WATER AVAILABILITY AND SOIL SUITABILITY FOR IRRIGATION WATER IMPOUNDMENTS IN THE FEDERAL DISTRICT OF BRAZIL

A Thesis

Presented to the Faculty of the Graduate School of Cornell University for the Degree of Master of Science

by

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ABSTRACT

Agriculture on the Central Plateau of Brazil is poorly developed. The main reasons are the poor soil fertility and the high aluminum toxicity of the soils, restricting the rooting depth of many crops.

Shallow rooting is responsible for the occurrence of serious soil-water stress conditions, even in the wet season. One of the alternatives for minimizing the adverse effects of droughts is supplemental irrigation.

This thesis deals with a limited number of aspects related to the supplemental irrigation problem, and concentrates more specifically on irrigation water supply and storage.

The author spent the months of June, July, and August 1974 in the Federal District in Brazil to carry out field work and laboratory analyses.

At representative sites, physical soil tests were performed and soil samples were collected for further study. Part of the soil tests were executed by locally trained technicians in a field laboratory at the Experimental Station near Planaltina.

Data on climate, hydrology, geology and soils were collected from other sources. Additional physical soil properties were analyzed in Ithaca, at Cornell's engineering laboratory.

For a year with average rainfall about one third of precipitation goes to deep percolation. This water is released

from the subsoil and subsequently is gradually discharged by the rivers and streams. The quality of such water for irrigation is excellent.

The most important sources for irrigation water supply are expected to be the rivers and streams. During the wet season water for irrigation is plentiful. The minimum river discharge in a year with average rainfall is 5 $l/s.km^2$. Much of this water could be used for irrigation.

With the creation of storage facilities the amount of potential irrigation water can be increased to at least 10 $l/s.km^2$, sufficient to irrigate perhaps 5 to 10 per cent of the Federal District.

Groundwater could become an important irrigation water source, especially at high elevations. Water from springs is readily available and can be used for irrigation to a minor areal extent.

Surface runoff impoundment does not seem to be a viable solution for irrigation water supply, especially in the promising agricultural areas of the Federal District.

Physical properties of soils of typical agricultural areas in the Federal District were determined. Engineering tests show high initial infiltration and permeability properties of the soils which can be reduced by compaction at favorable moisture conditions. In properly compacted canals and farm ponds seepage and percolation losses will be at an acceptably low level. The costs of compaction as a method to prevent water losses is one tenth of the cost of plastic linings.

Topography, soils and rainfall of the Federal District are representative for a large part of the Central Plateau. Therefore, the findings in this thesis can in general be extrapolated to other areas on the Central Plateau. Local differences must always be taken into account.

BIOGRAPHICAL SKETCH

Jan Pruntel was born on March 1, 1936 in Staphorst, The Netherlands. He is the son of Geert and Klaasje Pruntel. He graduated from the College of Forestry and Rural Engineering, Arnhem, The Netherlands, in 1957. He served the Dutch army from 1957 to 1959. His final rank was reserve First Lieutenant with the Artillery.

He was employed by the Koninklijke Nederlandsche Heidemaatschappij in the period of 1959 to 1963, as a soil surveyor and agricultural engineer. During this period he took a half year post graduate course at the Soil Survey Institute at Wageningen.

From 1963 to 1973 he was employed by International Land Development Consultants b.v., the Heidemaatschappij's subsidiary dealing with study assignments abroad. He was engaged in soil surveys. Later he spent a major portion of his time in the design of irrigation and drainage systems, in the following countries: Colombia, Ghana, Malaysia, Pakistan, Senegal, Spain, Syria and Tanzania.

In pursuit of a Master of Science degree the author entered the Graduate school of Cornell University in the fall of 1973, with a major in Agronomy and a minor in International Agricultural Development.

He is married to Ina S. Mulder, and they have two children: Petra and Mark.

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I INTRODUCTION

It is almost two decades now since the new Brazilian capital was founded on the Central Plateau of Brazil. With its cerrado vegetation, extensive livestock production was and still is the main agricultural activity on the Plateau. Agriculture is poorly developed. The main reason being the poor soil fertility. Also there is the high aluminum toxicity of the soil, and a dry-wet rainfall pattern marked by irregular rainfall distribution during the wet season. With the continuing development of the new capital, the need for agricultural products grows. This need results in a stimulant for the agricultural development of the area.

At the Brasilia station, near Planaltina, soil fertility and water management studies are underway. Results of these studies indicate that soil nutrients are severely deficient. They also show that serious soil-water stress conditions normally occur even in the wet season. Thus, it is probable that intensive production, with major requirements for investment in fertilizer, would be economically justifiable only when the risk of adverse soil moisture conditions is minimized.

Two general alternatives, not mutually exclusive, for minimizing the potential adverse effects of short drought periods in the wet season are:

- Increasing the root zone water storage through reduction of toxic conditions in the soil profile, and/or the selection of appropriate crops.

- Supplemental irrigation.

The former is being explored in other phases of the soil research project; limited aspects of the latter will be discussed in this thesis.

Only one of a number of questions related to the supplemental irrigation problem is the subject of this thesis: what is the availability and adequacy of water for supplemental irrigation? A definite answer to even this limited question would require a major study. Therefore the objectives for this research are further limited to the following:

- To define the potentials for small scale impoundments.
  - to what extent are the topographical features suitable for impoundments?
  - what are the suitabilities of the major soil types for impoundment construction?
  - what is the hydrological potential for runoff impoundment storage?
- To explore the potentials for other types of water supplies from available data.

The above mentioned questions will be discussed, considering the Federal District of Brasilia as a sample area for a larger part of the Central Plateau, and disregarding the urban water needs.

The assumption, that the Federal District is representative for a large part of the Central Plateau depends, for the purpose of this study largely upon three environmental factors: topography, soils and rainfall. These will be discussed in Chapter II.

II GENERAL BACKGROUND

1. Location.

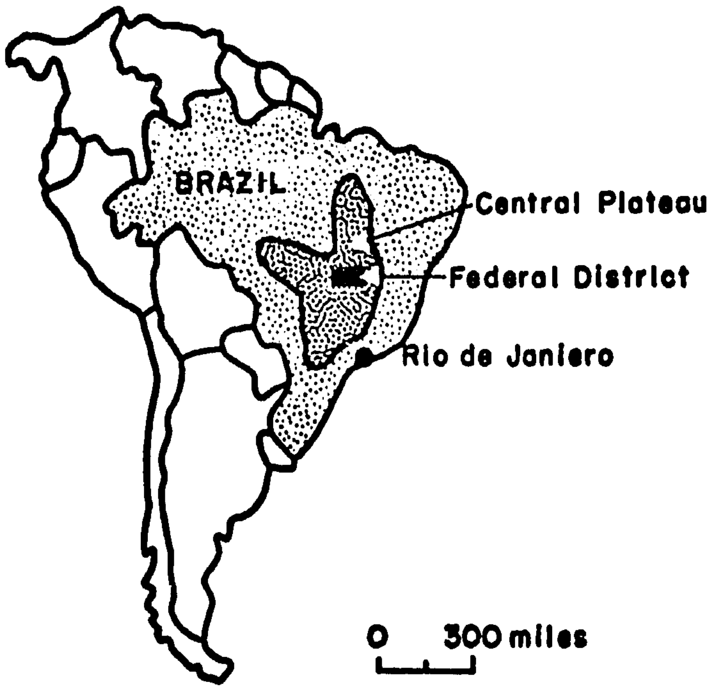
The Federal District is located between the rivers Descoberto and Preto, and the meridians 48°12' and 47°25' W. respectively. The North and South limit are defined by the parallels 15°30' and 16°03' S. (see Figure 2). The area is 5,814 square kilometers (15).

The Federal District is situated on the Central Plateau, including major portions of the states of Mato Grosso and Goias and parts of the states of Bahia and Minas Gerais. The cerrado part of the Central Plateau, as indicated in Figure 1, comprises a total area of approximately 1.5 million square kilometers, or about 20 per cent of the total country.*)

2. Topography.

The topography of the Federal District has been described in detail by Feuer (23). Although he mentions an area which is somewhat larger, it includes the Federal District. He identified three distinct general landscape levels, which he assigned the terms "first erosion surface" for the uppermost level, "second erosion surface" for the middle level, and "third erosion surface" for the lowest level. Cline and

*) Verbal communication with M. N. Camargo, professor of Soil Science at the Federal University of the State of Rio de Janeiro.



<u>Figure 1</u>: Map of South America showing location of Federal District of Brazil, and Central Plateau.

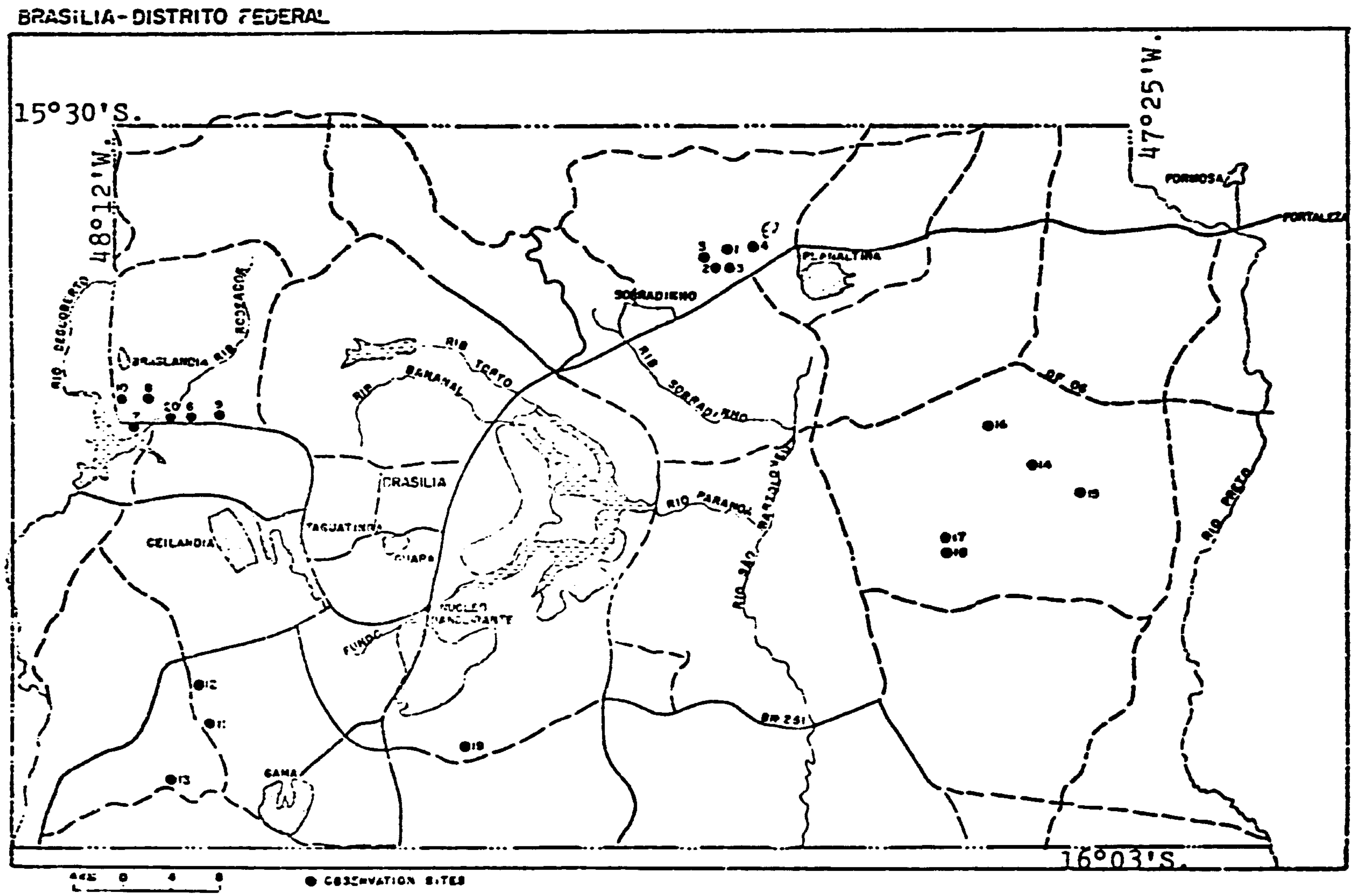


Figure 2: Brasilia D.F. and observation sites.

Buol (14) confirm the general findings and conclusions of Feuer for a larger area including parts of the Sao Francisco, Parana, Araguaia and Tocantins drainage basins, forming all part of the Central Plateau. However, they distinguish at least two, in most places three and in some places four distinct erosion surfaces. Daniels (19) recognizes, near the experimental station near Planaltina, "two major surfaces, with some later surfaces of possible small areal extent". Codeplan (15) also describes the three distinct levels and claims that the highest levels or "chapadas" have an elevation of 1000 meters or more.

The slopes are described by Feuer (23) as follows:

> "Three distinct conditions of slope can be distinguished; these are closely correlated with landform, erosion surface. The Humic Latosols of the formerly forested valley slopes, third erosion surface, have slopes of 7 to 15 per cent with a few slopes up to 20 per cent. These slopes are smooth, generally increasing in gradient downslope to the valley bottom. Most of the slopes of these areas are less than 1,000 feet in length. The Humic latosols of the formerly forested uplands and scrub-savanna uplands, second erosion surface, have smooth, even to slightly convex slopes of 3 to 5 per cent, rarely greater; a few areas are nearly level. Slopes are often extremely long, ranging from 1,000 to several thousand feet. The Humic Latosols of the scrub-savanna uplands, first erosion surface (chapada), are nearly level to very gently sloping, 0 to 3 per cent; a few areas have convex slopes, up to about 5 per cent. Slopes are smooth, long to extremely long, even or very gently convex; usually the margins of most chapadas (areas of Concretionary Lixosol soils of low productivity) slope very gently upward near the edge."

The slopes and elevations of the sites described by the author can be categorized as presented in Table 1.

Table 1. Slopes and elevations of surveyed sites

Relative position	Elevation, m.s.l. m	Slope, %
Upper level (chapadas)	1075 - 1175	2 - 4
Middle level	950 - 1000	2 - 3
Low level	925 - 975	2 - 3

Steeper slopes of up to 8 per cent were found on the "intergrades" between the highest and medium level.

The data presented in Table 1 are fairly consistent with those presented by Feuer, except for the lower level, where the author found more gentle slopes. This is due to a different interpretation of the relative position of the observed sites. The low level surface, as considered by the author, corresponds with the lower part of the middle surface as described by Feuer.

The author found that in the Federal District about 75 per cent of the land has the gentle and relatively long slopes, as discussed above. The remaining 25 per cent of the area is strongly dissected. It has very short and steep slopes. This land can be found North, South East and South West of the new capital.

The American International Association for Economic and Social Development (2), who studied about 750,000 square kilometers of the Central Plateau, located in the States of Minas Gerais, Goias and Mato Grosso, found that 80 per cent of their study area had favorable topography. This value compares well with the 75 per cent, given for the Federal District. It seems therefore reasonable to assume, that the general features of the topography of a large part of the Central Plateau are comparable to those of the Federal District.

3. Climate.

Attention will be focussed on aspects of the climate which are of special interest in the context of this study: temperature, rainfall, relative humidity, wind velocity, cloudiness, insolation, evaporation, and potential evapotranspiration.

3.1 Rainfall.

The rainfall in the Federal District has been analyzed by many, including Belcher (6). He concludes that no significant variation exists between the 25 years record of: Formosa, Goias, Luziania and Pirenopolis, all within the vicinity of the Federal District. Consequently he sets the mean annual rainfall of the Federal District equal to the average of the 4 stations, mentioned above.

