	61.0	4.96	6.04	7.98	81.02	33.36	11.19	15.69	13.22	8.19	18.35	2.68
37.5-45	1	39.0	22.0	61.0	4.4	6.4	3.8	85.4	33.16	7.95	13.50	16.55	12.20	16.65	2.6
	2	37.0	24.0	61.0	5.1	6.6	6.7	81.6	37.16	11.64	14.80	9.96	6.00	20.44	2.6
	3	42.0	20.0	61.0	4.7	3.6	5.5	86.2	27.12	7.20	17.04	18.52	10.48	19.64	2.7
	4	36.0	25.0	61.0	3.3	6.8	7.9	82.0	25.24	10.84	18.20	14.60	9.72	21.40	2.7
	5	40.0	21.0	61.0	5.0	9.7	11.6	74.0	39.73	10.52	13.10	10.94	3.36	22.35	2.7
	AVG.	39.0	22.0	61.0	4.5	6.62	7.1	81.84	32.48	9.63	15.33	14.11	8.35	20.1	2.66

Appendix Table A6. Dark red latosol particle size distribution (%), for all ten treatments at at six depths, after compaction (Average of 3 replications).

Depth (cm)	Particle Size	Treatments									
		1	2	3	4	5	6	7	8	9	10
	Coarse sand	5.5	8.6	8.02	8.3	8.1	5.5	7.4	6.8	6.2	7.1
7.5	Fine sand	18.2	12.0	12.6	11.6	13.2	8.2	12.2	10.9	11.8	11.6
	Silt	11.2	11.0	12.5	10.8	11.2	11.2	12.3	9.5	8.2	9.3
	Clay	75.1	68.5	66.8	69.0	69.3	75.1	70.17	72.3	73.8	74.2
	Coarse sand	5.9	7.6	7.6	7.1	7.1	5.9	5.6	6.8	4.7	5.7
15.0	Fine and	6.1	11.1	12.3	11.9	11.6	6.1	12.75	12.1	10.9	9.8
	Silt	8.6	12.0	14.2	9.0	9.7	8.6	12.17	7.3	11.2	5.7
	Clay	79.5	70.5	66.0	68.8	71.7	79.5	72.7	76.2	74.7	79.5
	Coarse sand	5.0	6.9	6.8	7.1	6.7	5.0	5.9	4.9	5.1	5.1
22.5	Fine sand	6.8	9.8	13.5	12.9	11.3	6.8	11.1	7.9	10.7	8.3
	Silt	11.5	16.8	9.8	9.5	6.8	11.5	9.0	7.2	7.7	9.0
	Clay	76.6	71.0	69.8	70.5	73.2	76.6	74.0	80.0	78.2	77.7
	Coarse sand	4.5	8.0	10.8	16.8	9.7	4.5	7.1	6.2	4.9	6.6
30.0	Fine sand	8.7	16.2	20.6	16.7	15.2	8.7	14.0	13.0	10.8	13.4
	Silt	8.3	18.2	17.5	17.3	14.7	8.3	14.0	8.3	12.5	16.0
	Clay	78.5	61.7	51.2	52.5	50.5	78.5	64.8	72.8	50.3	67.3
	Coarse sand	1.7	6.7	9.3	3.7	6.4	4.7	5.0	6.0	5.1	7.5
37.5	Fine and	5.6	18.5	14.5	8.6	11.9	5.6	10.6	13.0	11.0	14.1
	Silt	6.4	22.25	18.8	22.5	12.2	6.4	17.5	12.8	13.7	7.5
	Clay	83.3	68.8	57.3	60.2	69.5	83.3	69.8	70.6	64.8	67.8
	Coarse sand	4.3	6.4	9.3	7.7	7.6	4.3	6.7	6.5	5.6	7.9
45.0	Fine sand	6.6	14.6	15.8	14.6	13.3	6.6	15.1	13.1	13.1	14.0
	Silt	6.1	17.5	11.3	9.2	12.7	6.1	8.8	8.2	8.7	8.5
	Clay	83.0	66.2	63.5	68.5	66.5	83.0	69.0	72.3	72.50	66.8

Appendix Table A7. Dark red latosol aggregate stability (%), for all ten treatments at six depths, after soil compaction (Average of 3 replications).

		Sieve Size, (mm)					
Treatments	Depth (cm)	>2	2-1	1-0.5	0.5-0.25	0.25-1.105	<0.105
1		44.25	9.33	13.47	11.56	9.46	11.93
2		40.81	9.51	12.65	12.61	10.27	14.14
3		34.59	11.57	15.76	14.51	10.72	12.84
4		40.03	11.41	15.33	13.19	8.45	11.59
5	7.5	25.66	10.64	11.38	14.79	9.71	12.80
6		38.92	9.32	13.10	13.86	12.02	12.76
7		38.92	8.73	12.60	13.57	10.81	14.64
8		57.26	9.08	12.35	10.64	7.52	11.77
9		34.49	9.12	14.43	16.59	12.03	13.33
10		35.45	9.27	14.75	16.60	10.97	12.96
1		40.40	11.84	14.59	12.86	7.50	10.59
2		37.61	11.49	14.35	13.31	10.51	12.73
3		45.48	11.16	16.41	14.80	11.52	13.16
4		39.72	9.61	14.20	13.52	10.57	12.39
5	15	29.23	12.27	18.40	16.48	11.13	12.49
6		38.00	9.47	15.85	16.16	11.88	11.50
7		32.25	7.46	12.02	15.69	12.19	14.55
8		37.86	9.59	13.77	13.80	11.47	13.51
9		27.76	9.92	16.49	19.29	12.28	14.25
10		36.00	8.96	13.59	16.00	12.15	13.31
1		29.96	15.69	16.23	14.51	10.47	11.61
2		36.03	12.96	14.77	13.37	10.84	11.91
3		34.03	12.41	17.56	14.48	10.05	11.47
4		35.36	10.53	15.71	14.48	11.91	12.01
5	22.5	24.18	10.49	16.33	16.59	13.03	12.77
6		28.50	10.49	16.93	18.90	13.28	11.90
7		31.70	10.57	16.13	17.84	13.31	13.24
8		31.05	11.51	16.72	16.39	11.93	12.40
9		29.89	10.67	18.47	18.36	12.64	9.97
10		37.84	9.97	14.73	14.94	11.38	11.15
1		28.79	13.43	19.03	15.71	12.46	12.28
2		27.54	11.45	18.78	18.87	12.37	14.59
3		24.14	15.08	21.65	16.95	10.92	11.16
4		27.92	11.94	18.03	17.11	11.76	13.34
5	30	22.56	10.12	18.15	21.12	12.45	13.34
6		25.25	10.08	17.29	20.69	13.60	13.00
7		28.31	10.41	16.53	17.34	13.39	16.35
8		20.91	11.21	20.12	20.94	13.12	13.85
9		27.29	10.85	20.32	19.49	11.99	13.08
10		30.20	10.95	16.99	17.44	11.43	13.00

Appendix Table A7 (cont.)

Treatments	Depth (cm)	Sieve Size, (mm) >2	2-1	1-0.5	0.5-0.25	0.25-1.105	<0.105
1		21.28	12.60	21.15	18.79	12.91	13.28
2		18.56	13.42	21.16	25.65	13.32	10.44
3		21.68	14.32	23.55	17.61	10.61	12.24
4		24.51	12.88	20.87	1.76	10.80	13.33
5	37.5	14.77	10.13	27.25	24.00	16.33	11.10
6		24.16	9.63	16.76	20.52	14.61	14.32
7		26.72	8.28	13.66	18.67	13.64	18.38
8		14.00	9.87	20.13	22.79	14.65	15.24
9		23.23	10.64	19.69	20.33	13.23	15.54
10		25.97	11.99	19.36	18.72	12.18	11.91
1		20.09	11.56	15.94	19.33	13.76	15.61
2		16.56	12.89	22.52	19.84	12.44	15.75
3		21.83	11.36	20.79	20.56	12.93	15.02
4		22.11	11.28	21.79	19.09	12.41	13.44
5	45	15.48	10.08	20.20	22.63	14.15	17.47
6		21.12	8.08	17.24	23.31	16.55	13.71
7		21.89	12.01	20.91	19.12	14.68	13.75
8		19.51	9.00	18.83	20.63	15.97	16.07
9		19.40	7.27	18.10	23.49	16.33	15.39
10		17.32	10.29	20.05	23.37	15.33	17.72

Appendix Table A8. Dark red latosol particle size distribution, (Mean weight diameter), mm, before and after compaction at different depths.