The mean annual rainfall has been determined by various investigators (6, 15, 26, 27, 45, 53, 63). The values are in the range of 1460 and 1700 mm, depending on the stations and the years of observation used. The most recent study has been performed by Wolf (63), who combined at least 42 years of observations of three different stations (Formosa, Brasilia and EEB), resulting in a mean annual rainfall of 1580 mm. He also found that 80 per cent of the annual precipitation occurs in the period of November to March, and that dry spells of 2 to 3 weeks in the wet season are possible.

The data are presented in Table 3.

An analyses of variance by Belcher (6) shows that: "the variation of rainfall between years is highly significant. This indicates that a frequency analyses of the annual rainfall will provide pertinent information." In Table 2 the results of Belcher's analyses are given. It should be noted however that the present author has calculated, and slightly modified the 5, 10, and 20 per cent values.

Table 2. Prediction of dry-year annual rainfall

Per cent years	Annual rainfall less or equal to
1	850 mm
2	950 ,,
3	1025 ,,
5	1100 ,,
10	1225 ,,
20	1350 ,,

Source: Selection of the five sites most favorable for the location of the new capital of the United States of Brazil, Belcher, D. J. and Associates Inc., 1955.

The climatological data presented in Table 3 are representative of the Meteorological Station at Brasilia.

Rainfall intensity data have been presented in Table 3. The highest intensity registered in the 11 year observation period is 132.8 mm per 24 hours, and occurred in November 1963.

3.2 Temperature.

The mean monthly temperatures are presented in Table 3. The mean annual temperature is 20.5°C and the fluctuation in the monthly mean is 3.9°C. The mean yearly maximum and minimum temperatures are 26.8°C and 15.6°C respectively. The recorded absolute maximum temperature is 35.5°C and the minimum 6.0°C.

3.3 Relative humidity.

The relative humidity is higher than 70 per cent between October and May, and between 50 and 70 per cent from June to September.

3.4 Wind velocity.

The predominant wind direction is West. The wind velocity is highest in July and August, with values of over 3 m per second, at 0.50 m height. The annual average is 2.9 m/sec.

3.5 Cloudiness.

Cloudiness has been measured as a fraction of ten, and has values of less than 5 from May to October, and between 5 and 7 for the rest of the year.

Table 3: Climatological data - Brasilia D.F.

Month	Mean temp. °C	Precipitation mm/month	Max. *) rain mm/24 hrs	Rel. hum. %	Wind velocity m/sec	Cloudiness tenth	Insolation hrs/month	Relat. Duration sunshine %
Jan.	21.2	239.5	100.7	79.2	3.0	5.6	168.1	42.0
Feb.	21.1	210.0	65.3	78.9	2.7	7.1	136.3	38.2
March	21.5	225.9	111.0	70.3	2.7	6.3	195.3	51.6
April	20.9	104.7	55.5	75.6	2.8	5.6	197.6	55.7
May	19.2	17.8	73.6	69.9	2.8	4.6	238.6	67.2
June	18.1	3.4	29.8	64.5	2.8	3.6	224.3	66.5
July	18.0	5.4	17.9	56.7	3.6	3.3	264.3	75.1
Aug.	20.0	6.1	4.8	49.6	3.3	3.6	265.7	73.5
Sept.	21.9	37.0	77.4	55.9	3.2	4.2	209.0	57.9
Oct.	21.7	144.6	47.9	70.4	2.7	6.6	158.6	41.0
Nov.	21.3	254.9	132.8	70.3	2.9	6.8	147.9	38.5
Dec.	20.9	330.9	106.8	73.6	2.7	6.7	149.7	37.1
Year	20.5	1580.2	132.8	67.9	2.9	5.3	2355.4	53.7

Source: Meteorological Station Brasilia, period 1961 - 1971

*) 42 years of observations of Formosa, Brasilia and EEB (63)

3.6 Insolation.

Insolation, being inversely related to cloudiness, obtains values of over 200 hours per month from May to October, and is lower in the rest of the year. The relative duration of sunshine has been calculated from insolation and the theoretical possible duration of sunshine.

3.7 Evaporation.

Piche evaporation data (35) are available, and are presented in Table 4. The mean annual value is 1330 mm for Brasilia, which compares well with the 1283 mm given for a 30 year observation period in Formosa by Codeplan (15). The fluctuation in the yearly evaporation is relatively low (53).

Pan evaporation data, measured in the standard A-pan, specified by the U.S. Weather Bureau (59), are available for only one year: July 1973 - June 1974, at the Experimental Station Planaltina. The total yearly value is 1979, with a peak in August and September.

3.8 Potential evapotranspiration.

Potential evapotranspiration for the Federal District can be found in various reports (6, 15, 23, 45, 53) usually calculated by the method of Thornthwaite,with values of 600 to 1000 mm per year, and by the Blaney-Criddle method with a total of about 1800 mm per year.

In Table 4 evaporation and evapotranspiration data are shown as calculated by the present author using various methods. The calculations utilized the data of the Meteorological Station at Brasilia, observation period 1961 - 1971.

3.8.1 Blaney-Criddle method.

The yearly potential evapotranspiration, calculated by the Blaney-Criddle method (8) and using a k-factor of 0.8 amounts to 1400 mm per year. The monthly values range from 100 mm in June to 129 mm in January. As the mean monthly temperature is almost constant throughout the year, the data reflect very strongly the monthly per cent of day time hours, which is lowest in June. The data compare very poorly with the evaporation figures, also presented in Table 4. They show a peak from July to September, whereas the Blaney-Criddle data are relatively low during that part of the year.

3.8.2 Thornthwaite method.

The Thornthwaite method (57) is also based on temperature and latitude and shows a good relation with the results obtained by application of the Blaney-Criddle method. However the values are on a lower level. These data in Table 4 are calculated as suggested by Criddle (29). The yearly total amounts to 969 mm.

3.8.3 Penman method.

The Penman method takes into account various climatological variables (44). The calculations are more complicated,

Table 4: Comparison of evaporation and evapotranspiration calculated by various methods - Brasilia D.F.

Month	Evap.*) Piche mm/month	Class A Pan**) mm/month	Potential Evapotranspiration*) mm/month Blaney/***) Criddle	Thornth- waite	Penman Eo	Penman***) ET
Jan.	83.1	175.8	129.0	94.4	134.9	155.1
Feb.	64.6	146.7	113.6	93.7	116.5	134.0
March	98.6	152.5	122.7	88.7	140.1	161.1
April	81.8	149.1	113.4	83.8	121.8	140.1
May	103.6	140.4	108.5	61.8	116.9	134.4
June	114 6	142.8	100.4	52.8	102.3	117.6
July	128.4	179.5	104.0	53.9	134.2	154.3
Aug.	187.4	221.3	112.6	68.6	157.5	181.1
Sept.	192.8	194.1	118.3	92.7	154.8	178.0
Oct.	117.3	147.3	125.4	91.5	139.8	160.8
Nov.	79.6	156.6	124.4	96.6	138.6	159.4
Dec.	78.7	173.3	128.6	90.5	134.9	155.1
Year	1330.5	1979.4	1400.9	969.0	1592.3	1831.0

*) Meteorological Station Brasilia, period 1961 - 1971

**) Station EEB, period 1973 - 1974

***) Blaney and Criddle, k=0.8
Penman ET=1.15 Eo

but the results have been found to be relatively widely applicable. The calculation method followed in this report is that developed by Ilaco (28). The Eo value obtained represents the evapotranspiration of a hypothetical surface, as specified by Penman (44).

However the potential evapotranspiration ET of a crop differs from the Eo value, such that ET = (f) x (Eo). The value of the factor f depends on a number of variables (28), of which the aero-dynamic properties of the crop is one of the most important. For the purpose of this study, a value of f=1.15 has been used, representing more or less the combined tree and grass vegetation of the cerrado.

The results of the calculations are shown in Table 4. These data compare well with the Piche and class A-pan evaporation. They peak in potential evapotranspiration in August and September. This peak is caused, in part, by the low relative humidity, the high wind velocity and the low degree of cloudiness in those months. The annual value of the potential evapotranspiration amounts to 1592 and 1831 mm for Eo and ET respectively. The yearly Eo, calculated for Formosa, just outside the Federal District, is 1598 mm assuming a 25 per cent lower wind velocity.

3.9 Classification of the climate.

The climate in the Federal District has been classified by some investigators (2, 17, 63) as Aw in the Koppen system. This implies that the mean temperature of the coldest month is 18°C or higher, and that the precipitation in the driest month is less than 37 mm (defined as: 100 - average annual rainfall ÷ 25). Others (15, 27) have defined the climate as Cw, because the mean monthly temperature of the observation period prior to 1970 (Brasilia) dropped just below 18°C in June and July. However including the 1970 and 1971 data, the temperature in the coldest month rises exactly to 18°C thus justifying the Aw classification.

From the Climatological Atlas (21) it can be seen that the largest part of the Central Plateau has the Aw type of climate, with some inclusions of Cw in the Southern part. Much of what has been said about climate in this section can, to a large extent be extrapolated to the part of the Central Plateau, indicated in Figure 1. The temperature however increases from South to North by some degrees. The mean annual rainfall fluctuates between 1250 and 2000 mm. For 80 per cent of the area, investigated by AIA (2), the mean annual rainfall is between 1500 and 2000 mm.

4. Hydrology.

The hydrology of the Federal District will be discussed in two sections: surface and subsurface water.

4.1 Surface water.

The first report on the hydrology of the Federal District was written by Cruls (15) in 1892. He was impressed by the abundance of surface water. Most rivers in the Federal District are perennial (15, 26). They contribute to three of the most important drainage basins of Brazil: the Amazon to the North, Sao Fransisco to the North East and Parana to the South. In this head water region, no large rivers are found.

Belcher (6) who studied the region in 1955 found only a very limited amount of stream flow data available. There were a number of interruptions in most of these records. However he could use the 2-year records of the Paranoa river for hydrologic purposes. These calculations will be referred to in Chapter III, section 1 of this study.

The Company of Water and Sewers of Brasilia, CAESB published a report on the hydrology of the District in 1970 (26). They include a larger amount of stream flow data for a longer observation period. Records for the period 1947 - 1957 were supplied by the Division of Water of the Ministry of Mines and Energy. CAESB has installed 5 continuous recorders in the principal rivers of the District. Some have been in operation since 1967. Rivers and recording sites are shown in Figure 2.

During the construction phase of Brasilia (1956 - 1960) a dam was built on the Paranoa river. Thus creating a lake of about 40 square kilometers at an elevation of 1000 m. The discharge at the Paranoa dam is regulated, and depends upon the demand for electricity in the region. Therefore the records at the gauging station in the Sao Bartolomeu river near road BR-251 are no longer natural.

In the Alexandre de Gusmao District, a land reform project North West of the new capital, the discharge of the river Rodeador was measured in 1959 and 1960. Discharge data for the year 1960 are presented in Figure 3. The form of the hydrograph, presented in Figure 3, is more or less typical for the Federal District. CAESB*) explained that the maximum stream flows usually occur in November or April, the mean in May. Flows gradually decrease untill the minimum stream flow is obtained in September.

In Figure 4 a frequency distribution of mean daily stream flows is presented. The curve was determined by taking the weighed averages of the records of a number of representative streams in the Federal District. Expressing the discharge in liters per second per square kilometer makes the data applicable throughout the District. This may be done by simply multiplying the watershed area and the discharge given.

During 25 per cent of the year the discharge is more than 20 $l/s.km^2$, during 50 per cent of the year between 10 and 20 $l/s.km^2$, and 25 per cent less than 10 $l/s.km^2$.

4.2 Sub surface water.

4.2.1 Groundwater.

Most of the rainfall infiltrates in the deep (45) soil of the District, with its predominantly high infiltration

*) verbal communication with Dr. L. Gomide L., Superintendant of CAESB.

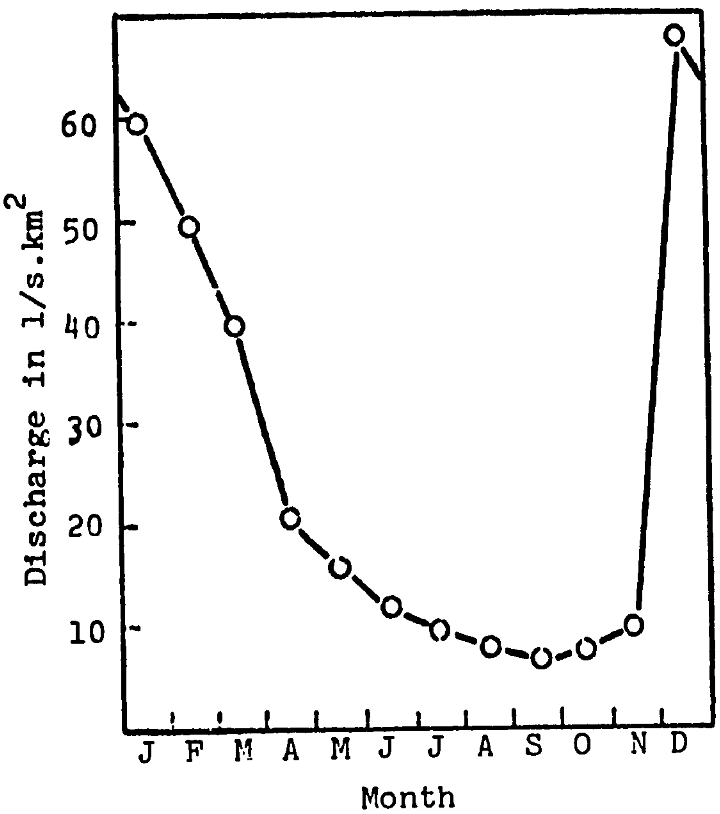


Figure 3: Mean monthly discharge of the Rodeador river in 1960.

Source: Instituto Brasileiro de Reforma Agrária.

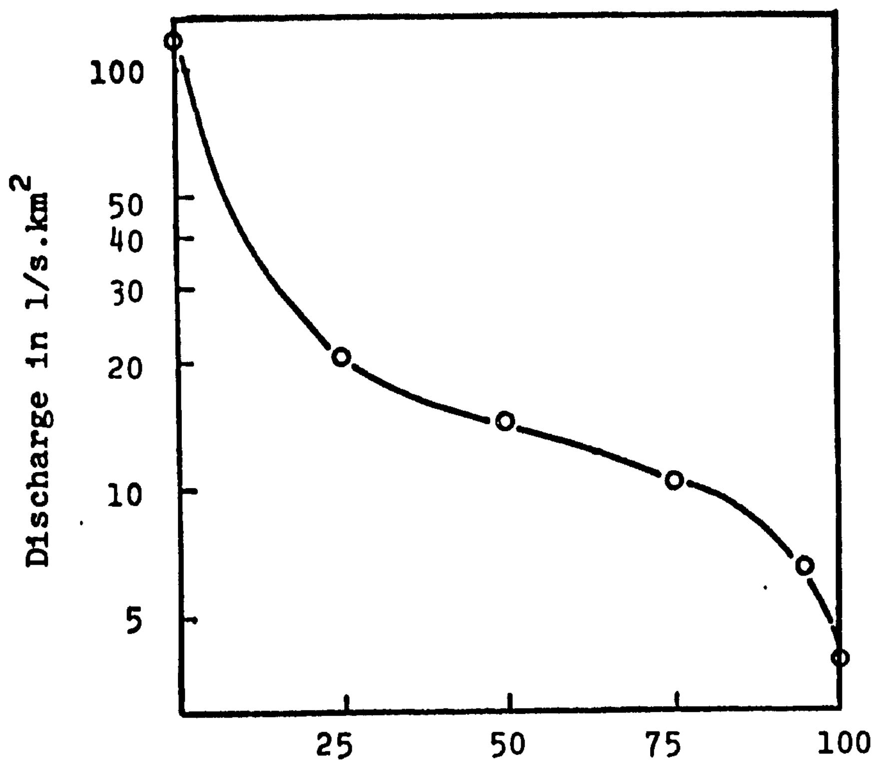


Figure 4: Frequency distribution of mean daily stream flows - Brasilia D.F.

Source: CAESB - Brasilia.

capacity. Belcher (6) states:

> " It is a very accurate comparison when we say that the Chapada acts like a sponge in absorbing the rainfall almost completely, storing it up as groundwater and discharging it at a slow rate into the streams of the region."

In the dry period of May to October, the total rainfall is about 70 mm, little of which could be expected to reach the groundwater. In the same period an equivalent of 130 mm of rain is discharged by the rivers. This is not as spectacular as suggested in the foregoing quotation. It is still of considerable importance for the development of irrigated agriculture, as will be seen later.

Daniels (19) expects fairly large saturated zones in the soil.

Lopez*) distinguishes two types of groundwater: shallow and deep. The shallow aquifer occurs between about 5 and 50 m depth, and the deep one from 70 to over 200 m. The two aquifers are separated by an impermeable layer of phillites. The shallow water contains clay particles in suspension. The author registered high groundwater levels, also on the chapadas, at the end of August, at the height of the dry season.

The most complete and detailed information about groundwater is reported by Planidro (45). They collected and elaborated on the information available prior to 1970. They

*) Verbal communication with D. Lopez, of Bombas Submergidas Brasilia Ltda.

report that the subsoil pattern is complicated and dissected by folds and faults. This makes it difficult to control the sub surface water. They recognize alternating layers of permeable and impermeable materials.
More field investigations are required to develop a better insight in the groundwater situation.

4.2.2 Springs.

A surprisingly high number of springs occur in the region. The author clearly distinguishes two types. One is the seepage type, usually with a water associated vegetation. The other is of a pothole type, circular holes of 20 to 40 cm in diameter, with spontaneously emerging water that does not affect the nearby vegetation. The latter type is not easily located in the field. However these may yield much more water than the seepage zones.

Planidro (45) reports 4 types of springs:

- Springs associated with phreatic water, which are recharged every wet season. The discharge decreases towards the end of the dry season. This type of spring occurs between 40 and 100 m below the highest point of the chapadas[*)].
- Contact springs; in this case the water penetrates to greater depth through cracks in the rocks. Where it meets more clayey and less permeable material, the water moves

[*)] Prospec - Geologia Econômica Aplicada a uma parte do Planalto Central do Brasil.

laterally over this stratum and emerges in erosion dissected valleys. The level at which such springs emerge is less regular. They occur less frequently than the type mentioned above.

- Depression springs, which can be found in the streams around Brasilia.
- Tubular springs, which are characterized by an almost vertical rising of the water. This type can be high yielding and deliver from 2 to 10 liter per second.*)

5. Geomorphology and Geology.

General descriptions of landforms, as they occur in the Federal District have been given by van Wambeke (62):

> " Ferralsolic regions are typically situated in areas which have not been subjected to intensive folding during recent geological periods, but rather went through long periods of broad and gentle upwarping into swells and downwarping into basins. These minor movements in the earth's crust took place on stable continental platforms, usually with crystalline foundations."

As an example of such a stable continental shield he mentions the Brazilian shield, of which the Federal District is a part. Daniels (19) says of the Brasilia area:

> "The long slopes, multiple levels, and deep incision of the streams below the divides suggest to me that the Oxisol landscapes have a long and complicated erosional history."

Cline and Buol (14) remark that:

> " The landforms of the region are classic examples of

*) Glossário Hidrogeológico - Abrão Hausman (1963).

the results of multiple geomorphic erosion cycles".

In various reports (14, 15, 19, 23) the existence of the erosion surfaces, as described in the section on Topography, is confirmed. Prospec (46) also explains the erosion process and the resulting differences in erosion levels. The surfaces are covered with a thick layer of partly laterized deposits, which can be sandy, silty or clayey, conform the original parent material.

The main geological formations in the region are the basement rocks of the Canastra series and Araxa group, both of Precambrian age, and the Bambui group of Cambrian age, consisting mainly of carbonates (45).

The most recent and detailed geological study of the Federal District, mapped at a scale of 1:50,000, was conducted by the University of Brasilia. A partial legend of that study is presented in Table 5. In Table 5 only those mapping units are presented, which coincide with the location of the sample sites of the author, discussed in section 3.1 of Chapter V. The units represent at least 80 per cent of the District. The QTl-unit covers more than 50 per cent of the total area.

6. Soils.

About one quarter of the soils of the Federal District have been mapped (15). Many publications generally describe the properties of the soils of the Federal District and surrounding areas (2, 6, 14, 15, 17, 18, 23, 27, 42). The

Table 5: Geological mapping units - Brasilia D.F.

Code	Description
Qa 1	Alluvials, eluvials and colluvials.
QT 1	Quarternary/Tertiary. Reddish brown concretionary lateritic crust.
Bq	Precambrian/Bambui group. White to reddish grey, fine to medium size compact to friable quartzite.
Basq 2	Precambrian/Bambui group. Rythmitic rocks, consisting predominantly of meta siltite and meta argilite and less frequently interbedded meta quartzite.
Cxq	Precambrian/Araxa-Canastra group. Quartz-muscovite-chlorite schist, with thin interbeddings of white fine muscovitic-quartz-itic and graphitic phillite.

Source: University of Brasilia, Department of Geo sciences (not published).

soils have been most recently described by Cline and Buol (14). They used the terminology of the Brazilian pedological investigations, to permit easy reference to Brazilian publications. The same system will be used throughout this thesis.

6.1 Dark Red and Red Yellow Latosols.

Four main varieties plus phases of each, based on vegetative type have been distinguished. They would be classified as Haplustox and Acrustox great groups of the U.S. Soil Taxonomy (14). The Dark Red Latosols have a B2 redder than 5YR and values of 4 or less; the Fe_2O_3-content is 10 per cent or more.[*)] In the case of soils of medium texture the per cent Al_2O_3/per cent Fe_2O_3 should be less than 2.0. The Red Yellow Latosols have a B2 of 5YR or more yellow, and values above 4, with less iron, usually less than 10 per cent[*)] (7).

Cline and Buol (14) found that clayey Dark Red Latosols appear to be dominant on the first and second erosion surfaces in the Federal District, North to the dissection of the Tocantins drainage basin, and South East-ward almost to Cristalina. Red Yellow Latosols dominate South of Cristalina.

Physically, both Dark Red and Red Yellow Latosols are friable, porous, permeable and highly aggregated (14).

[*)] Changed into values of 4 1/2 and Fe_2O_3-content of 9, in the modern Brazilian classification, according to M.N. Camargo.

Clayey Latosols feel like sand. The phenomena of this "pseudo sand" has been reported by Mohr and Van Baren (37), Magnien (34) and Buhring (12), and has been explained as the cementing of clay particles by iron. The percentage of natural clay or water dispersable clay is low. Wolf (63) determined from field studies a water availability of 35 mm per 30 cm of soil for a Dark Red Latosol. It is well known that the soils are acid. They are of an extremely low natural fertility (14, 18, 23, 42). High aluminum saturation causes shallow rooting of the crops (23, 42).

The Dark Red and Red Yellow Latosols predominate in the Federal District. The author's observations relate mainly to this type of soils. Cline and Buol (14) conclude that:

> " The results of the cooperative soil research at the site currently used on the Experimental Station of Brasilia*) (Estação Experimental de Brasilia) should apply in principle to an immense area of the Central Plateau of Brazil."

AIA (2) found that 80 per cent of the area they studied on the Central Plateau, contained soils with excellent physical structure and topography. It seems reasonable to assume that the results of this study can be extrapolated to a large part of the Central Plateau.

6.2 Humic Gley Soils.

In some valleys considerable areas of Humic Gley Soils can be found. Their color is distinctly gray. Their natural

*) a Dark Red Latosol.

fertility is also low. Physically they behave much more like a clay than the Dark Red and Red Yellow Latosols. Representative samples were studied of this type of soil. One of the profiles is located on the Experimental Station of Brasilia.*)

6.3 Other soils.

Other kinds of soils, described in the Cline-Buol report (14) are: Dusky Red Latosols, Red Yellow Podzolic Equivalents, with a relative high base status, and Lithosolic soils. The first two categories occur to a relatively small extent. The Lithosolic soils are common, but of less interest in the context of this study.

*) Boletin Técnico no. 8: Levantamento Semidetalhado dos Solos de Áreas do Ministério da Agricultura no Distrito Federal. Ministério da Agricultura. Profile no. 14.

III AVAILABILITY AND QUALITY OF WATER FOR IRRIGATION

1. Quantity of water calculated from climatological data.

Estimates, based upon climatological data, of the quantity of water available for irrigation have been made by a number of investigators. Feuer (23) states that 20 to 28 per cent of the annual rainfall (355 - 500 mm) will become available through deep percolation and runoff and subsequent release by streams. Belcher (6) found for the Paranoa river watershed, that 29 and 30 per cent (396 and 354 mm) of the annual rainfall of 1951 and 1952 respectively was released. The Planidro report (45) calculated ET using Turc's formula*).

$$ET = \frac{P}{0.9 + \left(\frac{P}{L}\right)^2}$$

where:

ET = mean annual evapotranspiration in mm

P = mean annual precipitation in mm

T = mean annual temperature in ^{o}C

L = $300 + 0.05T^3 + 25T$

Planidro (45) concluded that, assuming a mean annual rainfall of 1460 mm, the corresponding evapotranspiration would be 979 mm, leaving 481 mm per year for runoff and deep

*) " Le Bilan d'eau des sols; relation entre les pricipitations, l'evaporation et l'ecoulement ". Paris 1954

percolation. The same formula applied to the climatological data used in this thesis yields 995 mm per year for evapotranspiration. The resulting water availability is 1580 - 995 = 585 mm per year. This is 37 per cent of the mean annual rainfall. In the author's opinion this value is too high, because of a too low calculated evapotranspiration.

A more realistic solution probably is to apply the water balance, presented in Figure 5. The data are taken from Tables 3 and 4. Figure 5 is based on the following assumptions:

- The real evapotranspiration is lower than potential and probably approaches Penman's hypothetical Eo-value during the wet season. Theoretically, the evapotranspiration under optimum moisture conditions of the cerrado vegetation would have been higher, as was explained in section 3.8.3. However the actual evapotranspiration drops considerably below the potential evapotranspiration during and shortly after prolonged dry spells in the rainy season (63).
- Actual evapotranspiration during the dry season, from April to October is 140 mm. This amount is indicated in Figure 5 as: "soil moisture utilization". The line drawn is schematic: the actual water use will be more gradual. It will decrease towards the end of the dry season. The 140 mm value was arrived at by assuming that all available water will be consumed to 1.20 m depth, or

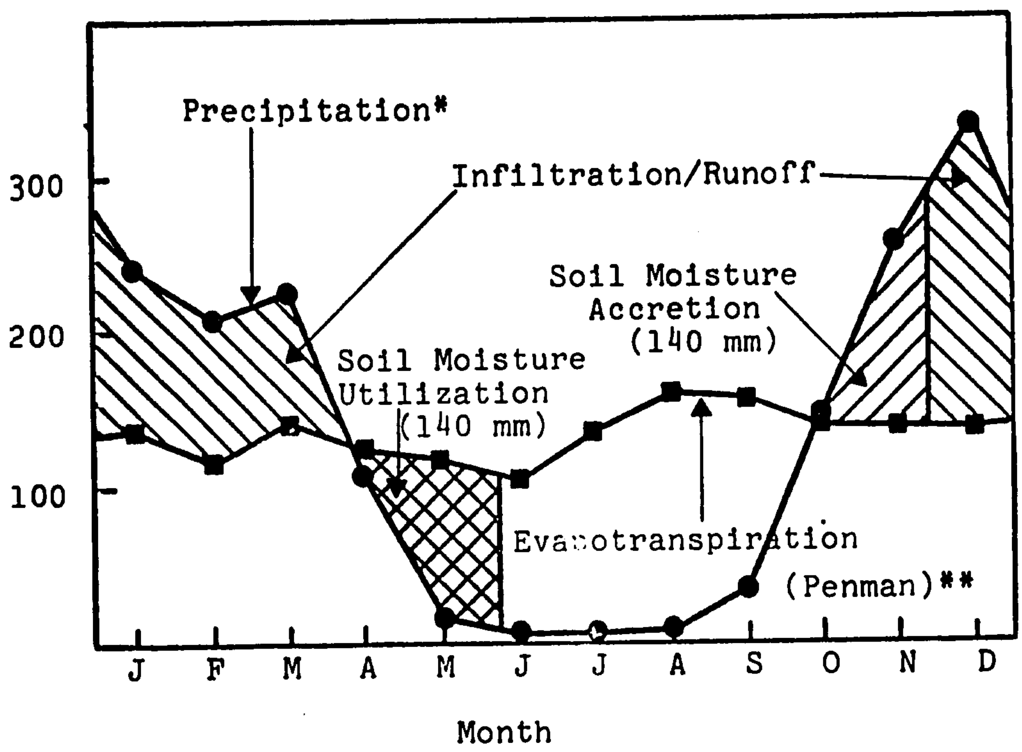


Figure 5: Hydrologic water balance - Brasilia D.F.

* Precipitation data, 42 years from Wolf (63)

** Brasilia D.F. average for the period 1961-1971

35 mm per 30 cm of soil (63).

- The excess precipitation during the period November - March represents deep percolation and runoff. This water reappears in the streams during the year.

Taking the above mentioned assumptions into consideration, the maximum quantity of available water for irrigation can be calculated. The results are presented in Table 6.

The net surplus of 461 mm per year is based on the mean annual rainfall of 1580 mm. This surplus represents 29 per cent of that value. This quantity is consistent with Belcher's observations(6). This percentage can not be applied uniformly to the rainfall in any specific year. As can be seen from Table 2, the expected annual rainfall is only 850 mm once every 100 years, and 1350 mm every 5 years. In such years, lower amounts of available water will have to be expected. It is impossible to forecast an appropriate percentage, which depends upon the monthly rainfall. If the rainfall is concentrated in a few months, a considerable surplus can be expected. However when this amount of 850 mm per year is spread out over 6 or more months, the resulting deep percolation will be practically nil.

2 Quantity of water calculated from hydrological data.

The water availability as calculated from the most recent and complete hydrological data are presented in this section. In Table 7 the characteristics of the mean daily

Table 6: Maximum water availability for irrigation calculated from climatological data*) - Brasilia D.F.

Month	Precipitation**) mm/month	Actual Evapotranspiration mm/month	Surplus mm
January	239.5	134.9	104.6
February	210.0	116.5	93.5
March	225.9	140.1	85.8
October	144.6	139.8	4.8
November	254.9	138.6	116.3
December	330.9	134.9	196.0
Year			601.0
Actual evapotranspiration during dry season:			140.0
		Net surplus:	461.0

*) Meteorological Station Brasilia, period 1961 - 1971

**) 42 years of data for Formosa, Brasilia and EEB (63) flows of some rivers are presented. The average values for the District are calculated. The regulated flow in the Sao Bartolomeu river near road BR-251 is excluded. Care was taken not to double count part of the area. The area considered for the calculations covers about one third of the Federal District.

The consistency of the data suggests it reasonable to assume that the weighed annual average of all mean daily stream flows is about 14.4 liters per second per square kilometer, and the minimum flow 4.7 $l/s.km^2$.