Depth (cm)		Treatments (after soil compaction)										Before Soil
	1	2	3	4	5	6	7	8	9	10	Soil	Compaction
	1	1.821	1.666	1.766	1.750	1.957	1.820	1.691	1.449	1.687	1.828	2.26
0-7.5	2	1.852	1.942	1.665	1.844	1.397	1.583	1.649	1.970	1.295	1.358	2.207
	3	1.839	1.337	1.245	1.457	1.286	1.399	1.479	2.133	2.058	1.403	1.964
	AVG.	1.837	1.649	1.559	1.684	1.547	1.601	1.606	1.851	1.680	1.530	2.036
	1	1.803	1.606	1.698	1.694	1.485	1.713	1.388	1.414	1.278	1.855	1.966
7.5-15	2	1.908	1.787	1.450	1.789	1.514	1.852	1.563	1.696	1.383	1.408	1.739
	3	1.380	1.435	1.347	1.361	1.309	1.288	1.400	1.639	1.390	1.322	1.870
	AVG.	1.697	1.609	1.498	1.615	1.436	1.618	1.452	1.582	1.350	1.528	1.858
	1	1.495	1.490	1.614	1.480	1.726	1.707	1.670	1.398	1.249	1.746	1.861
15-22.5	2	1.924	1.639	1.619	1.770	1.304	1.342	1.359	1.571	1.570	1.614	1.790
	3	2.194	1.636	1.437	1.399	1.268	1.109	1.376	1.412	1.467	1.450	1.82
	AVG.	1.871	1.588	1.557	1.550	1.433	1.386	1.468	1.460	1.429	1.603	1.824
	1	1.573	1.409	1.441	1.447	1.232	1.581	1.344	1.099	1.598	1.687	1.688
22.5-30	2	1.574	1.386	1.303	1.510	1.960	1.249	1.400	1.239	2.094	1.340	1.473
	3	1.167	1.065	1.358	1.217	1.316	1.061	1.468	1.196	1.221	1.272	1.837
	AVG.	14.38	1.287	1.367	1.391	1.503	1.297	1.404	1.178	1.638	1.433	1.666
	1	1.377	1.272	1.370	1.320	1.254	1.388	1.122	1.293	1.383	1.572	1.565
30-37.5	2	1.260	1.145	1.274	1.481	1.123	1.198	1.469	1.788	1.054	1.270	1.450
	3	1.122	1.166	1.281	1.257	0.970	1.175	1.340	1.058	1.362	1.234	1.582
	AVG.	1.253	1.194	1.308	1.353	1.115	1.254	1.310	1.380	1.270	1.359	1.532
	1	1.313	1.246	1.460	1.233	1.270	1.122	1.099	1.235	1.235	1.377	1.431
37.5-45	2	1.222	1.201	1.117	1.307	0.841	1.176	1.193	1.236	0.949	0.892	1.581
	3	1.037	0.974	1.190	1.243	1.051	1.185	1.485	0.926	1.140	1.075	1.287
	AVG.	1.191	1.140	1.256	1.261	1.054	1.161	1.259	1.132	1.108	1.115	1.433

Appendix Table A9. Plant height (cm): Corn, 4 weeks after planting (Planting date - 11/09/83).

Treatments	Replications	Plant numbers 1	2	3	4	5	6	7	8	9	10	Average
	1	62	63	66	61	53	65	58	57	59	60	60.4
1	2	51	55	54	46	45	47	40	43	38	43	46.2
	3	52	55	57	61	50	49	49	49	51	52	52.5
											AVG.	53.03
	1	71	65	55	48	52	63	58	55	53	64	58.4
2	2	52	43	47	45	49	51	53	43	40	43	46.6
	3	51	53	54	61	61	51	60	69	50	50	54.9
											AVG.	53.3
	1	65	55	68	53	60	51	50	59	60	60	58.1
3	2	59	61	60	57	56	48	55	49	53	47	54.5
	3	52	57	61	46	50	42	49	53	44	43	49.7
											AVG.	54.10
	1	55	53	53	57	64	55	55	49	57	57	55.5
4	2	39	38	41	46	43	41	40	39	44	43	41.4
	3	58	48	47	52	47	44	45	51	53	50	49.5
											AVG.	49.5
	1	51	55	55	55	59	54	64	60	57	60	57.0
5	2	44	48	42	45	43	48	48	47	52	45	46.2
	3	51	47	48	47	49	40	50	45	52	45	47.4
											AVG.	47.7
	1	47	46	57	59	49	50	57	49	56	63	53.3
6	2	43	45	59	52	47	49	46	44	52	44	48.1
	3	55	51	53	60	55	55	58	57	47	54	54.5
											AVG.	51.8
	1	44	55	54	56	53	52	57	54	59	55	53.9
7	2	47	46	44	38	39	42	49	38	43	43	42.9
	3	51	52	61	56	49	551	49	52	53	64	53.8
											AVG.	50.2
	1	6	58	64	58	53	50	59	52	56	67	57.8
8	2	46	34	40	39	38	43	35	37	39	40	39.1
	3	59	51	55	54	57	46	44	56	61	53	53.6
											AVG.	50.17
	1	56	51	52	61	51	47	50	56	60	48	53.2
9	2	47	46	45	47	41	38	37	36	36	36	40.9
	3	47	53	51	50	53	56	50	47	49	55	51.1
											AVG.	48.4
	1	48	52	47	49	52	56	58	51	61	63	53.7
10	2	39	42	46	36	35	40	42	43	43	38	40.4
	3	56	49	51	56	57	56	46	51	53	55	53.0
											AVG.	49.03

Appendix Table A10. Plant height (cm): Corn, 8 weeks after planting (Planting date - 11/09/83).

Treatments	Replications	Plant numbers 1	2	3	4	5	6	7	8	9	10	Average
	1	190	185	195	195	1801	190	180	175	195	190	187.5
1	2	155	160	140	145	170	155	160	145	150	160	154.0
	3	210	215	195	190	180	220	215	220	105	215	206.6
											AVG.	182.7
	1	195	175	210	220	210	190	195	215	210	180	200.0
2	2	180	195	185	205	195	190	210	200	170	185	191.5
	3	185	190	195	180	185	210	195	215	215	210	198.0
											AVG.	196.5
	1	195	185	200	210	190	195	185	175	180	185	185.0
3	2	190	185	220	230	220	210	205	190	195	195	204.0
	3	180	175	170	185	175	65	180	185	190	165	177.0
											AVG.	188.7
	1	160	150	145	155	175	160	180	185	190	165	166.5
4	2	135	140	160	150	180	165	170	185	170	150	160.5
	3	120	125	140	145	150	155	140	145	160	170	145.0
											AVG.	157.3
	1	155	145	170	175	185	180	175	175	180	190	173.0
5	2	175	180	185	190	195	175	190	170	175	180	181.5
	3	140	145	150	165	170	155	165	175	160	165	159.0
											AVG.	171.2
	1	170	165	165	155	180	160	165	150	140	160	160.5
6	2	125	115	135	140	150	155	145	140	135	130	137.0
	3	145	150	155	170	175	180	165	175	160	165	164.0
											AVG.	153.8
	1	150	170	155	175	170	160	150	155	160	175	262
7	2	120	130	145	135	130	125	135	150	155	145	137
	3	165	175	150	165	160	155	145	150	140	150	155.5
											AVG.	155.5
	1	160	165	185	180	190	185	175	190	180	175	178.5
8	2	160	165	140	145	130	135	120	130	125	125	137.0
	3	125	130	135	145	150	160	165	145	140	160	145.5
											AVG.	153.7
	1	175	185	170	140	150	175	185	190	195	175	174
9	2	125	130	115	130	140	135	145	135	120	130	130.5
	3	120	115	140	130	150	140	135	130	145	160	137.0
											AVG.	147.2
	1	150	170	185	180	190	160	175	165	165	180	172
10	2	120	115	125	130	125	120	115	110	115	135	121
	3	160	140	150	145	165	170	150	155	155	160	155
											AVG.	149.3

Appendix Table A11. Corn root weight (g) per core (volume of 288.63cm^3) for all ten treatments measured in rows at different soil depths (1983).

Depth (cm)		Treatments 1	2	3	4	5	6	7	8	9	10
0-7.5	1	0.505	0.360	0.564	0.724	0.457	0.232	0.425	0.717	0.184	0.354
	2	0.664	0.865	0.442	0.542	0.279	0.109	0.365	0.846	0.528	0.552
	3	0.415	0.769	0.686	0.448	0.501	0.510	0.568	0.423	0.680	0.816
	AVG.	0.528	0.665	0.564	0.571	0.412	0.284	0.452	0.662	0.464	0.574
7.5-15	1	0.184	0.246	0.372	0.464	0.214	0.123	0.420	0.417	0.449	0.205
	2	0.448	0.158	0.316	0.122	0.172	0.107	0.193	0.415	0.490	0.283
	3	0.534	0.105	0.344	0.193	0.193	0.174	0.183	0.075	0.331	0.362
	AVG.	0.389	0.170	0.344	0.260	0.458	0.135	0.265	0.302	0.390	0.283
15-22.5	1	0.110	0.239	0.225	0.117	0.086	0.077	0.189	0.112	0.041	0.083
	2	0.137	0.056	0.036	0.087	0.109	0.023	0.046	0.162	0.116	0.354
	3	0.180	0.009	0.122	0.103	0.264	0.093	0.137	0.045	0.068	0.213
	AVG.	0.142	0.101	0.128	0.102	0.153	0.064	0.124	0.106	0.075	0.217
22.5-30	1	0.067	0.145	0.185	0.049	0.087	0.034	0.053	0.048	0.014	0.037
	2	0.011	0.021	0.034	0.069	0.044	0.012	0.057	0.074	0.012	0.075
	3	0.014	0.037	0.032	0.050	0.053	0.020	0.070	0.025	0.050	0.129
	AVG.	0.061	0.067	0.084	0.056	0.061	0.022	0.060	0.049	0.025	0.080
30-37.5	1	0.052	0.090	0.117	0.033	0.058	0.030	0.027	0.040	0.018	0.041
	2	0.022	0.024	0.037	0.035	0.032	0.012	0.038	0.076	0.032	0.010
	3	0.045	0.043	0.013	0.052	0.026	0.038	0.019	0.012	0.041	0.091
	AVG.	0.040	0.052	0.056	0.040	0.039	0.027	0.028	0.042	0.030	0.047
37.5-45	1	0.042	0.077	0.114	0.042	0.068	0.032	0.021	0.036	0.033	0.037
	2	0.013	0.019	0.029	0.034	0.058	0.028	0.036	0.069	0.030	0.002
	3	0.052	0.031	0.016	0.047	0.016	0.036	0.041	0.007	0.029	0.075
	AVG.	0.036	0.042	0.053	0.041	0.047	0.032	0.033	0.037	0.031	0.038

Appendix Table A12. Soil moisture content by volume (cm) throughout the season at the depth of 20 cm for each of the ten treatments (1983).