A mean daily stream flow of 14.4 $l/s.km^2$ is equivalent to a deep percolation and runoff of 454 mm per year. Codeplan (15) reports a mean annual precipitation during the observation period of 1577 mm per year. Consequently 29 per cent of the rain has been discharged by the rivers. This figure corresponds with the data presented by Belcher, reported in section 1 of this Chapter. Mean, maximum, and minimum monthly stream flows are 16.6, 36.1 and 6.0 $l/s.km^2$ respectively. This minimum flow usually occurs in September.

3 Quality of irrigation water.

CAESB*) reports that the water in the District is of excellent quality. The pH of the water ranges from 5.0 to 6.6. The total soluble salts are between 10 and 20 ppm. Samples of springs, analyzed at the EEB laboratory, confirm the water acidity: the pH values were between 5.3 and 6.0.

*) Verbal communication with Dr. L. Gomide L., superintendant

Table 7: Daily stream flows - Brasilia D.F.

River	Drainage area, km^2	Mean		Maximum		Minimum	
		m^3/sec	$l/s.km^2$	m^3/sec	$l/s.km^2$	m^3/sec	l/s.
Bananal	124.3	2.40	19.30	9.00	72.50	0.80	6.4
Richo Fundo	228.9	3.80	16.60	18.00	78.80	1.45	6.3
Torto	205.0	2.75	13.40	14.60	71.30	0.88	4.2
Descoberto	453.0	6.40	14.12	88.00	194.50	1.40	3.1
Bartolomeo DF-06	704.0	9.40	13.35	65.00	92.40	3.60	5.1
Bartolomeu BR-251	2203.6	25.18	11.40	167.20	75.00	9.70	4.3
Paranoa	1011.6	14.70	14.40	162.60	159.50	4.65	4.5
Sobradinho	166.0	1.65	9.95	10.73	64.60	0.45	2.7
Federal District			14.4		113.6		4.7

Source: CAESB, Divisão de Aguas - Ministério das Minas e Energia.

CAESB analyzed the water at the Experimental Station of Brasilia and other representative sources. The electrical conductivity ranged from 4 to 16 micromhos/cm. The pH was 5.7 to 6.7. The calcium content ranged from 0.02 to 0.07 meq/l, while the magnesium content ranged from 0.00 to 0.70 meq/l. The water can be classified (60) as C1-S1, having low sodium and salinity hazard.

4. Summary and conclusions.

Surplus water can be calculated from climatological and hydrological data. The results are respectively 461 and 454 mm for the year with mean annual rainfall. This represents 29 per cent of the mean annual rainfall. In a year wetter than the mean, more surplus water may be expected. In dryer years there will be less, and in extremely dry years the amount may be practically nil.

The amount of surplus water calculated in this section is not necessarily all available for irrigation. This will depend largely upon the techniques of water management.

The water quality is excellent.

IV SOURCES OF WATER FOR IRRIGATION

1. Potential for surface runoff impoundment storage.

The soils of the Federal District are highly permeable and the rainfall infiltrates rapidly. Planidro (45) assumes that 5 per cent of the total annual rainfall reaches the streams as overland flow. This surface flow only will occur in case of high rainfall intensities. The maximum rainfall per 24 hours reported for the Federal District is 132.8 mm (15). Quantities of 50 to 100 mm per 24 hours are not uncommon during the wet season. Infiltration rates measured by the author, range from 10 to 70 cm per hour (see Table 10). The initial infiltration rates are much higher. Some examples are shown in Figure 6. Although the author has no values of short duration rainfall intensities, he is inclined to conclude that the chance for catching surface runoff is practically nil. Some surface runoff may be expected on part of the shallow Lithosols. These areas, however, are less interesting from an agricultural point of view. Also, some surface runoff has been noticed as a result of mechanical compaction of the topsoil, under moist soil conditions. This reduces considerably the infiltration capacity, as will be reported in section 6 of Chapter V.

A major conclusion is that surface runoff impoundment storage is not a viable solution. It will be very hazardous during the rainy season, and non functioning during the dry part of the year.

2. River flows.

The most important sources for irrigation water are, undoubtedly, the rivers and streams. Figures 3 and 4 imply that during the wet season more than 15 $l/s.km^2$ of water are available. If irrigation is required during a dry spell in the rainy season, ample water is available, without taking many water conservation measures. Simple diversion structures without storage capacity will be sufficient to cope with the demand. However, during the dry season the river flows decrease, till a minimum of less than 5 $l/s.km^2$ is obtained usually in September/October. Without storage facilities, this amount, at the most, would be available for irrigation. The low supply coincides with high potential evapotranspiration, thus limiting the extent of the irrigated area.

Landers (31) comments that the cheapest way to irrigate is the direct use of river water, adapting the area under irrigation to the river flow.

The construction of storage dams can regulate the amount of available water. Theoretically 14.4 $l/s.km^2$ is available daily during the whole year. If it were possible to store all the water discharging during the wet season, from October to April, an amount of twice the mean daily flow, or 28.8 $l/s.km^2$ would be available, neglecting evaporation and seepage losses. This water could be used during the following dry period of six months. In practice, this will be impossible. On the other hand it seems reasonable to assume that part of the surplus water can be stored, and be used in the dry season. A supply of 10 $l/s.km^2$ appears to be a reasonable estimate to this author. With this amount, approximately 5 to 10 per cent of the total area could be irrigated. This would depend on irrigation efficiency, crops, etc..

The land to be irrigated can be found along the numerous small rivers,,spread over the Federal District.

The determination of the economic feasibility of this irrigation is beyond the scope of this thesis.

3. Subsurface water.

3.1 Groundwater.

General information about groundwater has been presented in Chapter II, section 4.2.1. In this section data on groundwater yields will be analyzed.

In the North East of Brazil an attempt has been made to classify the groundwater potential (36). In the Eastern part of Maranhao, for instance, a yield of more than 3 $l/s.km^2$ is expected. In other areas, such as a large part of Bahia, this is only 0.1 $l/s.km^2$. A problem in the North East is the quality of the water.

In the Federal District the water is expected to be of excellent quality. Belcher (6) reports that a potential groundwater reservoir exists that can be utilized to a limited extent. Planidro (45) collected data on the deep wells constructed until 1970, in the Federal District. A summary of this and other work is presented in Table 8. Most of the wells listed in Table 8 are located in, or nearby, the city of Brasilia, at elevations of 1050 to 1300 m. The depth of the wells is between 70 and 361 m; the average depth is 143 m. The static head, as far as is known, varies from 2 to 106 m, the average is 46 m. The dynamic head is between 20 and 103 m; the average is 59 m. The average drawdown is 13 m.

The results of pumping tests vary widely. In some cases*) the yield was nil, in others it was as high as 40 m^3/hr (equivalent to 11.1 l/sec). The average yield of producing wells is 15 m^3/hr, or 4.2 l/sec. Lopez**) attributes the low water yields in part to the poor quality of the filters used. He also explains that usually only the deep aquifer is accepted for use as potable water. The shallow, clay polluted, aquifer, described in Chapter II, section 4.2.1, is prevented from entering the filter. For irrigation purposes both aquifers contain water of excellent quality. Lopez supports the idea that a higher water yield might be possible, if the two aquifers could be pumped together.

*) In addition to the data presented in Table 8, information from Cia T. Janer exists, showing that at least 6 dry wells of at least 100 m depth were drilled in the Brasilia area.

**) Verbal communication with D. Lopez of Bombas Submergidas Brasilia Ltda.

Table 8: Characteristics of deep wells - Brasilia D.F.

Well nr.	Elevation m	Total depth of well m	Static head m	Dynamic head m	Test discharge m^3/hr
Executed by DNPM - PROSPEC/1960					
1	1135	361	-	-	no test
2	1093	300	-	50	7.2
3	1172	224	-	-	no water
4		60	7	-	no test
Ordered by NOVACAP 1967-1969					
DPJ-P-001	1096	130	76	-	18
DPJ-P-002	1075	140	60	76	8
DPJ-P-003	1109	136	86	not measured	33
DPJ-P-004	1075	76	63	63	8
DPJ-P-005	1099	137	68	72	18
DPJ-P-006	1108	121	-	-	-
DPJ-P-008	1125	145	104	104	8.4
DPJ-P-009	1127	127	106	dropped fast	3
DPJ-P-010	1094	147	-	-	3
Executed by Cia T. Janer					
431/1	1083	157	60	83	6
C.dom Bosco	1111	116	90	103	5
2 541/1	1300	160	18	78	2.5
2 541/2	1285	160	18	72	7.2
1 871/1	1060	110	2	60	6
2 722/1		116	90	103	5
2 007/1	1050	110	49	55	15
2 012/1	1200	73	21	40	10

Table 8: continued.

Well nr.	Elevation m	Total depth of well m	Static head m	Dynamic head m	Test discharge m^3/hr
Executed by Cia T. Janer*)					
3.314		102	33	34	22
3.319		70	24	42	8
3.365/1		150	47	60	40
3.365/2		200	41	60	22
3.391		122	25	60	40
3.605		110	17	20	22
3.519		151	7	26	36
3.496		121	12	24	11
3.511		150	33	50	24

Source: Água Subterrânea para Fins de Abastecimento de Água e Irrigação no Distrito Federal. Planidro, September 1970.

*) ,, Letter of Cia T. Janer to author, August 15, 1974.

Planidro (45) reports that the yield of wells relatively close together may vary widely. This is caused by the occurrance of folds and faults. They recommend a systematic survey, at a regional scale.

Groundwater probably can be exploited succesfully on the higher slopes and chapadas, which lend themselves for large scale agricultural development. In these locations the possibilities of river supply does not exist, or is very limited.

Energy may be one of the decisive cost factors in developing groundwater resources. However during the dry season and especially at high elevations, rather strong winds occur. It seems worthwhile to investigate the possibility of groundwater lifting by means of windmills.

If indeed groundwater is going to be used on a large scale in the future, this may well result in a reduction of the water supply from other sources.

3.2 Springs.

Few data on capacities of springs exist. Planidro (45) refers to the example of INCRA in the Alexandre de Gusmao project. Water from the springs that form the Jatobazinho river are used for the irrigation supply. The estimated discharge is 200 l/sec. Such high yields are exceptions however. It is true that many small springs exist, producing in general between 0.5 and 10 l/sec. Most of them decrease their flow toward the end of the dry season. Part of the spring water is already being used in irrigation. It is also used for cattle watering or for the household. Although this water is readily available, the author doubts that large areas can be irrigated from this source.

4. Summary and conclusions.

Surface runoff impoundment does not seem to be a viable solution for irrigation water supply, especially in the promising agricultural areas of the Federal District. The most important source is expected to be the rivers and streams. Structures can divert the water to storage reservoirs or directly to the irrigated areas. During the rainy season, river discharges are high and irrigation water supply is abundant. During the dry season only 5 $l/s.km^2$ can be expected to be discharged by the rivers. Part of the water, as much as technically feasible, could be used for the irrigation of 1 to 5 per cent of the land. With the creation of storage facilities, the amount of water could be increased and regulated. The author's estimate is that 10 $l/s.km^2$ could be made available, sufficient to irrigate 5 to 10 per cent of the total area, depending upon irrigation efficiency, crops etc..

Information on groundwater yields are scarce and concentrated in areas near the city of Brasilia. Deep well yields vary from nil to 40 m^3/hr. More investigations are required, to get a complete picture of the groundwater situation. Groundwater could be an important irrigation water source. This is especially true on the high slopes and chapadas. Wind may prove to be an adequate source of energy to lift the water.

Many springs, with a capacity of 0.5 to 10 l/sec, are being found, at various elevations in the Federal District. The water is readily available and is already partially used for irrigation. The author does not expect that a large area can be irrigated with this water source.

V SUITABILITY OF THE MAJOR SOIL TYPES FOR IMPOUNDMENT CONSTRUCTION

1. Definition of impoundment.

In the introduction to this thesis the desirability of the construction of impoundments has been discussed.

Two major categories of impoundments should be distinguished. The first one is the reservoir type. It is usually of large size. Water can be released throughout the year for irrigation and other purposes. The second category of impoundments is the farm pond, in which water is stored, usually for a short period of time. The farm pond is relatively small in size. The inflow is often low, but continuous. Water collected during the night can be used for irrigation the next day. Examples of farm ponds in the Federal District can be found in the Alexandre de Gusmao project, near Taguatinga.

In this Chapter the suitability of the major soil types for the second category of impoundments will be discussed. Attention will be focussed on seepage losses and the stability of such structures.

2. Location of sample sites.

One of the most critical questions to be asked in carrying out the fieldwork for this thesis was where to select the sample sites. The author has limited his field observations to those areas which have an agricultural destination. He also selected those locations which are representative for the soils of the Federal District. Shallow soils and dissected areas were disregarded. He has familiarized himself with these soils by sampling some specific sited at the Experimental Station (EEB) near Planaltina. The soils of these sites have been analyzed and described in other studies (17), thus providing a basis for comparison. They are representative of the majority of the soils of the Federal District. It was convenient to start at the station. Here unlimited quantities of soil material were available, which could be used in the training of the new laboratory staff. A total of five sites were sampled at the EEB. Mechanical and chemical analyses existed for four of the sites (17).

A second interesting area was the land reform project Alexandre de Gusmao, near Taguatinga. Here a total of six sites was selected. The test results from these sites can be related to farm ponds already existing in the project.

The remaining sites were selected in areas which also have a future agricultural destination. Three sites on the government farm Tamandua, three and two respectively in the rural nuclei Rio Preto and Tabatinga. One representative site was selected at the experimental farm of the University of Brasilia.

The locations of the sites are indicated in Figure 2.

3. General site and soil characteristics.

In Table 9 general site conditions and soil characteristics are presented.

Slope and altitude data have been discussed previously in Chapter II, section 2.

3.1 Geological formations.

All sample site locations have been plotted on the new geological map at the University of Brasilia. A partial legend to this map was presented in Table 5, section 5 of Chapter II. Most of the sites studied correspond to the geological mapping unit QTl, reddish brown concretionary lateritic crust. At site 19, on the experimental farm of the University of Brasilia, the lateritic crust was found within one meter depth. At all other sites the depth to this crust is at least more than one. In some cases it is several meters.

The existence of lateritic crusts of large areal extent is inconsistent with the theory presented by Feuer (23) who assumed that: "the major occurences of laterite in the District is as a narrow belt around the margin of nearly all remnants of the first erosion surface". He also observed that concretionary laterite occurs to a lesser extent on the fringe of the second erosion surface. Cline and Buol (14) confirm this theory.

A number of sample sites correspond to the geological mapping units Basq 2 and Bq, described in Table 5.

Table 9: General site and soil characteristics - Brasilia D.F. *)

Site nr.	Slope per cent	Altitude m	Geological formation	Depth of sampling cm	Color	Soil class	Soil texture	Remarks
1	3	1000	QTl	0- 20	2.5 YR^{3}/4	DRL	C	Profile 1 **)
				70- 90	2.5 YR^{3}/6		C	
2	2	1150	QTl	0- 20	5 YR^{3}/3	DRL	SL	Profile 5 **)
				90-110	5 YR^{4}/6		SCL	
3	8	1100	Bq (QTl)	0- 20	5 YR^{5}/6	DRL	C	Profile 4 **)
				60- 80	2.5 YR^{4}/6		C	
				130-150	2.5 YR^{4}/8		C	
4	3	975	Qa (QTl)	0- 20	10 YR^{6}/1	HGS	C	Near profile 14 **)
				80-100	10 YR^{7}/2		C	
				150-170	10 YR^{7}/1		C	
5	5	1100	Bq	0- 20	5 YR^{4}/4	DRL	SCL	
				150-170	2.5 YR^{4}/6		SCL	
				230-250	2.5 YR^{4}/8		SCL	
6	4	1100	QTl	0- 20	7.5 YR^{4}/4	RYL	C	
				80-100	5 YR^{5}/8		C	
7	5	1075	QTl	0- 20	10 YR^{4}/4	RYL	C	
				100-120	5 YR^{5}/8		C	

Table 9: continued.