Treatments	Replications	Weeks									
		1	2	3	4	5	6	7	8	9	10
		11/16	11/23	11/30	12/07	12/14	12/21	12/28	01/04	01/11	01/18
	1	7.92	8.17	7.98	8.03	8.10	6.96	7.75	6.29	6.32	5.72
1	2	7.78	8.28	7.29	8.62	7.92	6.49	8.46	6.91	6.76	5.89
	3	8.28	8.75	8.31	8.85	8.95	7.32	10.06	6.99	7.71	6.11
	AVG.	7.99	8.40	7.85	8.50	8.32	6.93	8.76	6.73	6.83	5.91
	1	8.63	8.28	8.35	9.57	9.12	7.32	8.48	6.79	6.78	5.73
2	2	8.01	8.54	7.78	8.11	7.72	6.61	7.42	6.23	6.27	5.60
	3	7.74	7.96	7.26	7.90	7.78	6.34	7.40	6.42	6.56	5.57
	AVG.	8.13	8.26	7.80	8.53	8.21	6.82	7.79	6.48	6.54	5.63
	1	9.04	9.30	8.95	9.38	9.28	7.68	8.57	7.26	7.20	6.27
3	2	8.32	8.42	8.27	8.83	8.71	7.08	8.67	6.31	6.55	6.10
	3	8.42	9.30	8.33	9.53	8.84	6.79	8.69	6.58	6.38	5.17
	AVG.	8.59	9.01	8.52	9.21	8.94	7.18	8.77	6.72	6.71	6.18
	1	9.27	9.24	7.39	9.09	6.09	7.80	8.36	7.02	7.01	5.76
4	2	8.07	8.48	7.31	8.74	8.59	7.50	8.36	6.91	6.85	5.75
	3	7.52	8.73	7.91	9.48	9.08	6.89	8.67	6.87	6.60	5.93
	AVG.	8.28	8.81	7.54	9.10	8.18	7.40	8.46	6.93	6.82	5.81
	1	8.82	8.71	7.49	8.64	8.82	7.50	8.22	7.06	7.20	5.94
5	2	8.54	8.81	8.25	8.72	8.45	7.01	8.56	6.99	7.44	6.36
	3	7.24	7.80	7.00	8.05	7.85	6.79	8.17	6.42	6.42	5.81
	AVG.	8.20	8.44	7.58	8.47	8.37	7.10	8.31	6.82	7.02	6.04

Appendix Table A12 (cont.)

Treatments	Replications	Weeks									
		1	2	3	4	5	6	7	8	9	10
		11/16	11/23	11/30	12/07	12/14	12/21	12/28	01/04	01/11	01/18
	1	7.38	7.85	7.21	7.88	7.44	7.35	7.78	6.79	7.28	8.60
6	2	7.38	7.85	7.18	6.64	8.18	6.48	7.89	76.73	6.41	7.56
	3	7.09	8.19	7.49	7.80	7.97	6.82	7.92	6.69	6.63	7.69
	AVG.	7.55	7.96	7.29	7.44	7.86	6.88	7.86	6.73	6.77	7.95
	1	8.28	8.40	7.54	8.60	8.55	7.17	8.19	6.94	7.05	7.72
7	2	7.60	7.76	7.63	7.78	7.72	6.82	8.17	6.42	6.98	5.91
	3	7.55	7.92	7.34	8.34	8.29	6.86	7.85	6.32	6.46	6.86
	AVG.	7.81	8.02	7.50	8.24	8.19	6.95	8.07	6.56	6.72	6.83
	1	8.38	9.24	7.60	8.51	8.18	7.46	8.05	6.44	6.33	6.37
8	2	8.24	8.28	7.61	8.83	8.55	7.84	8.24	6.77	6.88	7.16
	3	7.92	8.21	8.02	8.58	8.06	6.75	7.80	6.25	6.22	7.25
	AVG.	8.18	8.57	7.76	8.64	8.26	7.35	8.03	6.48	6.48	6.93
	1	8.73	8.02	8.37	9.41	8.27	8.25	8.02	6.77	6.50	5.97
9	2	8.28	8.28	8.15	8.83	8.10	7.36	8.05	6.91	6.43	5.85
	3	8.20	8.21	8.33	9.50	8.31	7.41	8.07	6.83	6.55	7.56
	AVG.	8.41	8.60	8.29	9.24	8.23	7.34	8.05	6.84	6.49	6.46
	1	8.17	8.30	7.77	8.30	8.06	7.32	8.00	6.87	6.72	7.60
10	2	8.19	8.17	8.37	8.85	8.27	7.25	9.08	7.09	7.01	6.47
	3	7.29	8.52	7.78	8.36	8.47	6.65	8.22	6.91	6.86	6.80
	AVG.	7.89	8.33	7.97	8.50	8.27	7.07	8.43	6.96	6.97	6.96

Appendix Table A12 (Cont.)

Treatments	Replications	Weeks 11	12	13	14	15	16	17	18	19
		01/25	02/01	02/08	02/15	02/22	02/29	03/08	03/14	03/21
	1	8.22	6.67	6.34	5.91	5.75	5.39	5.54	6.11	7.26
1	2	7.94	6.60	6.04	5.85	5.54	5.41	5.77	5.86	6.97
	3	8.78	6.66	6.23	6.22	6.06	5.49	5.74	6.73	6.91
	AVG.	8.31	6.64	6.20	6.00	5.79	5.43	5.68	6.23	7.05
	1	8.03	7.26	5.99	4.96	5.97	5.53	5.39	5.96	7.03
2	2	8.43	6.75	5.65	5.53	5.37	5.35	5.09	5.87	6.65
	3	8.14	6.39	6.79	5.69	5.57	5.42	5.40	6.54	5.79
	AVG.	8.20	6.76	6.15	5.39	5.53	5.43	5.29	6.12	6.49
	1	8.47	7.32	6.29	6.17	5.99	5.69	5.53	6.27	7.59
3	2	8.57	6.70	5.93	6.02	5.96	5.44	6.08	6.66	7.82
	3	7.92	6.55	6.75	6.02	5.78	5.63	5.51	6.88	6.84
	AVG.	8.32	6.86	6.32	6.07	5.91	5.58	5.71	6.60	7.41
	1	7.96	7.29	6.60	5.77	5.57	5.34	5.55	5.98	7.29
4	2	8.14	6.80	5.91	5.51	5.29	5.15	5.61	6.11	6.91
	3	8.41	6.38	6.38	5.43	5.29	5.12	5.00	6.00	6.59
	AVG.	8.17	6.82	6.29	5.57	5.38	5.20	5.39	6.03	6.93
	1	8.35	7.32	6.63	5.82	5.52	5.45	5.23	6.67	7.46
5	2	8.95	6.68	5.95	6.32	6.24	5.70	5.68	6.68	7.39
	3	7.76	6.30	7.13	5.60	5.44	5.30	5.28	6.04	6.12
	AVG.	8.35	6.77	6.57	5.91	5.73	5.48	5.40	6.46	6.99

Appendix Table A12 (Cont.)

Treatments	Replications	Weeks								
		11	12	13	14	15	16	17	18	19
		01/25	02/01	02/08	02/15	02/22	02/29	03/08	03/14	03/21
	1	8.29	7.31	7.16	6.56	7.01	7.28	7.29	6.82	7.33
6	2	9.10	6.54	6.55	6.81	6.56	7.25	7.57	7.45	7.85
	3	8.88	7.24	5.88	6.54	6.72	6.86	7.07	7.32	6.65
	AVG.	8.76	7.03	6.53	6.83	6.76	7.13	7.31	7.20	7.28
	1	8.41	7.35	7.09	7.73	6.87	7.39	7.12	7.74	7.65
7	2	7.31	7.50	6.97	6.52	6.70	6.69	6.46	7.72	7.14
	3	8.88	7.24	5.88	6.54	6.72	6.86	7.07	7.32	6.65
	AVG.	8.76	7.03	6.53	6.83	6.76	7.13	7.31	7.20	7.28
	1	7.23	7.10	6.65	6.71	5.77	5.21	5.12	6.05	6.81
8	2	7.59	7.15	6.81	6.05	6.48	6.06	5.35	6.85	7.22
	3	7.51	6.47	6.07	7.15	6.64	5.22	6.87	6.81	7.10
	AVG.	7.44	6.91	6.51	6.61	6.30	5.91	5.78	6.57	7.01
	1	8.26	8.23	6.22	6.71	7.32	7.00	7.26	7.93	7.88
9	2	7.92	6.97	6.39	6.21	5.94	5.90	5.80	6.92	7.23
	3	7.61	7.21	5.84	6.57	6.98	6.13	7.06	6.46	6.91
	AVG.	6.93	7.14	6.15	6.49	6.72	6.34	6.7	7.10	7.34
	1	8.67	7.18	7.00	6.16	7.10	6.69	7.75	7.35	7.95
10	2	8.47	7.20	6.60	6.40	5.97	5.78	6.77	6.95	7.06
	3	9.59	6.42	6.31	6.02	6.71	5.59	7.18	9.95	6.21
	AVG.	8.58	6.93	6.64	6.34	6.59	6.02	7.23	7.08	7.07

Appendix Table A13. Soil moisture content by volume (cm) throughout the season at the depth of 40 cm for each of the ten treatments (1983).

Treatments	Replications	Weeks									
		1	2	3	4	5	6	7	8	9	10
		11/16	11/23	11/30	12/07	12/14	12/21	12/28	01/04	01/11	01/18
	1	8.30	8.32	7.36	8.20	7.90	7.08	7.42	6.26	6.23	5.71
1	2	8.42	8.15	7.87	7.67	7.94	7.05	7.12	6.44	6.37	5.88
	3	8.57	8.44	8.23	9.11	7.19	7.24	8.26	7.12	7.20	6.13
	AVG.	8.43	8.30	7.82	8.33	7.67	7.12	7.60	6.61	6.60	5.90
	1	8.07	7.94	7.89	7.54	7.67	7.05	7.31	6.41	6.05	5.48
2	2	7.40	7.56	7.42	7.59	7.20	6.46	7.21	6.03	6.07	5.31
	3	8.20	8.64	7.87	8.09	7.71	6.76	7.02	6.55	5.94	5.70
	AVG.	7.89	8.05	7.73	7.74	7.53	6.76	7.18	6.33	6.02	5.49
	1	8.42	8.97	8.33	8.72	8.47	7.58	7.91	6.69	6.25	5.74
3	2	8.24	8.34	7.75	8.41	7.86	7.19	7.51	6.53	6.32	5.82
	3	8.30	8.21	8.19	8.01	8.05	7.50	7.89	6.44	6.41	5.78
	AVG.	8.32	8.50	8.09	8.78	8.12	7.42	7.77	6.55	6.32	5.70
	1	8.52	8.86	7.68	8.24	8.61	6.89	7.49	6.49	6.20	5.65
4	2	8.36	8.19	7.93	8.18	8.31	7.17	7.49	6.63	6.39	5.53
	3	8.00	8.09	7.95	8.28	7.95	7.65	7.64	6.61	7.01	5.46
	AVG.	8.29	8.38	7.85	8.23	8.29	7.24	7.54	6.58	6.53	5.55
	1	8.11	8.36	7.96	7.88	8.16	7.04	7.54	6.27	6.53	5.55
5	2	9.15	8.99	8.67	8.66	7.99	7.86	8.50	7.36	7.33	6.14
	3	7.89	8.07	7.42	7.74	7.60	7.21	7.68	6.87	7.01	5.64
	AVG.	8.38	8.47	8.02	8.10	7.92	7.38	7.90	6.83	6.76	5.81

Appendix Table A13 (Cont.)