Site nr.	Slope per cent	Altitude m	Geological formation	Depth of sampling cm	Color	Soil class	Soil texture	Remarks
8	4	1100	QTl	0- 20	5 YR^4/6	DRL	C	
				80-100	2.5 YR^5/8		C	
9	4	1175	QTl (Sa)	0- 20	5 YR^3/4	RYL	SCL	
				40- 60	5 YR^5/8		SCL	
				80-100	2.5 YR^4/8		SCL	
10	3	1050	Qal	0- 20	10 YR^4/4	RYL	C	
				90-120	5 YR^5/8		C	
11	3	975	Basq 2	0- 20	2.5 YR^3/4	DRL	C	
				80-120	2.5 YR^3/6		C	
				170-210	2.5 YR^3/4		C	
12	3	975	Basq 2	0- 20	2.5 YR^3/4	DRL	C	
				80-100	10 R^4/8		C	
13	3	1075	QTl (Cxq)	0- 20	2.5 YR^4/6	DRL	C	
				100-130	2.5 YR^4/8		C	
14	2	950	QTl s	0- 20	2.5 YR^3/6	DRL	C	
				80-100	2.5 YR^4/6		C	

Table 9: continued.

Site nr.	Slope per cent	Altitude m	Geological formation	Depth of sampling cm	Color	Soil class	Soil texture	Remarks
15	1	900	Basq 2	0- 20	10 YR^{4}/4	RYL	C	
				40- 60	10 YR^{5}/8		C	
				80-100	7.5 YR^{5}/8		C	
16	4	1125	Bq	0- 20	5 YR^{4}/6	DRL	C	
				80-100	2.5 YR^{4}/6		C	
17	2	975	Basq 2	0- 20	2.5 YR^{3}/6	DRL	C	
				80-100	2.5 YR^{4}/8		C	
18	2	925	Basq 2	0- 20	10 YR^{4}/1	HGS	C	
				40- 60	5 Y^{7}/1		C	
				80-100	5 Y^{7}/1		C	
19	5	1125	QT1	0- 20	7.5 YR^{4}/4	RYL	C	
				50- 70	7.5 YR^{5}/8		C	
20	4	1050	QT1	±100-120	2.5 YR^{4}/8	DRL	C	

*) Discussion of Table 9 in Section 3 of Chapter V.

**) Reference number in: Boletim Técnico no. 8, Levantamento Semidetalhado dos Solos de Áreas do Ministério da Agricultura no Distrito Federal. Ministério da Agricultura.

It was expected that a relationship would be found between texture and the parent rock from which the soil had developed. The geological units Basq 2 and Cxq were expected to yield fine textured soils, while from the unit Bq would develop a coarse textured soil. No prediction was made for the important unit QTl. Lateritic crust could have developed from any parent material. However the texture turned out to be fine in almost all cases. This was true also in the mapping unit Bq, where a coarse texture was expected. Apparently most of the soils are too old to reflect the properties of the parent material.

3.2 Depth of sampling.

The sampling depth has been arbitrarily chosen. In most cases the slightly more humic topsoil has been sampled to a 20 cm depth. A second desired depth is at one meter. It is assumed that the excavation for farm pond construction will go that deep. In some cases, where changes in the profile occurred within one meter depth, intermediate samples were taken. For comparison, samples were taken at greater depths, mainly at the Experimental Station near Planaltina.

3.3 Soil color.

The Munsell color notation (39) has been used throughout this thesis. In Chapter II, section 6, it was noted that the soil color has an important function in the Brazilian soil classification system.

Most of the soils are 5YR or redder, with values of 4 or lower.

3.4 Soil classification.

In addition to color, the iron content of the soil is an important criterium in the Brazilian soil classification system (see Chapter II, section 6). The iron content has not been determined for the samples used in this thesis. The classification in this case has been based on color only.

Most of the sample sites are on Dark Red Latosols (DRL). Some of these may be Dusky Red Latosols, if their iron content is 17 per cent or more. Second in number are the Red Yellow Latosols (RYL). Only a few Humic Gley Soils (HGS) were studied. The distribution of the soil classes, presented in this thesis, reflects well the occurrence of the soils in this Federal District*) (14).

3.5 Soil texture.

Soil texture has been presented according to the classification of the Soil Survey Manual (55). Practically all samples have a clayey texture, although most felt medium textured in the field. This phenomena was discussed in Chapter II, section 6.

*) Verbal communication with M. N. Camargo, professor of Soil Science at the Federal University of the state of Rio de Janeiro.

Some medium textured soils were analyzed. The sites were found at higher elevation. Sites 2 and 9, both of medium texture were located almost at the top of the first erosion surface (chapada). According to Camargo*) these medium textured soils occur in narrow bands along the edges of the chapadas and are by no means representative of the texture at high elevations.

4. Physical soil characteristics.

4.1 Particle size distribution.

The clay particles are cemented by iron, so that the content of natural clay, or water dispersible clay is low (12). Van Wambeke (62) points out that the mean size of the micro peds is in the coarse silt and fine sand fraction. They have a considerable stability in the field. They resist four hours end-over-end shaking in the laboratory. Ahn (1) found that the A-horizons have some water dispersable clay, which is not found in the oxic B. Thus indicating the action of organic matter on dispersion. In one of their examples of a B-horizon, the particle size changed from 600 - 20 micron without treatment to practically all clay sized particles after treatment with hexametaphosphate.

Cline and Buol (14) compare the results of particle size analyses executed with the Soil Conservation Service

*) Verbal communication with M. N. Camargo, professor of Soil Science at the Federal University of the state of Rio de Janeiro.

method (54) and its Brazilian equivalent EPFS (61). They concluded that the Brazilian methods appear to give more complete dispersion for particle size analyses. Camargo*) supposes that this is due to the use of different dispersion agents. He feels that the 6 per cent solution of sodium hydroxide they use is more effective than the sodium metaphosphate used by the Soil Conservation Service, at least for the Brazilian Latosols. It is questionable whether optimal dispersion is desirable, when one is studying engineering properties of a soil. As will be seen in section 5 of this Chapter, the micropeds to a large extent determine the engineering characteristics.

The author decided to characterize the "soil texture" in two ways, e.g. by means of optimal dispersion, and by aggregate stability measurements.

The following procedure for determining the grain size percentages is used in this thesis. First the per cent clay size particles was determined, using the "Pipette" method. The sample was prepared in the same manner as for the hydrometer test, described by Lambe (30). The deflocculant used was a 6 per cent solution of sodium hydroxide.

The prepared suspension was put into a plastic one-liter graduated cylinder which has a small hole in its side exactly 10 cm below the liter mark. This hole was closed with a small brass plug.

*) Verbal communication with M. N. Camargo, professor of Soil Science at the Federal University of the state of Rio de Janeiro.

The cylinder was then shaken for 30 seconds and placed on a table. The time needed for all particles smaller than 2 micron to settle below the level of the hole in the side of the cylinder was calculated, using Stoke's law.

At the end of the required time period, the plug was withdrawn and approximately 10 ml of suspension was drawn off in a small graduated cylinder. The exact volume of the suspension obtained was recorded; the contents of the small cylinder were washed into an evaporation dish and oven dried to obtain the weight.

The contents of the large graduated cylinder were washed through a nest of sieves numbered 10, 70 and 270 (ASTM designation), with diameters of 2 mm,210 and 53 micron respectively. All subsamples were dried individually and the weight per cent of each was calculated.

Results of the particle size analyses are presented in Table 10. The coarse sand fraction is between 2000 and 210 micron, the fine fraction between 210 and 53 micron.

It was the aim of the author to get results comparable to those obtained by the Brazilian methods. This should make reference to Brazilian work easy. In Table 11 results of particle size analyses by, respectively, the "Pipette" method, used and described in this thesis, and the EPFS method (61) are presented.

Although the depth of sampling is not exactly equal, comparison is allowed because of the homogeneous soils.

Table 10: Physical soil characteristics - Brasilia D.F.*)

Site nr.	Depth of sampling cm	Particle size, per cent Sand Coarse	Sand Fine	Silt	Clay	Specific gravity	Natural moisture per cent	Infiltration cm/hr
1	0- 20	18	24	11	47		9.2	18
	70- 90	20	13	20	47	2.88	11.5**)	
2	0- 20	37	37	13	13		6.3	33
	90-110	44	23	11	22	2.63	7.2**)	
3	0- 20	10	24	19	47		15.7	
	60- 80	6	20	24	50	2.79	19.7**)	
	130-150	12	19	20	49		24.3**)	
4	0- 20	18	10	10	62		22.5	10
	80-100	7	13	15	65	2.58	38.8**)	
	150-170	6	12	15	67		46.8**)	
5	0- 20	34	25	7	34		8.1	
	150-170	29	23	19	29	2.94	10.2**)	
	230-250	24	25	19	32		11.7**)	
6	0- 20	2	4	36	58		28.4	10
	80-100	3	2	35	60	2.75	28.5	
7	0- 20	8	18	16	58		15.3	22
	100-120	9	11	16	64	2.69	35.1**)	

Table 10: continued.

Site nr.	Depth of sampling cm	Particle size, per cent				Specific gravity	Natural moisture per cent	Infiltration cm/hr
		Sand		Silt	Clay			
		Coarse	Fine					
8	0- 20	2	4	31	63		27.3	2***)
	80-100	2	2	25	71	2.95	45.4	
9	0- 20	38	35	4	23		7.6	13
	40- 60	40	28	6	26	2.64	13.1	
	80-100	40	25	7	28		11.1	
10	0- 20	5	14	17	64		31.9	13
	90-120	3	9	23	65	2.67	47.4**)	
11	0- 20	5	9	16	70		12.1	25
	80-120	3	8	17	72	2.85	15.0**)	
	170-210	2	8	24	66		28.9**)	
12	0- 20	4	10	13	73		13.8	20
	80-100	2	7	14	77	2.97	26.6	
13	0- 20	7	13	10	70		18.6	50
	100-130	4	4	5	87	2.76	20.6	
14	0- 20	5	8	15	72		16.0	33
	80-100	7	6	15	72	2.96	27.8	
15	0- 20	9	15	25	51		25.7	18
	40- 60	6	12	32	50		31.7	
	80-100	5	12	28	55	2.75	34.9	

Table 10: continued.

Site nr.	Depth of sampling cm	Particle size, per cent				Specific gravity	Natural moisture per cent	Infiltration cm/hr
		Sand		Silt	Clay			
		Coarse	Fine					
16	0- 20	6	10	12	72		23.6	65
	80-100	6	8	13	73	2.70	3.6**)	
17	0- 20	3	3	17	77		14.7	18
	80-100	3	3	20	74	3.02	21.7	
18	0- 20	6	23	24	47		11.0	10
	40- 60	6	10	27	57	2.56	24.0**)	
	80-100	5	9	32	54		23.3	
19	0- 20	15	8	16	61		24.2	70
	50- 70	10	7	22	61	2.58	29.8	
20	±100-120	6	15	16	63	2.73	30.6**)	

*) Discussion of Table 10 in Section 4 of Chapter V.

**) Sample taken from previously opened spots, like ditches, profile pits, road cuts etc. In such cases the natural moisture content is not representative for subsoil moisture conditions.

***) Low value influenced by extremely high groundwater level.

<u>Table 11</u>: Comparison of different methods of grain size analyses - Brasilia

Reference nr.		Sand, %				Silt, %		Clay, %	
"Pipette"	EPFS*)	Coarse		Fine					
		Pip.	EPFS	Pip..	EPFS	Pip.	EPFS	Pip.	EPFS
1/0- 20	1/0- 10	18	16	24	17	11	23	47	44
70- 90	70-150	20	14	13	19	20	21	47	46
2/0- 20	5/.0- 18	37	35	37	33	13	14	13	18
90-110	60-105	44	32	23	33	11	12	22	23
3/0- 20	4/0- 12	10	9	24	19	19	27	47	45
60- 80	50- 85	6	7	20	17	24	28	50	48
130-150	125-160	12	5	19	17	20	28	49	50

*) From Boletin Técnico no. 8: Levantamento Semidetalhado dos Solos de Áreas do Ministério da Agricultura no Distrito Federal. Ministério da Agricultura.

The percentage of clay size particles is almost the same in both cases. Silt percentages are slightly higher with the EPFS method. On the whole, the two methods gave comparable results.

Table 10 shows that the percentage of clay sized particles is,in general,high. Approximately 50 per cent of the particles are kaolinite and chlorite; the other half are free Fe_2O_3 and Al_2O_3, Gibbsite and amorphous materials (14).

4.2 Specific gravity.

Lyon Associates Inc. (33) reports that lateritic soils have been found to have very high specific gravities of between 2.6 and 3.4 (20). It has been found that gravel fractions have higher specific gravities than the fine fractions, due to the concentration of iron in the gravel fraction. Aluminum is concentrated in the silt and clay fractions (40, 43).

Bennema (7) established a relation between color and iron content for the Brazilian Latosols. The Dark Red Latosols have an iron content of more than 10 per cent; the Red Yellow Latosols of less than 10.

The procedure followed for determining the specific gravity is outlined in the ASTM - Test for Specific Gravity of Soils, designation ASTM D-854-72 (3). It should be noted that the de-airing processes were accomplished by placing the vessel containing the fluid in a vacuum jar. It was subjected to a vacuum equivalent to 25 inches of mercury for 15 minutes.

The mean specific gravity for the Dark Red Latosols, clayey texture, is 2,86, with a standard deviation of 0.11. This value is considerable higher than for soils developed from quartz (2.65). It is due to the high iron content. The Red Yellow Latosols have a mean specific gravity of 2.69 with a standard deviation of 0.07. The value for the medium textured Latosols is 2.63, except for one. The particle density of the Humic Gley Soils is the lowest, with a mean value of 2,57.

4.3 Natural moisture content.

The natural moisture content, or moisture content during sampling, is given as á reference for evaluating engineering soil characteristics. As will be seen in section 5 of this Chapter, some engineering properties of a soil will change, depending on the initial moisture content of that soil.

To facilitate sampling procedures, soil was taken from previously opened spots, such as ditches, profile pits, road cuts, etc. In such cases the moisture content is not representative of natural subsoil moisture conditions. In some profiles extremely low subsoil moisture contents were found, due to the direct drying action of the sun. Some subsoils were wet, because of high groundwater levels. Topsoils were, in general, dry. Some topsoils were wet or moist, caused by irrigation practices.

4.4 Infiltration.

The infiltration capacities of soils of the Federal District are high (see Chapter II, section 4.2.1 and Chapter IV,section 1).

Puerto Rican Oxisols are reported to have similar high infiltration rates (32). The infiltration rate after 8 hours of infiltration ranges from 3.39 to 6.16 inches/hr (8.6 - 15.6 cm/hr). They measured infiltration rates using the buffer compartment method, outlined by Nelson and Muckenhirn (41).

The average permeability of ferrallitic soils (mostly Oxisols) in Africa was observed to be about 14 cm/hr in the surface layer and 6.5 cm/hr in the subsoil (16).

The author measured the infiltration using the "double ring" method (51). He placed 3 sets of concentric rings of diameter 20 and 40 cm respectively, at distances of 10 - 20 m, per observation site. The rings were driven about 5 cm into the ground. Vegetation was partly removed. Care was taken not to disturb the soil surface. Water was poured carefully into the rings. A head of 5 - 15 cm of water was maintained during the observation period. Reading intervals increased with time, as infiltration rates decreased. The test was stopped when the infiltration rate approached a constant value. The results of the 3 tests were then averaged. In some cases tests were continued the next morning, to check whether any changes took place due to swelling of the clay particles. This effect was negligible.

The constant infiltration capacity of the Dark Red and Red Yellow Latosols is between 10 and 70 cm/hr, with an average of 29 cm/hr. The average for the Humic Gley Soils is 10 cm/hr.

In Figure 6 characteristic infiltration curves are presented. The sites are located at the Experimental Station near Planaltina, and are representative for the soils of the District. Site 1, a clayey Dark Red Latosol, is near the road where the Cornell/North Carolina experiments are located. Site 2 is on top of the hill (Chapada) and represents a medium textured Dark Red Latosol. Site 4 is almost at the valley bottom on a clayey Humic Gley Soil.

Due to dry soil conditions the initial infiltration capacities are very high (more than 100 cm/hr for the medium textured DRL). After a few hours they level off and become constant. Wolf (63) determined the infiltration rate of a clayey Dark Red Latosol, similar to site 1. He twice flooded an area of 6 x 11 m and found infiltration rates of 17 - 22 cm/hr.

5. Engineering soil characteristics.

5.1 Compaction.

No systematic attempt has been made to consider all factors which determine density and compaction for African lateritic soils.(33). The result is that there are no clear conclusions. Some findings are conflicting. Certain reported

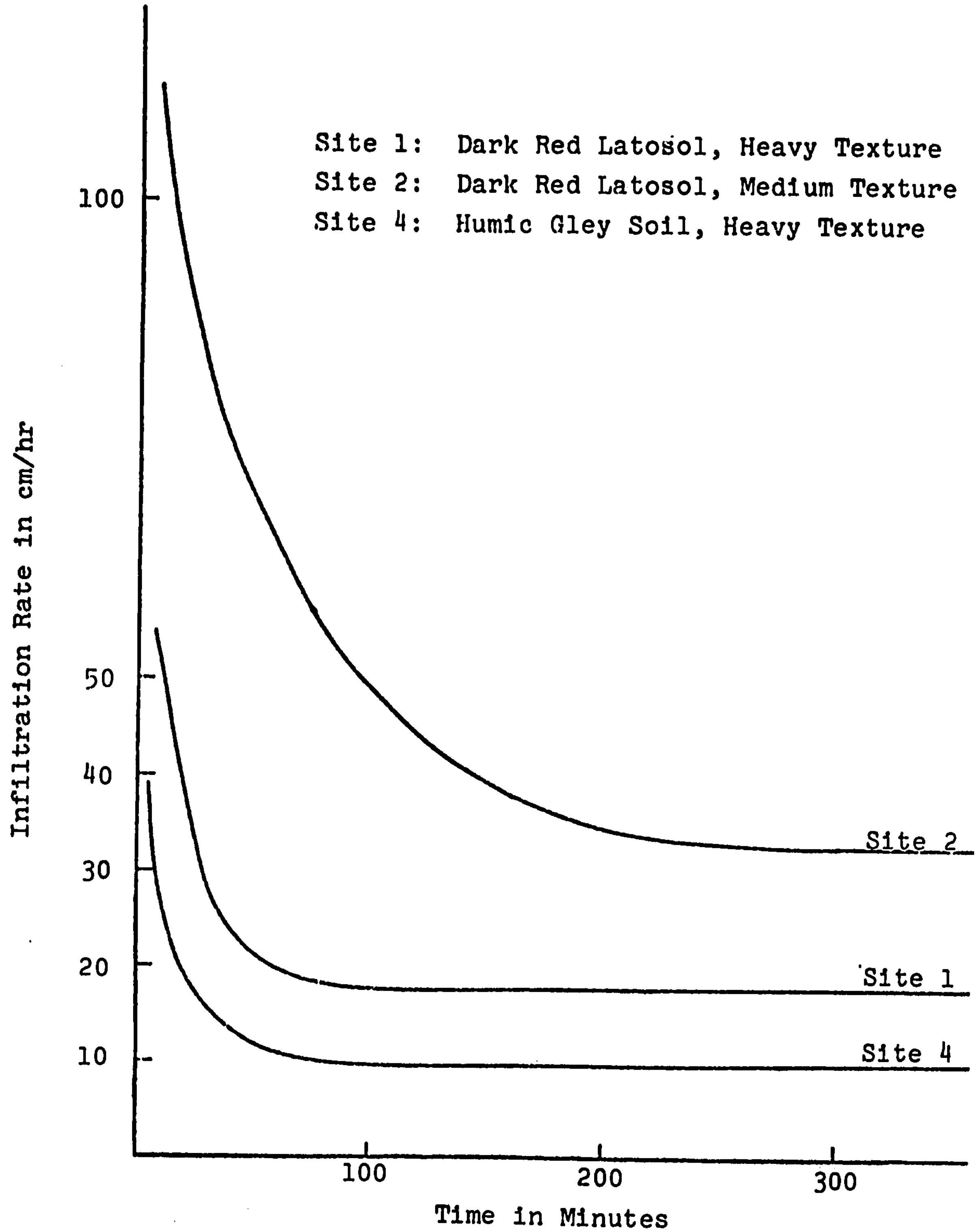


Figure 6: Characteristic infiltration curves-Brasilia D.F.

maximum dry bulk densities and corresponding optimum moisture percentages are presented in Table 12.

Table 12: Maximum dry bulk densities and related optimum moisture percentages, reported for African lateritic soils.

Material		Maximum dry bulk density		Optimum moisture per cent
		pcf*)	g/cm^3	
Indurated	laterites	>140	>2.24	0- 6
Lateritic	gravels	115-145	1.84-2.32	6-16
,,	gravel-sand-clay	100-120	1.60-1.92	16-24
,,	sand-clay	,,	,,	,,
,,	clays	<100	<1.60	24

Source: Laterite and lateritic soils, and other problem soils of Africa. Lyon Associates Inc., and Building & Road Research Institute, Ghana, 1971.

*) Pound per cubic foot.

The maximum dry bulk density of a Hawaiian Oxisol was 1.56 g/cm^3 at a moisture content of 28 per cent (5). Quinones (47) found that certain:

> " Hawaiian soils display irreversible changes with drying which are either caused by the dehydration of the hydrated oxides of iron and alumina or of the mineral halloysite. Compaction curves developed from the air-dried or oven-dried condition display higher maximum densities and lower optimum moistures than compaction curves developed by determining points as the soil dries from its natural moisture content."

Brand and Hongsnoi (10) noted less significant changes due to this dehydration process in Thai soils. In this study the Standard Proctor Compaction Test, designation ASTM D 698-66T, described by Bowles (9) has been used. About 5 kg of soil was passed through a no. 4 sieve. Water was added by increments of 1 - 2 per cent. Compaction was carried out in a 1/30 cu ft cylinder in three layers with 25 blows per layer, using a 5.5 lb hammer dropping 12 in. The mould was weighed. A moisture sample was taken. The same soil was used throughout the test, until the point of maximum density was passed. The samples used were air dried and therefore the maximum dry bulk density is possibly higher at a lower optimum moisture percentage than would have been the case if a soil that were at natural moisture conditions had been used. This phenomena has been reported by Quinones (47), quoted earlier in this section.

The results of the compaction tests are presented in Table 13. The compaction values for the medium textured soils vary between 1.68 and 1.82 g/cm^3 at optimum moisture percentages of 17.7 and 13.5 respectively. The values for the clays are from 1.29 to 1.63 g/cm^3 and 34.8 to 21.3 per cent of optimum moisture. These data compare well with those mentioned for Africa in Table 12, and for Hawaii. The compaction curves show pronounced peak values. Some typical compaction curves are presented in Figure 14.

Data (63) of site 1 show natural bulk densities of

Table 13: Engineering soil characteristics - Brasilia D.F.*)

Site nr.	Depth of sampling cm	Compaction		Plasticity, Moist.%			Aggregate Stability per cent
		Max.dry B.D. g/cm^3	Optimum moist.%	Liquid limit	Plastic limit	Plast. index	
1	0- 20	1.56	22.5	31.5	28.3	3.2	93.4
	70- 90	1.63	21.3	30.0	23.5	6.5	-
		1.59**)	21.5**)				
2	0- 20	1.76	16.2	25.0	18.0	7.0	95.2
	90-110	1.82	13.5	19.5	15.8	3.7	-
		1.78**)	15.0**)				
3	0- 20	1.53	23.7	37.0	29.3	7.7	91.6****)
	60- 80	1.61	22.5	37.2	29.4	7.8	-
		1.59**)	22.5**)				
	130-150	1.58	24.0	38.0	29.4	8.6	77.0****)
4	0- 20	1.39	28.4	45.5	32.1	13.4	100.0
	80-100	1.42	29.4	56.8	39.0	17.8***)	85.7
	150-170	1.49	25.8	55.2	41.9	13.3***)	66.9
5	0- 20	1.76	17.5	22.4	18.4	4.0	94.2
	150-170	1.82	15.3	27.3	18.5	8.8	-
	230-250	1.80	16.0	27.1	18.9	8.2	58.0****)
6	0- 20	1.40	29.0	48.0	32.1	15.9	86.5
	80-100	1.52	24.8	47.2	33.3	13.9	-
7	0- 20	1.44	27.0	45.3	31.6	13.7	85.9****)
	100-120	1.54	24.5	44.1	28.7	15.4	75.2****)

Table 13: continued.

Site nr.	Depth of sampling cm	Compaction		Plasticity, Moist.%			Aggregate Stability per cent
		Max.dry B.D. g/cm^3	Optimum moist.%	Liquid limit	Plastic limit	Plast. index	
8	0- 20	1.29	34.8	54.4	40.8	13.6	88.2
	80-100	1.43	28.5	49.5	35.0	14.5	83.8
9	0- 20	1.68	17.7	23.8	20.0	3.8	-
	40- 60	1.80	14.5	22.1	17.2	4.9	-
	80-100	1.82	13.8	23.4	19.8	3.6	-
10	0- 20	1.31	31.0	48.8	37.9	10.9	92.9
	90-120	1.46	28.0	47.5	32.3	15.2	92.4
11	0- 20	1.33	33.5	45.2	36.4	8.8	91.8
	80-120	1.38	30.3	42.8	34.6	8.2	-
	170-210	1.33	33.5	44.7	36.2	8.5	81.2
12	0- 20	1.31	34.6	49.4	40.5	8.9	89.1
	80-100	1.35	33.0	52.2	38.7	13.5	-
13	0- 20	1.31	34.0	49.7	41.6	8.1	88.7
	100-130	1.41	29.5	46.1	36.5	9.6	-
14	0- 20	1.42	29.0	42.3	33.6	8.7	-
	80-100	1.43	29.6	48.2	36.6	11.6	-
15	0- 20	1.42	26.0	46.5	33.0	13.5	83.1
	40- 60	1.48	26.0	45.4	33.6	11.8	-
	80-100	1.51	24.0	46.8	33.1	13.7	80.4

Table 13: continued.

Site nr.	Depth of sampling cm	Compaction		Plasticity, Moist.%			Aggregate Stability per cent
		Max.dry B.D. g/cm^3	Optimum moist.%	Liquid limit	Plastic limit	Plast. index	
16	0- 20	1.32	32.6	46.6	35.3	11.3	83.0
	80-100	1.43	28.0	43.5	35.1	8.4	92.7
17	0- 20	1.32	32.5	54.8	43.6	11.2	-
	80-100	1.37	32.5	51.2	43.1	8.1	-
18	0- 20	1.44	23.5	46.4	36.4	10.0	91.2
	40- 60	1.58	21.0	47.5	26.9	20.6	73.8
	80-100	1.59	21.0	52.8	28.9	23.9	71.7
19	0- 20	1.31	33.5	48.8	39.8	9.0	81.1
	50- 70	1.38	30.5	49.1	38.6	10.5	-
20	±100-120	1.48	27.0	47.7	33.3	14.4	85.0

*) Discussion of Table 13 in Section 5 of Chapter V.

**) Using soil only once for compaction tests.

***) The test was repeated after respectively drying and rewetting with the following results:

	Liquid limit	Plastic limit	Plast. index
Site 4, 80-100 cm,	48.7	32.9	15.8
,, 4, 150-170 cm,	47.9	35.8	12.1

****) More than 25% of the aggregates consist of concretionary laterite.

1.05 g/cm^3 at 7.5 cm depth and 0.95 g/cm^3 at 60 cm depth. The maximum dry bulk densities, obtained by Standard Proctor Compaction, for these layers are respectively 1.56 and 1.63 g/cm^3, or an increase in density of approximately 60 per cent over the natural bulk density is obtained. In Figure 7 a relationship between per cent clay sized particles and maximum dry bulk density is presented. The per cent clay sized particles was obtained after dispersion of the soil aggregates with sodium hydroxide. The topsoils have a lower maximum dry bulk density than the subsoils at the same clay per cent. This lower value corresponds with a higher optimum moisture percentage. Despite the existence of iron coated micro peds, a significant relation at the 1 per cent level, exists between maximum dry bulk density and per cent clay sized particles.

In a number of tests, indicated in Table 13, the soil was replaced after each compaction, thus avoiding an increasing destruction of the micro peds. The results of these compaction tests indicate a slight decrease in maximum dry bulk density at a little higher optimum moisture content. Apparently the re-use of the soil and the resulting destruction of a part of the micro peds causes a denser packing of the soil material, and is responsible for the increase in maximum dry bulk density.

In the Federal District the laboratoria of DER and NOVACAP have performed many compaction tests, mainly for road construction purposes.

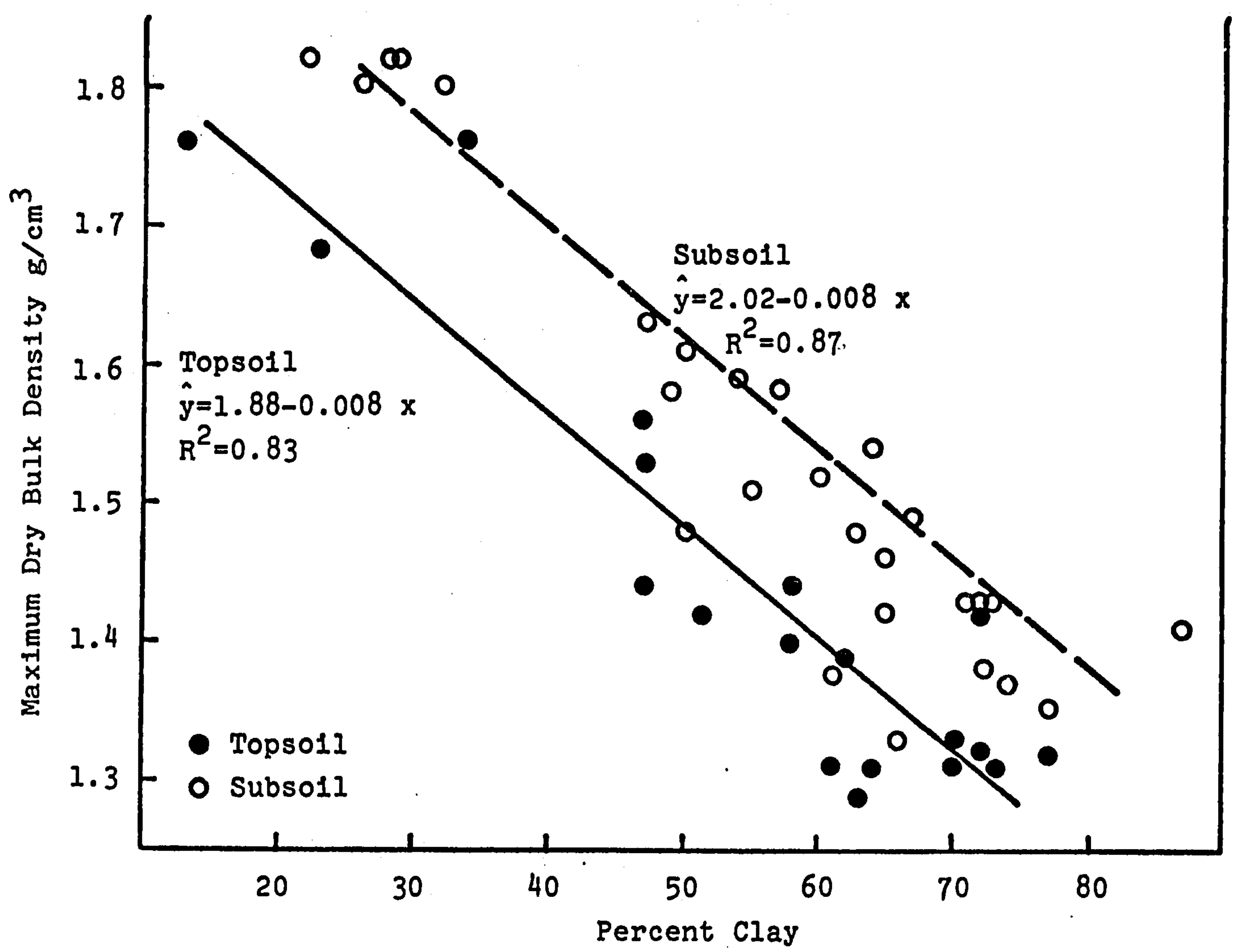


Figure 7: Relation between clay percentage and maximum dry bulk density-Brasilia D.F.