Treatments	Replications	Weeks									
		1	2	3	4	5	6	7	8	9	10
		11/16	11/23	11/30	12/07	12/14	12/21	12/28	01/04	01/11	01/18
	1	8.36	7.80	8.27	8.11	7.50	7.24	7.39	6.94	6.95	7.70
6	2	8.65	8.54	8.59	8.37	8.37	7.41	7.47	6.66	6.26	7.20
	3	8.34	8.17	7.51	8.12	8.23	6.95	7.29	6.62	6.22	6.51
	AVG.	8.45	8.17	8.05	8.20	8.03	7.20	7.38	6.75	6.47	7.14
	1	8.91	8.26	7.54	8.18	7.99	7.38	.03	7.46	7.25	6.95
7	2	8.28	8.30	7.84	8.26	8.14	7.38	7.61	6.80	6.90	5.77
	3	8.28	8.48	7.95	7.83	8.18	7.04	8.19	.59	6.31	6.13
	AVG.	8.49	8.35	7.17	8.09	8.10	7.27	7.94	6.95	6.82	6.28
	1	7.87	8.34	7.73	7.99	7.41	6.78	7.09	6.29	6.03	6.03
8	2	8.09	7.96	7.29	8.18	7.94	6.89	7.08	6.97	6.16	6.41
	3	8.20	8.34	7.80	7.74	8.39	7.04	7.28	6.39	6.00	6.11
	AVG.	8.05	8.21	7.61	7.97	7.91	6.90	7.15	6.55	6.06	6.18
	1	8.19	8.48	7.71	8.03	8.29	7.16	7.36	5.93	6.09	5.54
9	2	8.05	8.21	7.91	8.16	7.97	6.88	7.56	6.88	6.10	5.95
	3	7.17	7.83	7.20	7.55	7.55	6.65	6.94	6.40	5.94	7.14
	AVG.	7.98	3.17	7.61	7.92	7.94	6.90	7.28	6.40	6.06	6.21
	1	8.48	8.50	7.82	8.11	7.95	7.24	6.04	6.35	6.98	6.26
10	2	8.20	9.01	7.87	8.47	8.01	7.33	9.73	6.73	6.60	5.83
	3	7.92	8.44	7.56	7.50	7.74	6.71	7.29	6.63	6.67	5.89
	AVG.	8.20	8.65	7.75	8.03	7.90	7.09	7.69	6.57	6.42	5.99

Appendix Table A13 (Cont.)

Treatments	Replications	Weeks 11	12	13	14	15	16	17	18	19
		01/25	02/01	02/08	02/15	02/22	02/29	03/08	03/14	03/21
	1	7.56	6.58	5.93	5.88	5.77	5.52	5.53	5.33	6.42
1	2	7.51	6.97	6.06	5.00	5.67	5.26	5.22	5.11	5.73
	3	7.61	7.39	6.71	5.58	5.49	5.28	5.34	5.75	6.88
	AVG.	7.56	6.98	6.23	5.49	5.64	5.35	5.36	5.40	6.34
	1	7.64	6.54	6.01	5.46	5.39	5.13	5.13	5.27	6.12
2	2	7.96	5.99	5.45	5.41	5.19	5.19	5.09	5.09	5.82
	3	7.73	7.09	6.18	5.66	5.44	5.26	5.33	5.30	6.72
	AVG.	7.77	6.54	5.88	5.51	5.34	5.19	5.18	5.22	6.22
	1	7.88	6.91	5.66	5.47	5.37	5.29	5.20	5.06	6.07
3	2	7.85	6.64	5.97	5.55	5.46	5.31	5.46	5.50	6.18
	3	7.88	6.90	6.56	5.69	5.64	5.23	5.37	5.65	6.71
	AVG.	7.87	6.82	6.06	5.57	5.49	5.28	5.34	5.40	5.32
	1	7.61	6.78	5.70	5.58	5.24	5.41	5.42	5.17	5.31
4	2	7.71	6.51	4.64	5.64	5.32	5.10	5.13	5.51	6.12
	3	7.71	6.48	6.75	5.31	5.48	5.13	5.22	5.42	6.55
	AVG.	7.67	6.59	6.03	5.41	5.34	5.21	5.25	5.37	6.32
	1	7.57	6.97	5.92	5.36	5.32	5.37	5.31	5.95	6.01
5	2	8.84	7.03	6.44	5.99	5.94	5.75	5.19	5.72	6.61
	3	7.39	6.52	6.40	5.54	5.26	4.32	5.18	5.40	6.59
	AVG.	7.93	6.75	6.26	5.63	5.50	5.48	5.23	5.69	6.37

Appendix Table A13 (Cont.)

Treatments	Replications	Weeks 11 01/25	12 02/01	13 02/08	14 02/15	15 02/22	16 02/29	17 03/08	18 03/14	19 03/21
6	1	7.74	6.82	6.39	6.21	6.24	7.00	7.38	7.48	6.59
	2	7.76	6.60	7.42	6.49	6.70	6.55	6.47	6.67	7.09
	3	7.55	6.62	5.71	6.55	6.65	6.65	6.94	7.32	7.19
	AVG.	7.69	6.68	6.17	6.45	6.53	6.73	6.93	7.16	6.95
7	1	8.29	7.24	6.97	6.83	6.51	6.42	7.15	6.70	6.91
	2	8.67	7.55	7.23	6.46	6.17	5.46	5.53	6.94	7.08
	3	8.18	6.84	6.07	6.54	6.35	5.86	7.16	6.62	7.05
	AVG.	8.38	7.21	6.76	6.61	6.34	5.91	6.61	6.75	7.01
8	1	7.39	6.19	5.92	5.75	5.25	5.11	5.19	5.07	5.67
	2	7.57	6.75	6.49	5.80	5.83	5.56	4.88	6.46	6.30
	3	7.74	6.82	5.74	6.03	5.99	5.92	6.06	6.71	6.89
	AVG.	7.54	6.59	6.05	5.87	5.69	5.53	5.37	6.08	6.29
9	1	7.80	6.81	6.34	6.38	5.76	6.67	6.74	7.18	6.97
	2	7.31	6.82	6.23	6.05	5.50	5.65	5.44	6.54	6.35
	3	7.11	6.38	5.83	6.57	5.88	5.93	6.33	6.73	6.68
	AVG.	7.41	6.67	6.13	6.34	5.71	6.08	6.17	6.81	6.67
10	1	7.90	6.94	6.15	6.28	5.95	6.11	6.78	7.19	6.73
	2	7.69	7.01	5.04	5.41	5.40	5.30	5.59	6.11	6.41
	3	7.88	6.67	6.20	5.94	6.30	5.86	6.15	6.88	7.30
	AVG.	7.83	6.67	6.10	5.88	5.88	5.75	6.17	6.73	6.81

Appendix Table A14. Soil moisture content by volume (cm) throughout the season at the depth of 60 cm for each of the ten treatments (1983).

Treatments	Replications	Weeks									
		1	2	3	4	5	6	7	8	9	10
		11/16	11/23	11/30	12/07	12/14	12/21	12/28	01/04	01/11	01/18
	1	7.92	7.89	6.87	7.42	7.97	6.95	6.76	6.13	5.82	5.63
1	2	7.47	7.61	7.26	7.94	7.62	6.47	6.41	6.07	5.54	5.22
	3	8.05	8.21	8.10	8.12	7.78	6.82	7.59	6.50	6.42	5.71
	AVG.	7.81	7.90	7.41	7.83	7.79	6.75	6.92	6.23	5.93	5.52
	1	7.57	7.73	7.51	7.20	7.20	6.75	5.79	6.00	5.73	5.21
2	2	7.40	7.54	7.28	6.93	6.93	6.28	6.32	6.26	5.50	5.24
	3	7.38	7.51	7.20	7.71	7.47	6.59	6.55	5.98	6.48	5.32
	AVG.	7.45	7.62	7.33	7.28	7.20	6.54	6.22	6.08	5.90	5.26
	2	7.74	7.82	7.31	8.30	7.59	7.14	6.96	6.30	5.99	5.36
3	2	7.55	7.62	7.47	7.02	7.57	6.53	6.91	6.10	5.84	5.25
	3	7.55	7.75	7.31	7.49	7.88	7.01	7.09	6.23	5.72	5.56
	AVG.	7.61	7.73	7.36	7.60	7.68	6.89	6.95	6.21	5.85	5.39
	1	7.81	7.91	7.71	7.46	7.34	6.89	6.84	6.14	5.66	5.38
4	2	8.01	7.78	7.57	7.57	8.27	7.70	7.33	6.61	6.07	5.57
	3	7.72	7.76	7.63	7.99	7.55	7.17	6.80	6.80	6.26	5.48
	AVG.	7.85	7.82	7.64	7.67	7.72	7.25	6.99	6.52	6.00	6.48
	1	7.71	7.66	7.77	7.87	7.74	7.05	7.26	6.53	6.23	5.40
5	2	8.26	7.94	8.02	7.80	8.16	7.38	7.71	6.88	6.38	5.82
	3	7.52	7.92	7.34	7.44	7.23	6.75	7.08	6.42	6.37	5.31
	AVG.	7.83	7.84	7.71	7.70	7.71	7.06	7.35	6.61	.32	5.51

Appendix Table A14 (Cont.)