In Figure 8 the linear regression between maximum dry bulk density and optimum moisture content of 1411 samples of the DER has been compared with the results obtained by the author. The DER samples have also been tested at normal AASHO compaction energy. A significant relationship, at the 1 per cent level, exists between maximum dry bulk density (MDBD) and optimum moisture per cent (OMC), expressed by the formula:

$$MDBD = 2.16 - 0.026\ OMC$$

The results obtained by DER are very close to those obtained by the author.

In Africa (33) the relationship between maximum dry bulk density at AASHO modified compaction in pcf (9) and optimum moisture content is:

$$MDBD = 160 - 2.78\ OMC$$

This is equal to:

$$MDBD = 2.56 - 0.045\ OMC$$

when the maximum dry bulk density is expressed in g/cm^3.

The Modified Proctor Compaction test normally gives an optimum dry bulk density which is 5 to 10 per cent higher and an optimum water content which is a few per cent lower than the corresponding values obtained by the Standard Proctor Compaction test (30). Keeping this consideration in mind, it appears that the Brazilian and African Latosols give similar compaction results.

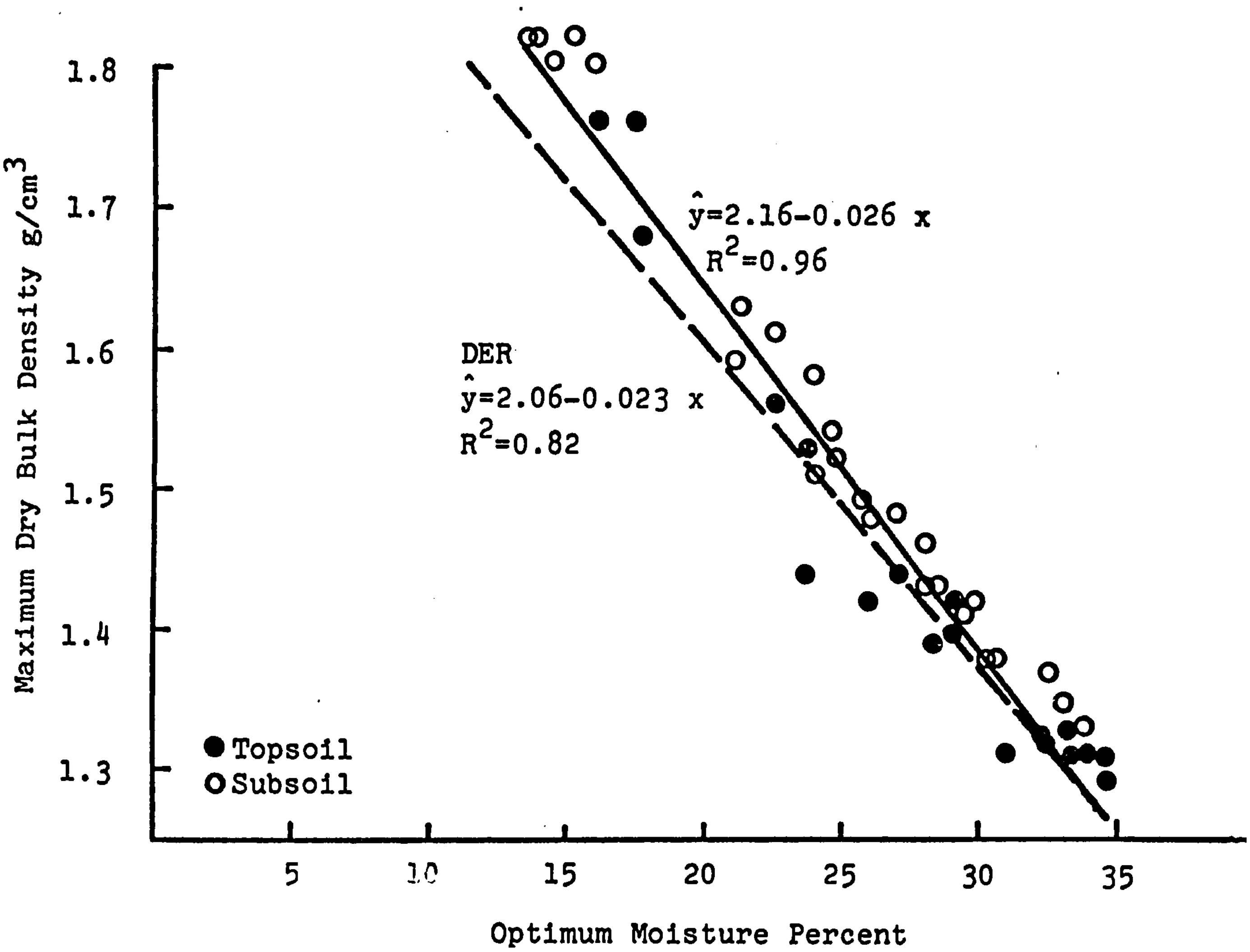


Figure 8: Relation between optimum moisture percent and maximum dry bulk density-Brasilia D.F.

At maximum Standard Proctor Compaction density a part of the voids is still filled with air instead of water. The soil is not completely saturated. The degree of saturation (S) at Standard Proctor Compaction has been calculated for different specific gravity classes. The calculated saturation percentages ranged from 60 to 100 per cent. The resulting values were plotted on a graph showing the relationship between maximum dry bulk density and optimum moisture content, as presented in Figure 8. For each point of the graph the degree of saturation was determined, taking into account the specific gravity of the sample presented by that point. The calculations indicate that the degree of saturation of the Brazilian soils depends upon their specific gravity. A high specific gravity corresponds to a low saturation percentage (see Table 14).

Table 14: Relation between specific gravity and the degree of saturation at maximum compaction density*) - Brasilia D.F.

Specific gravity	Saturation per cent
2.5 - 2.7	83 - 93
2.7 - 2.9	75 - 87
2.9 - 3.1	71 - 82

*) Standard AASHO - compaction.

5.2 Plasticity.

The most used indices of the plasticity of a soil are the plastic limit (PL) and the liquid limit (LL), commonly referred to as Atterberg limits. The designation for the LL is ASTM 423-66 and for the PL: D 424-71. The test procedures are described by Lambe (30) and Bowles (9).

The LL is determined with the liquid limit device of Casagrande and is arbitrarily defined as: "that water content at which a pat of soil is placed in a brass cup, cut with a standard groove, and then dropped from a height of one cm will undergo a groove closure of 1/2 in. when dropped 25 times" (9).

The PL has been arbitrarily defined as: "that water content of the soil at which a thread just crumbles when it is rolled down to a diameter of 1/8 in., or approximately 3 mm"(9). The numerical difference between LL and PL is defined as the plasticity index (PI), or: PI = LL - PL.

Various investigators (16, 24, 47, 48, 50) report changes in the limits due to drying, or pretreatment in general. Changes occur, especially, in soils containing much amorphous materials (52). Decreases in plasticity as a result of air-drying are associated with the slow reversibility of the soil system, when rehydrated (52). Also there is a probability that the iron coated micro peds are partially destroyed during mixing procedures, which would not take place under field conditions.

Belcher (6) reports an increase in plasticity due to compaction, for some friable clays of the Federal District. In one case the PI increased from 11.4 to 26.8 per cent; an increase of more than 15 points.

The results of the plasticity tests are presented in Table 13. In general soils were not air-dried before testing. The PL ranged between 19.5 and 56.8 per cent, the PL from 15.8 to 43.6 per cent. Significant relationships at the one per cent level exist between the PL, the LL and the per cent of clay sized particles (see Figure 9). The relations can be expressed as:

$$LL = 0.501 \text{ clay per cent} + 13.11$$

$$PL = 0.393 \text{ clay per cent} + 9.48$$

The PI has been defined as the difference between the two equations:

$$PI = 0.108 \text{ clay per cent} + 3.63$$

These relationships between clay sized particles and plasticity indices exist, despite the fact that micro peds are initially present in the sample. Figure 10 represents the relation between LL and PI. Both the results of this study and 1411 tests executed by the Roads Department of the Federal District (DER) are shown. The relationships can be expressed by the following equations:

$$PI = 0.264 \text{ LL} - 1.20$$

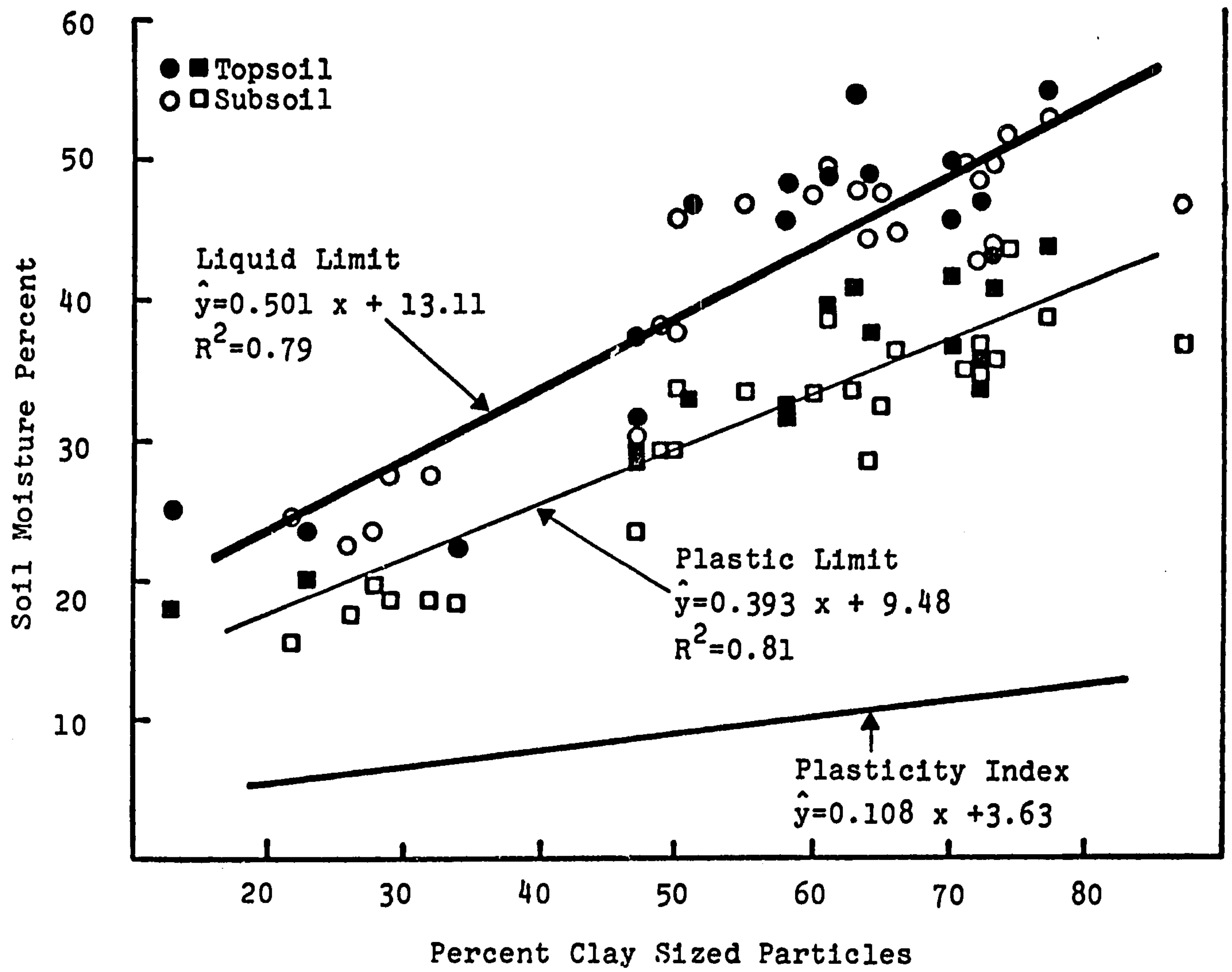


Figure 9: Relation between plasticity and percent clay sized particles-Brasilia D.F.

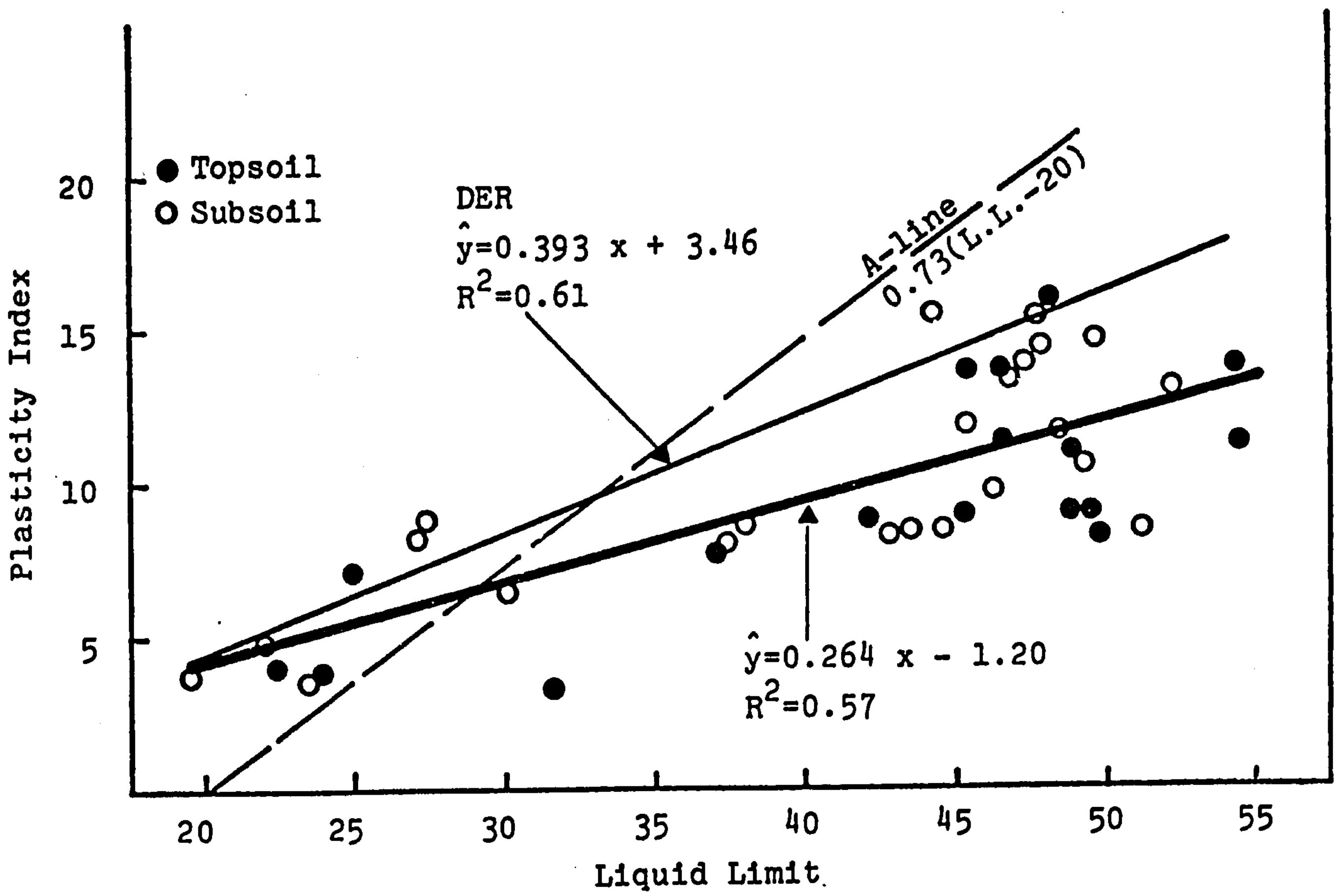


Figure 10: Relation between liquid limit and plasticity index-Brasilia D.F.

and

$$PI = 0.393\ LL - 3.46$$

The relationship for African ferrallitic soils (33) is:

$$PI = 0.57\ LL - 3.62$$

which differs considerably from the Oxisols of the Federal District.