Treatments	Replications	Weeks 1	2	3	4	5	6	7	8	9	10
		11/16	11/23	11/30	12/07	12/14	12/21	12/28	01/04	01/11	01/18
	1	7.72	7.73	7.73	7.67	7.39	6.76	6.99	6.87	6.46	7.14
6	2	7.53	7.25	7.31	7.34	7.41	6.59	6.95	6.27	5.52	5.25
	3	7.53	7.80	7.25	6.12	7.28	6.42	6.46	6.12	5.71	5.40
	AVG.	7.60	7.59	7.43	7.71	7.36	6.59	6.81	6.42	5.90	5.93
	1	7.47	7.51	7.87	7.47	7.01	6.38	5.59	6.08	5.96	5.49
7	2	7.74	8.02	7.86	7.57	7.25	6.95	7.51	6.08	6.09	5.38
	3	7.43	7.54	6.87	6.72	7.36	6.75	6.70	6.40	5.97	5.36
	AVG.	7.55	7.69	7.53	7.55	7.20	6.65	6.93	6.19	6.01	5.41
	2	7.05	7.47	7.57	7.08	7.06	6.59	6.62	5.98	5.71	5.31
8	2	7.62	7.80	7.12	7.25	7.05	6.61	7.06	6.30	6.20	5.35
	3	6.83	7.00	6.84	6.87	6.85	6.47	6.42	6.06	5.74	5.43
	AVG.	7.17	7.42	7.18	7.07	6.99	6.56	6.70	6.11	5.89	5.36
	1	7.78	8.24	7.31	7.71	7.28	7.10	6.53	6.34	5.63	5.16
9	2	7.71	7.78	7.52	6.97	7.47	6.92	6.91	6.19	5.69	5.46
	3	6.99	7.49	7.11	7.14	6.90	6.75	6.75	6.23	5.95	6.54
	AVG.	7.49	7.84	7.37	7.27	7.22	6.92	6.73	6.23	5.76	5.72
	1	7.59	7.36	6.95	7.17	7.37	6.56	6.70	6.34	5.79	5.51
10	2	8.15	7.54	7.36	7.17	7.45	7.61	6.76	6.21	5.95	5.31
	3	7.62	7.91	7.33	7.78	7.79	6.67	6.99	6.36	6.06	5.71
	AVG.	7.78	7.60	7.21	7.37	7.54	6.95	6.82	6.30	5.93	5.51

Appendix Table A14 (Cont.)

Treatments	Replications	Weeks								
		11	12	13	14	15	16	17	18	19
		01/25	02/01	02/08	02/15	02/22	02/29	03/08	03/14	03/21
	1	6.63	6.50	5.64	5.35	5.40	5.26	5.24	5.16	5.68
1	2	6.53	6.97	5.28	5.20	4.86	4.88	4.80	5.12	5.11
	2	6.53	6.97	5.28	5.20	4.86	4.88	4.80	5.12	5.11
	3	7.81	7.07	6.48	5.34	5.24	5.38	5.33	5.40	5.96
	AVG.	6.99	6.85	5.80	5.30	5.17	5.17	5.12	5.22	5.58
	1	7.33	6.55	5.48	5.33	5.34	5.20	5.16	5.31	5.31
2	2	7.10	6.28	5.42	5.21	5.30	5.16	5.24	5.21	5.21
	3	7.51	6.36	6.23	5.24	5.12	5.19	5.17	5.14	5.82
	AVG.	7.32	6.40	5.71	5.29	5.25	5.18	5.19	5.22	5.45
	1	7.10	6.13	5.42	5.43	5.12	5.24	5.22	5.03	5.50
3	2	8.90	6.38	5.39	5.67	5.11	5.20	5.26	5.17	5.47
	3	7.74	6.45	5.71	5.41	5.32	5.36	5.19	5.19	5.97
	AVG.	7.91	6.32	5.51	5.50	5.18	5.26	5.22	5.13	5.65
	1	6.44	6.45	5.33	5.33	5.07	5.51	5.33	5.10	5.23
4	2	7.38	6.74	5.55	5.48	5.50	5.50	5.11	5.36	5.56
	3	7.51	6.55	6.02	5.35	5.28	5.10	5.11	5.37	5.85
	AVG.	7.11	6.58	5.63	5.39	5.28	5.17	5.18	5.28	5.55
	1	7.88	6.95	5.58	5.37	5.38	5.23	5.15	5.21	6.06
5	2	8.18	6.54	6.42	5.53	5.44	5.67	4.88	5.36	5.70
	3	7.33	6.85	6.42	5.38	5.32	5.36	5.39	5.48	6.15
	AVG.	7.80	6.78	6.14	5.43	5.38	5.42	5.14	5.35	5.97

Appendix Table A14 (Cont.)

Treatments	Replications	Weeks 11 01/25	12 02/01	13 02/08	14 02/15	15 02/22	16 02/29	17 03/08	18 03/14	19 03/21
	1	7.92	6.78	6.47	6.16	6.31	6.11	6.51	6.54	6.76
6	2	7.20	6.64	5.85	6.37	6.36	6.87	6.51	6.68	7.02
	3	7.16	6.51	5.63	6.41	6.15	6.42	6.54	6.88	6.39
	AVG.	7.44	6.64	5.98	6.31	6.44	6.47	6.52	6.70	6.72
	1	7.36	6.55	6.44	6.23	6.53	6.59	6.41	6.91	6.37
7	2	7.71	6.85	5.99	5.62	5.48	5.45	5.53	6.78	6.32
	3	6.82	6.45	5.57	6.01	6.29	5.59	6.26	6.42	6.55
	AVG.	7.30	6.61	6.00	5.95	6.10	5.08	6.07	6.70	6.41
	1	6.47	6.23	5.61	5.79	4.99	5.22	5.20	5.13	5.15
8	2	7.39	6.52	6.13	5.58	5.77	5.37	5.14	6.36	6.18
	3	6.81	6.85	6.59	6.73	6.19	6.58	5.58	6.82	6.42
	AVG.	6.89	6.54	6.11	6.03	5.65	7.72	5.31	6.10	5.91
	1	6.64	6.34	5.77	5.70	6.26	6.21	6.28	7.38	6.72
9	2	6.10	6.58	5.92	5.95	5.32	5.26	5.11	5.83	6.17
	3	7.41	6.58	5.63	5.81	5.73	5.59	6.33	6.71	6.38
	AVG.	6.72	6.50	5.77	5.70	5.77	5.69	5.91	6.64	6.42
	1	7.20	6.66	6.55	6.04	6.04	5.50	6.78	6.75	6.65
10	2	7.10	6.39	5.67	5.29	5.15	4.93	5.23	5.78	5.63
	3	7.44	6.50	5.86	6.09	6.14	5.70	5.44	6.68	6.91
	AVG.	7.26	6.55	6.03	5.81	5.78	5.37	5.81	6.41	6.40

Appendix Table A15. Soil moisture content by volume (cm) throughout the season at the depth of 80 cm for each of the ten treatments (1983).

Treatments	Replications	Weeks									
		1	2	3	4	5	6	7	8	9	10
		11/16	11/23	11/30	12/07	12/14	12/21	12/28	01/04	01/11	01/18
	1	6.71	7.91	6.91	7.23	7.31	6.31	6.24	6.13	5.58	5.13
1	2	6.47	6.72	6.47	6.37	6.56	6.13	6.06	5.73	5.42	5.31
	3	7.24	7.29	7.25	6.07	7.02	6.53	6.91	6.41	6.31	5.55
	AVG.	6.86	7.21	6.88	6.55	6.96	6.32	6.40	6.09	5.77	5.33
	1	7.53	7.18	7.46	7.59	7.55	6.82	6.74	6.44	6.03	5.33
2	2	7.74	7.46	7.49	7.64	7.54	6.98	6.73	6.32	5.62	5.48
	3	7.50	8.11	9.13	7.18	7.13	6.79	6.46	5.79	5.73	5.30
	AVG.	7.59	7.82	8.02	8.03	7.47	7.40	6.86	6.65	6.18	5.79
	1	6.95	8.09	6.88	6.93	7.05	6.48	6.39	6.07	5.95	5.15
3	2	7.05	7.20	7.75	7.61	7.55	6.74	6.91	6.20	5.82	5.23
	3	7.05	7.78	7.25	6.68	7.31	6.41	6.42	5.95	5.74	5.13
	AVG.	7.02	7.26	7.29	7.07	7.30	6.54	6.57	6.07	5.84	5.17
	1	7.38	7.21	7.57	7.18	7.23	7.13	6.54	6.36	5.89	5.44
4	2	7.81	8.54	8.10	8.12	7.54	7.61	7.29	6.97	6.41	5.51
	3	7.57	7.36	7.77	7.80	7.88	6.98	7.14	6.59	6.44	5.54
	AVG.	7.59	8.06	7.81	7.70	7.55	7.24	6.99	6.64	6.25	5.50
	1	7.35	7.71	6.96	7.29	7.37	7.04	6.94	6.45	6.47	5.38
5	2	7.76	8.07	7.68	7.49	8.18	6.99	7.27	6.72	6.41	5.77
	3	7.64	7.94	7.75	7.46	7.28	7.05	6.93	7.14	6.60	5.66
	AVG.	7.58	7.82	7.46	7.41	7.61	7.03	7.01	6.77	6.49	5.60

Appendix Table A15 (Cont.)

Treatments	Replications	Weeks 1	2	3	4	5	6	7	8	9	10
		11/16	11/23	11/30	12/07	12/14	12/21	12/28	01/04	01/11	01/18
	1	7.05	6.32	7.11	7.98	7.94	6.41	6.53	6.11	6.12	6.10
6	2	7.21	7.54	7.01	6.92	7.22	6.42	6.41	6.24	5.85	5.45
	3	7.30	6.94	6.73	6.89	6.95	6.42	6.32	6.32	5.67	5.30
	AVG.	7.19	7.14	6.95	7.26	7.37	6.41	6.42	6.22	5.88	5.61
	1	7.27	7.69	6.73	7.28	7.09	6.57	6.63	6.18	5.97	5.75
7	2	7.10	7.71	6.87	7.17	6.92	6.71	6.69	5.93	5.63	5.41
	3	6.06	7.56	6.59	7.41	6.90	6.56	6.24	6.14	5.81	5.76
	AVG.	7.08	7.18	6.73	7.28	6.07	6.61	6.52	6.08	5.80	5.64
	1	7.11	7.34	7.11	7.31	7.64	6.69	6.69	6.39	5.95	5.59
8	2	7.10	7.05	7.56	7.23	7.34	6.91	6.61	6.25	5.94	5.58
	3	7.10	7.83	7.28	6.70	7.25	6.64	6.51	6.24	6.36	6.17
	AVG.	7.10	7.62	7.31	7.08	7.41	6.75	6.60	6.29	6.05	5.78
	1	7.11	7.49	6.51	6.73	7.09	6.55	6.32	5.86	5.89	5.29
9	2	6.95	7.18	7.31	7.52	7.22	6.71	6.34	6.15	5.80	5.51
	3	7.29	7.05	6.96	6.96	6.90	6.46	6.46	6.48	6.14	6.46
	AVG.	7.12	7.5	6.92	7.07	7.07	6.57	6.37	6.16	5.94	5.75
	1	6.00	7.76	7.03	6.37	6.33	6.86	6.13	5.88	5.58	5.28
10	2	7.92	7.11	7.04	6.92	7.45	6.82	6.61	6.39	5.97	5.54
	3	7.32	7.14	7.12	7.62	7.09	6.83	6.58	6.44	6.26	5.78
	AVG.	7.38	7.11	7.06	6.97	6.96	6.84	6.44	6.23	5.93	5.53

Appendix Table A15 (Cont.)

Treatments	Replications	Weeks 11 01/25	12 02/01	13 02/08	14 02/15	15 02/22	16 02/29	17 03/08	18 03/14	19 03/21
	1	4.88	6.01	5.65	4.97	5.50	4.88	4.70	4.88	4.97
1	2	5.10	6.41	5.42	5.77	5.16	5.26	5.14	5.09	6.19
	3	7.34	6.73	6.39	5.36	5.36	5.27	5.40	5.43	5.40
	AVG.	5.77	6.38	5.82	5.37	5.34	5.14	5.10	5.13	5.52
	1	6.50	6.67	5.99	5.45	5.44	5.38	5.07	5.27	5.38
2	2	6.91	6.48	5.42	5.38	5.39	5.24	5.35	5.10	5.25
	3	6.45	6.60	6.78	5.13	5.17	4.87	4.96	5.07	5.15
	AVG.	6.62	6.59	6.06	5.32	5.03	5.16	5.11	5.15	5.26
	1	5.46	6.07	5.25	5.10	5.01	5.04	4.96	5.04	5.26
3	2	6.28	6.08	5.45	5.50	5.34	5.03	5.33	5.09	5.17
	3	6.60	5.90	6.65	5.33	5.06	5.02	4.94	5.01	5.20
	AVG.	6.11	6.02	5.78	5.31	5.13	5.03	5.08	5.05	5.21
	1	5.34	6.34	5.25	5.41	5.24	5.06	5.02	5.23	5.32
4	2	7.11	6.87	5.61	5.49	5.71	5.22	3.02	5.24	5.21
	3	6.25	6.73	6.30	5.42	5.36	5.25	5.50	5.36	5.32
	AVG.	6.24	6.64	5.72	5.44	5.44	5.17	5.18	5.28	5.28
	1	7.51	6.56	5.70	5.27	5.14	5.10	5.43	5.02	5.32
5	2	7.83	5.99	5.89	5.63	5.23	5.34	5.23	5.31	5.53
	3	7.02	6.47	6.64	5.19	5.05	5.10	5.10	5.42	5.52
AVG.		7.45	6.34	6.08	5.36	5.14	5.18	5.25	5.25	5.45

Appendix Table A15 (Cont.)

Treatments	Replications	Weeks								
		11	12	13	14	15	16	17	18	19
		01/25	02/01	02/08	02/15	02/22	02/29	03/08	03/14	03/21
	1	7.34	6.28	6.12	6.08	6.43	6.76	6.75	6.88	6.50
6	2	7.14	6.10	5.92	5.97	5.83	6.01	6.58	6.67	6.37
	3	6.36	6.30	5.37	6.11	6.75	6.40	6.60	6.74	6.39
	AVG.	6.95	6.23	5.80	6.05	6.33	6.39	6.64	6.76	6.42
	1	7.47	6.70	6.51	6.78	6.63	6.41	6.68	6.91	6.77
7	2	6.53	6.60	6.35	6.00	5.77	5.74	5.39	6.92	6.37
	3	6.41	6.21	5.68	6.82	6.56	5.87	6.30	6.70	6.11
	AVG.	6.80	6.50	6.18	6.53	6.32	6.01	6.12	6.84	6.42
	1	6.66	6.11	6.37	6.11	5.69	5.12	5.24	5.04	5.21
8	2	6.35	6.58	6.16	5.91	5.75	5.54	5.18	6.31	6.14
	3	6.22	6.28	5.03	6.92	6.47	6.86	5.87	6.47	6.39
	AVG.	6.41	6.42	5.85	6.31	5.97	5.84	5.43	5.94	5.94
	1	5.39	6.00	5.42	5.48	6.00	5.63	5.50	6.26	6.58
9	2	5.24	5.80	5.73	5.62	5.36	5.46	5.26	5.28	5.68
	3	7.44	6.46	5.37	6.70	6.35	5.99	6.77	7.35	6.48
	AVG.	6.02	6.09	5.51	5.96	6.90	5.69	5.84	6.30	6.25
	1	5.99	6.06	5.86	5.65	5.59	5.36	7.09	6.01	5.69
10	2	7.11	6.32	5.79	5.45	5.43	5.36	5.33	5.21	6.77
	3	6.98	6.59	5.85	6.13	5.78	5.57	5.97	6.85	6.69
	AVG.	6.69	6.32	5.83	5.74	5.60	5.50	6.13	6.02	6.36

Appendix Table A16. Soil moisture content by volume (cm) throughout the season at the depth of 100 cm for each of the ten treatments (1983).

Treatments	Replications	Weeks									
		1	2	3	4	5	6	7	8	9	10
		11/16	11/23	11/30	12/07	12/14	12/21	12/28	01/04	01/11	01/18
	1	6.41	7.44	6.84	6.62	6.48	6.08	6.00	5.92	5.67	5.19
1	2	7.05	7.33	7.11	6.73	7.37	6.99	6.32	6.34	6.17	5.60
	3	7.35	7.59	7.57	7.54	7.49	6.06	6.83	6.50	6.60	5.95
	AVG.	6.94	7.40	7.17	6.96	7.11	6.61	6.38	6.25	6.15	5.58
	1	7.18	6.84	7.09	7.18	7.44	6.82	6.45	6.34	6.08	5.47
2	2	7.16	7.47	7.37	7.67	7.62	6.85	6.46	6.32	6.15	5.27
	3	6.98	7.78	7.01	6.90	7.25	6.60	6.34	6.37	5.50	5.30
	AVG.	71.0	7.41	7.17	7.28	7.43	6.76	6.51	6.34	5.90	5.34
	1	6.75	7.28	7.11	7.12	6.89	6.82	6.48	6.31	6.19	5.63
3	2	6.78	7.62	7.09	7.18	7.33	7.30	6.39	6.26	6.06	5.45
	3	7.42	8.03	7.33	7.15	7.23	6.98	6.74	6.99	6.12	5.23
	AVG.	6.98	7.42	7.17	7.15	7.15	7.03	6.53	6.52	6.12	5.44
	1	6.93	6.93	6.66	6.77	6.79	6.06	6.11	6.20	5.96	5.77
4	2	7.22	7.31	7.21	7.54	7.85	6.93	6.73	6.41	6.39	5.53
	3	7.27	7.71	7.44	7.71	7.52	6.99	6.81	6.76	6.51	6.14
	AVG.	7.14	7.28	7.10	7.34	7.38	6.66	6.55	6.46	6.29	5.81
	1	6.79	6.83	6.36	7.33	7.52	6.88	6.61	6.42	6.13	5.82
5	2	7.10	7.36	7.51	6.99	7.79	7.07	6.80	6.83	6.34	6.07
	3	7.22	7.71	7.64	7.22	7.09	7.02	6.88	6.65	6.43	5.35
	AVG.	7.04	7.56	7.17	7.18	7.47	6.99	6.76	6.63	6.30	5.75

Appendix Table 16 (Cont.)

Treatments	Replications	Weeks 1	2	3	4	5	6	7	8	9	10
		11/16	11/23	11/30	12/07	12/14	12/21	12/28	01/04	01/11	01/18
	1	7.18	6.59	7.21	7.14	7.59	6.47	6.76	6.86	6.25	6.15
6	2	6.85	7.33	6.75	7.08	7.29	6.69	6.39	5.97	5.73	5.52
	3	7.13	6.94	7.18	7.23	6.83	6.72	6.70	6.34	6.16	5.95
	AVG.	7.05	7.46	7.05	7.15	7.24	6.63	6.61	6.39	6.05	5.87
	1	7.45	7.69	7.01	6.92	7.17	6.57	7.11	6.48	6.22	6.36
7	2	6.92	7.41	6.90	7.15	7.20	6.53	6.39	6.36	6.16	5.49
	3	6.75	7.46	6.66	6.79	6.89	6.60	6.27	6.15	5.89	5.99
	AVG.	7.04	7.30	6.85	6.95	7.09	6.57	6.59	6.33	6.09	5.95
	1	6.56	7.68	6.97	6.96	7.31	6.29	6.29	6.31	5.88	6.06
8	2	7.29	7.34	7.25	7.26	7.52	6.59	6.31	6.45	6.15	6.37
	3	7.19	7.98	7.41	6.70	7.19	6.61	6.51	6.36	6.27	6.36
	AVG.	7.10	7.36	7.21	6.97	7.34	6.50	6.37	6.37	6.10	6.26
	1	6.80	7.52	6.28	6.72	7.34	6.24	6.31	6.32	6.05	5.56
9	2	7.24	7.31	7.31	7.31	7.79	6.79	6.99	6.70	6.37	5.76
	3	7.26	7.36	6.91	7.09	7.28	6.55	6.74	6.61	6.36	6.16
	AVG.	7.10	7.52	6.83	7.04	7.47	6.53	6.68	6.54	6.26	5.83
	1	6.24	7.29	7.12	6.22	6.82	7.04	5.96	5.90	5.87	5.54
10	2	7.32	7.42	7.00	7.08	7.09	6.34	6.62	6.54	6.20	5.71
	3	7.42	7.46	7.37	7.37	7.37	6.93	6.83	6.58	6.51	6.62
	AVG.	6.99	7.29	7.16	6.89	7.09	6.77	6.47	6.34	6.19	5.96

Appendix Table 16 (Cont.)

Treatments	Replications	Weeks								
		11	12	13	14	15	16	17	18	19
		01/25	02/01	02/08	02/15	02/22	02/29	03/08	03/14	03/21
	1	4.97	5.20	6.03	5.13	5.25	5.05	5.04	5.08	4.97
1	2	5.31	6.09	5.63	5.23	5.18	5.31	5.32	5.55	5.26
	3	7.78	7.15	6.64	5.48	5.43	5.35	5.71	5.29	5.31
	AVG.	6.02	6.15	6.10	5.28	5.29	5.24	5.36	5.31	5.18
	1	5.18	6.00	5.89	5.25	5.11	5.21	5.04	5.21	5.15
2	2	5.95	5.83	5.29	5.44	5.11	5.28	5.19	5.24	5.18
	3	5.20	6.17	6.40	5.22	5.25	5.09	5.04	5.19	5.09
	AVG.	6.48	6.00	5.86	5.30	5.18	5.19	5.09	5.21	5.14
	1	5.22	5.59	5.42	5.34	5.15	5.06	5.22	5.12	5.21
3	2	5.53	9.42	5.63	5.44	5.13	5.30	5.40	5.04	5.28
	3	5.78	6.21	6.18	5.41	5.48	5.56	5.07	5.43	5.33
	AVG.	5.51	7.07	5.74	5.40	5.25	5.31	5.23	5.19	5.27
	1	5.57	5.59	5.60	5.36	5.32	5.38	4.97	5.28	5.15
4	2	5.82	5.96	5.40	5.23	5.34	5.17	5.83	5.20	5.22
	3	5.67	6.27	5.05	5.60	5.47	5.24	5.23	5.49	5.33
	AVG.	5.69	5.94	5.68	5.40	5.37	5.26	5.17	5.32	5.23
	1	6.66	6.52	5.61	5.67	5.30	5.13	5.22	5.17	5.07
5	2	7.66	5.47	6.16	5.36	5.51	5.28	5.20	5.38	5.40
	3	6.18	6.58	6.44	5.38	5.45	5.33	5.14	5.40	5.3
	AVG.	6.83	6.19	6.07	5.47	5.42	5.25	5.18	5.32	5.25

Appendix Table 16 (Cont.)

Treatments	Replications	Weeks								
		11	12	13	14	15	16	17	18	19
		01/25	02/01	02/08	02/15	02/22	02/29	03/08	03/14	03/21
	1	7.64	6.32	6.02	6.12	7.03	6.72	6.18	7.10	6.82
6	2	6.82	6.27	6.34	5.82	5.79	6.25	6.50	7.01	6.76
	3	5.54	7.00	5.64	6.48	6.71	7.03	6.59	7.57	6.48
	AVG.	6.63	6.61	6.02	6.12	6.17	6.53	6.51	7.13	6.68
	1	7.64	6.92	6.76	7.10	7.03	6.72	6.18	7.10	6.89
7	2	6.13	6.36	6.10	6.25	5.70	6.04	5.47	6.70	6.40
	3	5.91	6.02	5.92	6.20	6.63	6.33	6.32	6.78	6.23
	AVG.	6.56	6.43	6.26	6.51	6.45	6.36	5.99	6.86	6.50
	1	5.70	6.48	6.02	5.92	5.84	5.48	5.14	5.25	5.25
8	2	5.14	6.45	6.27	6.00	5.56	5.79	5.10	5.54	5.85
	3	6.40	6.52	5.50	6.94	6.36	6.66	5.90	7.04	6.55
	AVG.	5.75	6.48	5.96	6.28	5.92	5.98	5.38	5.94	5.87
	1	5.34	6.81	5.52	5.52	6.25	5.09	5.80	6.60	6.53
9	2	5.73	6.05	6.29	5.88	5.91	5.59	5.55	5.57	5.46
	3	7.71	6.55	5.57	6.72	5.99	6.19	6.49	6.80	6.53
	AVG.	6.26	6.47	5.79	6.04	6.05	5.92	5.94	6.32	6.17
	1	5.53	6.16	5.79	6.23	5.88	5.75	7.12	6.16	6.30
10	2	6.02	6.52	6.10	6.25	5.47	5.37	5.35	5.34	5.35
	3	6.86	6.13	5.97	6.83	6.51	6.30	6.21	6.88	6.75
	AVG.	6.07	6.27	5.95	6.44	5.95	5.80	6.23	6.13	6.13

Appendix Table A17. Total Soil moisture content by volume (cm) throughout the season for the top 100 cm layer of soil for each of the ten treatments (1983).

Treatments	Replications	Weeks									
		1	2	3	4	5	6	7	8	9	10
		11/16	11/23	11/30	12/07	12/14	12/21	12/28	01/04	01/11	01/18
	1	37.26	38.34	35.96	37.51	37.77	33.38	34.17	30.72	29.63	27.37
1	2	37.36	38.08	36.01	37.33	37.41	33.14	34.38	31.49	30.27	27.90
	3	39.49	41.21	39.45	39.69	38.41	34.67	39.66	33.52	34.24	29.45
	AVG.	38.04	39.21	37.14	38.18	37.86	33.73	36.07	31.91	31.38	28.24
	1	38.98	39.32	38.29	39.08	38.99	34.76	34.77	31.97	30.64	27.21
2	2	37.72	39.07	37.35	37.94	37.01	33.37	34.15	31.16	29.61	26.90
	3	37.81	39.10	38.51	37.87	37.31	33.09	33.64	31.12	30.22	27.18
	AVG.	38.17	39.16	38.05	38.30	37.77	33.74	34.26	31.42	30.16	27.10
	1	38.90	40.23	38.58	40.46	39.27	35.71	36.69	32.63	31.57	28.15
3	2	37.95	39.21	38.33	39.05	39.03	34.84	36.39	31.40	30.58	27.85
	3	38.95	40.32	38.40	38.86	39.31	34.68	36.83	32.18	30.37	27.88
	AVG.	38.53	39.92	38.43	39.46	39.20	35.08	36.64	32.07	30.84	27.96
	1	39.92	40.54	37.01	38.74	36.85	34.77	35.34	32.21	30.72	28.00
4	2	39.48	40.30	38.12	40.16	40.55	36.92	37.20	33.54	32.11	27.90
	3	38.08	40.24	38.69	41.25	39.99	35.69	37.06	33.63	32.82	28.55
	AVG.	39.16	40.36	37.94	40.05	39.13	35.79	36.53	33.13	31.88	28.15
	1	38.78	40.07	36.53	39.01	39.61	35.50	36.58	32.74	32.51	28.20
5	2	40.82	40.67	40.13	39.65	40.56	36.31	38.74	34.77	33.90	30.15
	3	37.50	39.69	37.16	37.90	37.05	34.87	36.73	33.50	32.30	27.78
	AVG.	39.03	40.14	37.94	38.85	39.07	35.56	37.35	33.67	32.90	28.71

Appendix Table A17 (Cont.)

Treatments	Replications	Weeks 1	2	3	4	5	6	7	8	9	10
		11/16	11/23	11/30	12/07	12/14	12/21	12/28	01/04	01/11	01/18
	1	37.70	38.40	37.53	38.78	37.85	34.21	35.44	33.56	33.05	35.70
6	2	37.62	36.03	36.65	36.35	38.46	33.59	35.14	31.87	29.76	30.98
	3	38.19	38.56	36.15	38.16	37.26	33.33	34.71	32.09	30.40	30.85
	AVG.	37.81	38.33	36.78	37.65	37.86	33.71	35.10	32.51	31.07	32.51
	1	39.38	39.18	36.70	38.44	37.81	34.08	36.56	33.14	32.12	32.27
7	2	37.65	38.59	37.08	37.93	37.23	34.39	36.35	31.59	31.77	27.96
	3	36.38	37.83	35.38	37.98	37.62	33.81	35.26	31.61	30.43	30.09
	AVG.	37.97	38.53	36.38	38.12	37.55	34.09	36.05	32.11	31.44	30.11
	1	36.97	40.11	37.04	37.86	37.59	33.82	34.74	31.40	29.91	28.36
8	2	38.34	38.91	36.83	38.75	38.40	34.84	35.30	32.74	31.23	30.87
	3	37.25	38.56	37.35	36.60	37.73	33.50	34.53	31.30	30.60	31.33
	AVG.	37.25	39.19	37.07	37.74	37.91	34.05	34.86	31.82	30.58	30.52
	1	38.6	40.13	36.18	38.60	38.28	34.30	34.54	31.22	30.16	27.52
9	2	38.23	39.94	38.21	38.79	38.55	34.66	41.22	32.84	30.39	28.54
	3	37.45	38.86	36.50	38.25	36.95	33.82	34.96	32.53	30.96	33.87
	AVG.	38.10	39.64	36.96	38.55	37.93	34.26	36.91	32.20	30.60	29.98
	1	37.38	37.08	36.68	36.16	36.54	3.501	32.83	31.34	30.27	30.19
10	2	39.78	39.21	37.64	38.49	38.28	35.36	38.79	32.96	31.72	28.87
	3	37.56	40.68	37.16	38.63	38.47	33.80	24.9	32.92	32.36	30.79
	AVG.	38.24	38.99	37.16	37.76	37.76	34.72	35.84	32.41	31.45	29.95

Appendix Table 17 (Cont.)

Treatments	Replications	Weeks 11 01/25	12 02/01	13 02/08	14 02/15	15 02/22	16 02/29	17 03/08	18 03/14	19 03/21
	1	32.26	30.96	29.59	27.24	27.67	26.11	26.06	26.54	29.30
1	2	32.38	33.04	28.43	27.04	26.41	26.12	26.23	26.74	29.27
	3	39.32	34.99	32.45	27.98	27.58	26.77	27.54	28.60	30.46
	AVG.	34.65	33.00	30.16	27.42	27.22	26.33	26.61	27.29	29.68
	1	34.68	33.02	29.37	26.45	26.95	26.46	25.78	27.02	28.99
2	2	36.35	31.34	27.23	26.97	26.36	26.22	25.91	26.50	28.10
	3	35.04	32.62	32.38	27.03	26.55	25.83	25.90	27.27	28.57
	AVG.	35.36	31.65	29.66	26.82	26.62	26.17	25.86	26.92	28.55
	1	34.14	32.02	28.04	27.51	26.64	26.32	26.13	26.52	29.63
3	2	37.13	35.22	28.37	28.18	27.00	26.28	27.54	27.46	29.92
	3	35.94	32.00	31.84	27.86	27.28	26.79	26.09	28.16	30.04
	AVG.	35.74	33.08	29.42	27.95	26.97	27.13	26.59	27.38	29.86
	1	32.91	32.465	28.48	27.45	26.44	26.30	26.28	26.76	29.29
4	2	36.16	32.87	20.10	27.05	27.10	26.94	26.20	27.43	29.03
	3	35.55	32.41	31.50	27.11	26.88	25.84	26.05	27.65	29.63
	AVG.	34.87	32.58	29.36	27.20	26.83	26.03	26.16	27.28	29.32
	1	31.97	34.03	29.46	27.50	26.66	26.28	26.33	28.02	29.92
5	2	41.46	31.71	30.86	28.83	28.36	27.74	26.18	28.46	30.63
	3	35.69	32.72	33.03	27.09	26.52	26.40	26.09	27.74	29.59
	AVG.	38.37	32.82	31.12	27.81	27.18	26.81	26.20	28.07	30.05

Appendix Table A17 (Cont).

Treatments	Replications	Weeks 11	12	13	14	15	16	17	18	19
		01/25	02/01	02/08	02/15	02/22	02/29	03/08	03/14	03/21
	1	38.74	33.75	32.23	31.06	31.99	33.46	34.24	34.52	33.99
6	2	38.06	32.16	31.07	31.45	31.24	32.93	33.75	34.52	35.08
	3	35.60	33.66	26.24	32.19	33.03	33.36	33.74	35.82	33.11
	AVG.	37.42	33.19	30.51	31.57	32.24	33.25	33.91	34.95	34.05
	1	39.18	34.79	33.77	34.68	33.57	33.54	33.53	35.36	34.59
7	2	37.35	34.85	32.64	30.84	29.82	29.38	28.28	35.06	33.31
	3	35.91	31.84	29.15	32.52	33.04	29.66	33.27	33.92	32.68
	AVG.	37.21	33.82	31.85	32.68	32.14	30.86	31.72	34.78	33.53
	1	33.46	32.42	30.56	30.28	27.54	26.39	25.88	26.54	28.12
8	2	33.95	33.45	31.96	29.38	29.39	28.31	25.65	31.52	31.59
	3	34.67	32.96	28.94	33.77	31.65	32.24	30.28	33.86	33.35
	AVG.	34.03	32.94	30.49	31.14	29.53	28.98	27.27	30.64	31.05
	1	33.42	33.19	29.27	29.79	31.50	31.51	31.58	35.36	34.67
9	2	32.30	32.22	30.56	29.36	28.03	27.86	27.16	30.14	30.89
	3	37.28	33.18	28.24	32.46	30.93	29.83	32.98	34.04	32.98
	AVG.	34.33	32.86	29.36	30.54	30.15	29.73	30.57	33.18	32.85
	1	35.35	33.00	31.34	30.82	30.56	29.40	35.49	33.48	33.31
10	2	36.39	33.45	30.00	20.80	27.42	26.64	28.26	29.39	31.36
	3	37.55	32.40	30.20	31.01	31.41	29.31	30.95	34.25	33.86
	AVG.	36.42	32.95	30.54	30.21	29.81	28.45	31.57	32.37	32.70

Appendix Table A18. Stepwise regression for the compaction model (equation 2).

Step Number 3.
Variable entering into the model: SMC13

Variables	Coefficient	F-test for Ho: Variable = 0	Prob>F	Standard Error
Intercept	1.47947			
CL2	1.43897E-04	.692771	41.5%	1.72884E-04
PSDMA	-.0117962	7.68612	1.17%	4.25489E-03
PSDMI2	-1.14659E-04	5.05916	3.59%	5.09763E-05

Analysis of variance

Source	Sum of square	Degrees of freedom	Mean square	F-value	Prob >F	R-square	Standard deviation	Coefficient variation
Regression	.0176939	3	5.89797E-03	3.54812	3.3%	.347351	.0407711	3.85%
Residual	.0332456	20	1.66228E-03					
TOTAL	.0509396	23						

Appendix Table A19. Stepwise regression for the compaction model (equation 3).

Step Number 8.
Variable leaving the model: LCL

Variables	Coefficient	F-test for Ho: Variable = 0	Prob>F	Standard Error
Intercept	460.527			
CL	.0117716	4.43886	5.02%	5.58727E-03
CL2	-7.58957E-04	2.94289	10.44%	4.42415E-04
SMC	-8.44308E-03	1.35925	25.97%	7.24188E-03
SMC2	-.497864	1.29534	27.08%	.43744
LSMC	5.09276	5.0958	3.12%	2.16967
PSDMA	.019416	1.49442	23.82%	.0158827
PSDMA2	-.0010204	6.66464	1.94%	3.9526E-04
PSDM1	-.0145785	10.4408	.49%	4.51175E-03

Analysis of variance

Source	Sum of square	Degrees of freedom	Mean square	F-value	Prob >F	R-square	Standard deviation	Coefficient variation
Regression	.0460687	6	7.67811E-03	8.37039	.02%	.747108	.0302869	2.88%
Residual	.015594	17	9.17295E-04					
TOTAL	.0616627	23						

Appendix Table A20. Stepwise regression for the compaction model (equation 4).

Step Number 6.
Variable entering into the model: SMC13

Variables	Coefficient	F-test for Ho: Variable = 0	Prob>F	Standard Error
Intercept	.617594			
SMC	-9.5753E-05	6.61318E-03	93.61%	1.17746E-03
SMC2	5.60825E-04	2.62815	12.33%	3.45941E-04
PSDMA	-.0148097	4.33733	5.27%	7.11106E-03
PSDMA2	-7.5299E-05	.265809	61.27%	1.46051E-04
PSDMI2	-2.11987E-04	23.3651	.01%	4.38557E-05
AS2	.0178553	9.58011	.65%	5.76876E-03
AS22	-1.47132E-04	8.2069	1.07%	5.139E-05

Analysis of variance

Source	Sum of square	Degrees of freedom	Mean square	F-value	Prob >F	R-square	Standard deviation	Coefficient variation
Regression	.0323121	6	5.38535E-03	13.4294	.01%	.825778	.0200253	1.94%
Residual	6.81719E-03	17	4.01011E-04					
TOTAL	.0391293	23						

Appendix Table A21. Stepwise regression for the compaction model (equation 5).

Step Number 4.
Variable entering into the model: SMC13

Variables	Coefficient	F-test for Ho: Variable = 0	Prob>F	Standard Error
Intercept	1.37128			
PSDMA	-.045316	5.85875	2.56%	.0187218
PSDMA2	5.272797E-04	2.0735	16.61%	3.97786E-04
PSDMI	.0382527	.4299	52.32%	.0588225
PSDMI2	-7.21236E-04	.945298	34.31%	7.41811E-04

Analysis of variance

Source	Sum of square	Degrees of freedom	Mean square	F-value	Prob >F	R-square	Standard deviation	Coefficient variation
Regression	.0367783	4	9.19458E-03	8.64024	.03%	.645264	.0326214	3.18%
Residual	.020219	19	1.06416E-03					
TOTAL	.0569973	23						

Appendix Table A22. Stepwise regression for the compaction model (equation 6).

Step Number 4.
Variable entering into the model: SMC13

Variables	Coefficient	F-test for Ho: Variable = 0	Prob>F	Standard Error
Intercept	4.09263			
CL2	-1.36742E-03	4.29625	5.28%	6.59714E-04
SMC2	-9.88236E04	1.5826	22.44%	7.85551E-04
PSDMA2	3.0429E-04	1.771	29.22%	2.80467E-04
AS2	-.0740941	1.17153	29.33%	.0684554
AS22	6.15881E-04	1.39316	25.32%	5.2179E-04

Analysis of variance

Source	Sum of square	Degrees of freedom	Mean square	F-value	Prob >F	R-square	Standard deviation	Coefficient variation
Regression	.25138	5	.0502759	1.65826	19.56%	.315363	174122	18.1%
Residual	.545732	18	.0303184					
TOTAL	.797112	23						

VITA

VITA

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