Also in Figure 10 the Casagrande A-line is shown. This line has been developed for engineering soil classification purposes (56), for soils of temperate regions. Casagrande's work (13) resulted in the proposal and acceptance of the Unified Soil Classification System (64). According to this system the medium textured soils of the Federal District would classify as clayey silts (CL-ML) and all the fine textured soils as silts (inorganic) rock flours, silty fine sands with slight plasticity (ML).

The characteristics of the CL-soils (64) are:

- fair to poor value as a road foundation,
- medium swelling or shrinkage properties,
- practically impervious,
- a maximum dry bulk density at optimum compaction of more than 100 lb/ft^3, at a void ratio (e) of less than 0.70*).

The ML-soils can be characterized as follows:

- fair to poor value as a road foundation,
- medium swelling or shrinkage properties,
- fair to poor permeability,

*) 100 lb/ft^3 is equivalent to approximately 1.6 g/cm^3.

- a maximum dry bulk density at optimum compaction of more than 100 lb/ft^3, at a void ratio (e) of less than 0.70 *).

However the Brazilian Latosols appear to be used satisfactory in road foundations, show low swelling and shrinkage properties, and are highly permeable under natural conditions. The maximum dry bulk densities of most of the Latosols of the Federal District are lower than 1.6 g/cm^3. Therefore the Unified Soils Classification System does not appear to apply to the Brazilian Latosols.

In Figure 11 the plasticity limits are related to the maximum dry bulk densities, obtained in the Standard Proctor Test. The 1411 pairs of data of the DER are compared to the data developed in this work. The LL's of DER are consistently some points higher at the same maximum dry bulk density. The PL's are similar. Characteristic of the Dark Red and Red Yellow Latosols of the Federal District are the low plasticities, ranging from 3 - 16 per cent, even compared to the African ferrallitic soils. This phenomena is also reported by Geotecnica S.A. (25). For example a clayey Latosol of the Federal District with a LL of 45 per cent has a PI of only 10.5 per cent (see Figure 10). It is possible that this value can be doubled in case of compaction, as has been discussed previously in this section. The Humic Gley Soils show a higher PI than the Latosols. The observed maximum was 24 per cent.

*) 100 lb/ft^3 is equivalent to approximately 1.6 g/cm^3.

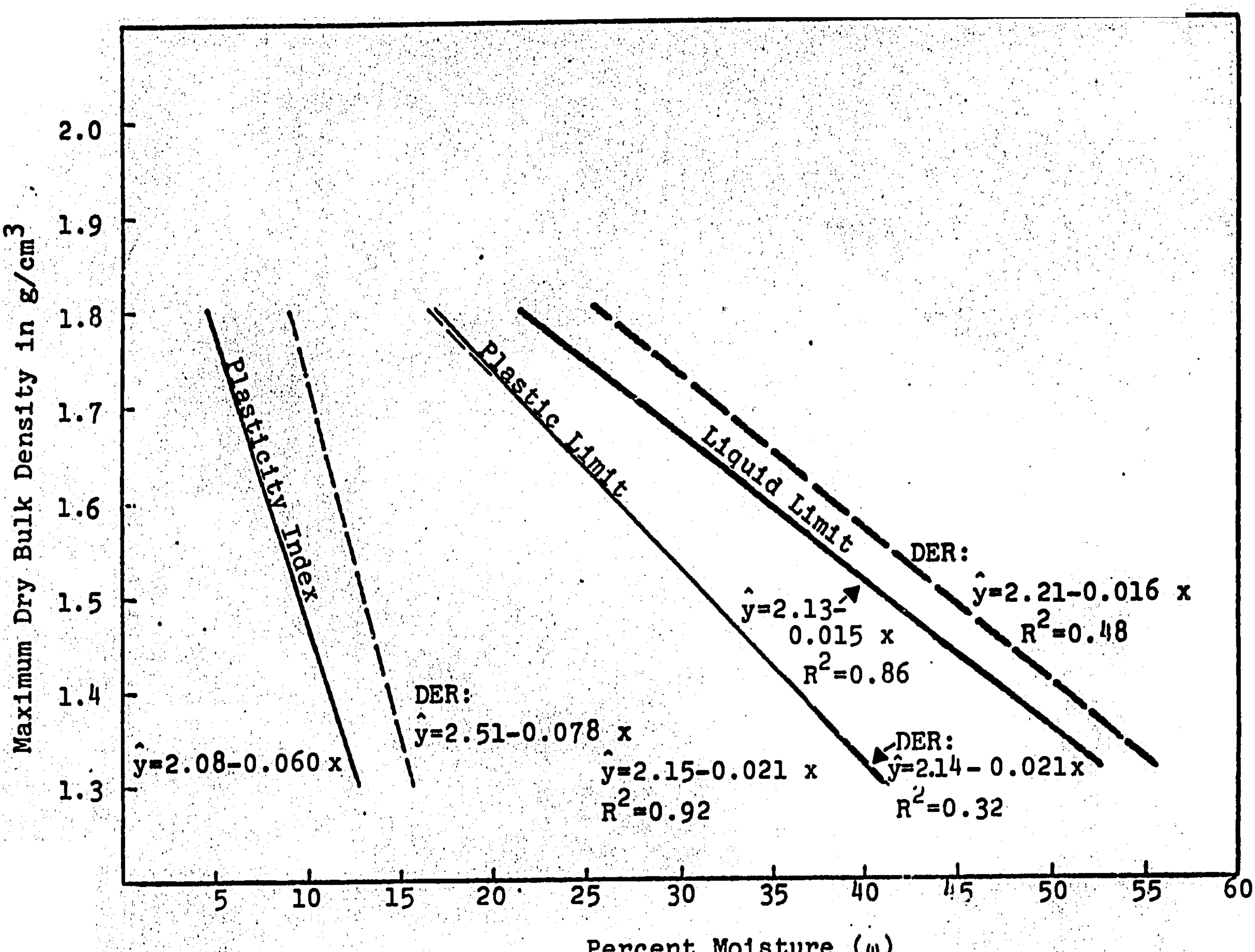


Figure 11: Relation between maximum dry density as obtained by Standard Proctor Compaction, the liquid limit, the plastic limit, and the plasticity index-Brasilia D.F.

5.3 Aggregate stability.

For Oxisols from Cameroon high aggregate stabilities have been reported , even after pretreatment with air and alcohol (38). The aggregates have been reported to have lost their stability after pretreatment with benzene (16). This was due to the low organic matter content. The method for aggregate stability determination applied in this thesis was developed by Bryant, Bendixen and Slater (11). Air dried aggregates, of diameters 3 to 5 mm were placed in a wet sieving apparatus on a nest of 2 sieves of 2 and 0.5 mm, respectively. The samples were soaked until they were thoroughly wet, in this case for 10 minutes. Mechanical equipment lowered the sieves 35 times a minute into a water-bath through a stroke length of 3/4 inch. The agitation lasted 2 minutes. The soil remaining on the sieves was dried at 105°C and weighed. Water stability was calculated as the percentage of the soil retained by the sieves, correcting for gravel, if any.

The results of the tests are presented in Table 13. Samples with more than 25 per cent of the aggregates consisting of gravel (concretionary laterite) are noted. Only those samples containing sufficient aggregates were analyzed.

The degree of stability of Brazilian Oxisols is high, especially for the topsoils. Some subsoil aggregates desintegrated upon exposure to water. The rapid entrance of water in the pores may compress the air and break down the aggregates (16). Particularly for the wet subsoils of the Humic Gley Soils, it was noted that aggregates were formed during the process of air drying. These aggregates became stable, a phenomena that also has been reported for African soils (33). Air dried aggregates contain 2 to 3 per cent more moisture than oven dried. Therefore the degree of stability may be higher than indicated in Table 13.

5.4 Direct shear.

Strength properties have been reported for a few African laterites (33). In a triaxial compaction test of a quartz-rich laterite soil from Cameroon, Baldovin (4) found a friction angle of above 40^{o}. Remillon (49) states that most lateritic soils display angles of over 40^{o}. Trow and Morton (58) report an angle of 36.5 (with 4 psi cohesion) for a lateritic soil from the Dominican Republic.

Effective stress strength parameters, ϕ'(internal friction angle), and c' (cohesion intercept) were obtained from direct shear tests. The basic procedures for such tests are described by Lambe (30). Three tests were run on each sample, using three different normal stresses. The peak shear stress obtained in each test was plotted against the normal stress used. The values of ϕ' and c' were determined from the resulting linear relation. Tests were run on samples from sites 1, 2, and 4 at the Experimental Station near Planaltina. The soils are representative for the District. Site 13 was selected because it has the highest percentage of clay sized particles.

The sample from site 2, being predominantly sand, was tested in an air-dry state and at a strain rate of 0.0122 in/min. The other samples were prepared by mixing with water to the consistency of a paste. The shear box was placed in a water-filled reservoir. The test was run at a strain rate of 0.0025 in/min to assure dissipation of excess pore water pressures. The water contents of the samples were measured both before and after the tests.

The results obtained are presented in Table 15.

Table 15: Effective stress strength parameters from direct shear tests - Brasilia D.F.

Site	Sampling depth cm	Internal friction angle ϕ' degrees	Cohesion intercept c' kg/cm^2	Moisture per cent	
				before test	after test
1	70- 90	37.9	0.10	36.0	27.7
2	90-110	41.6	0.10	-	-
4	80-100	39.8	0.07	51.5	30.9
13	100-130	39.3	0.10	40.4	35.9

The results for all four sites are very similar, despite the differences in clay content (site 2: 22 per cent, and site 13: 87 per cent). The characteristics of the clay are lost because of the aggregation of the clay into strong micro peds. All samples show high friction angles of around 40^{o} and negligible cohesion intercepts.

Geotecnica (25) found slightly lower friction angles for some Latosols in the Federal District, but confirmed the low cohesion intercepts. The results compare well with those mentioned for some lateritic soils in Africa and the Dominican Republic.

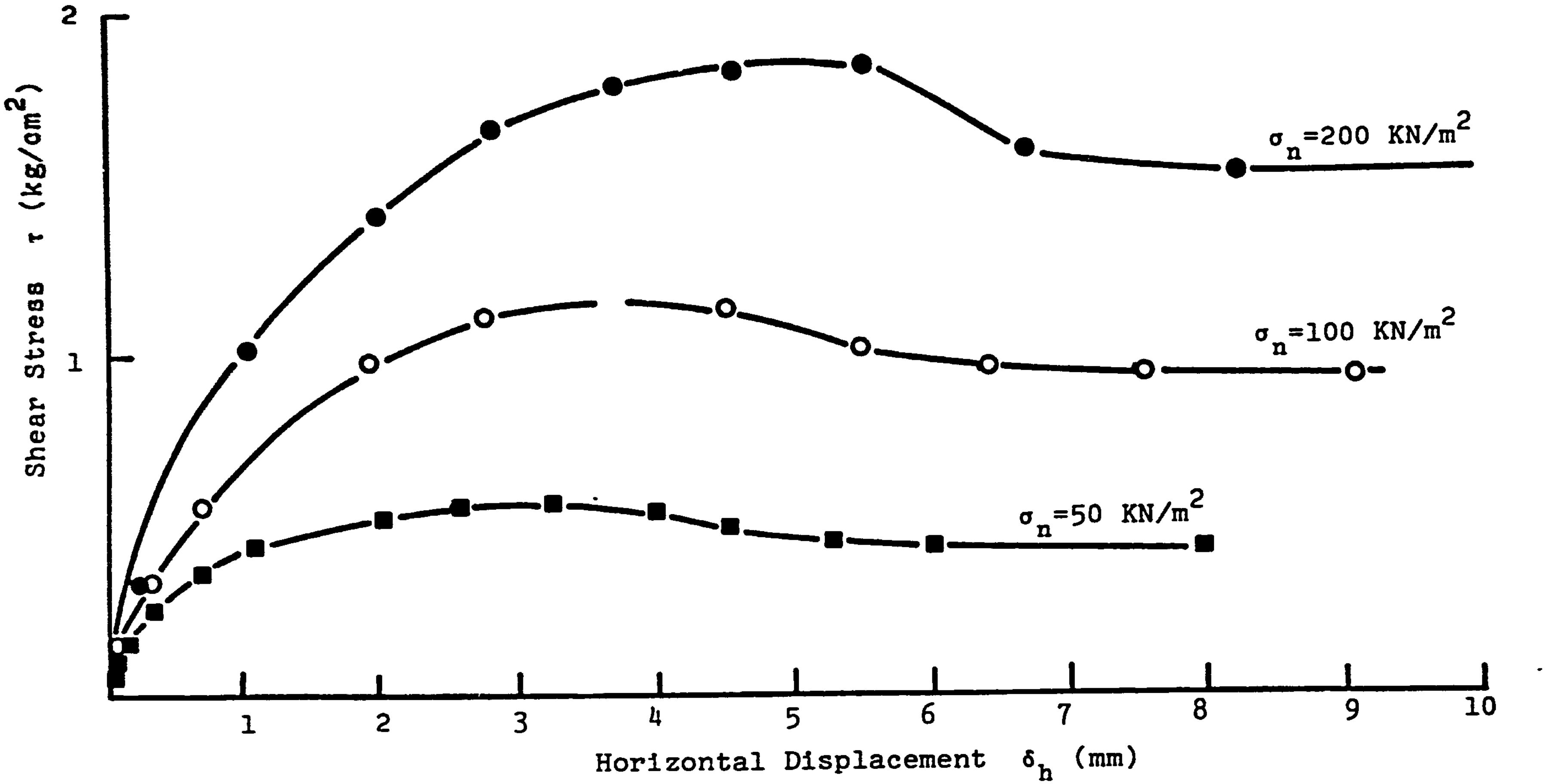
Representative shear curves, showing the relationship between horizontal displacement and shear stress are presented in Figures 12a, 12b and 12c. Figure 13 displays the relationship of normal stress versus shear stress, and shows the internal friction angles and cohesion intercepts.

6. Compaction, infiltration, and hydraulic conductivity.

Infiltration rates and hydraulic conductivity can be reduced through compaction. In this section the relationship between infiltration, hydraulic conductivity and compaction, under both laboratory and field conditions, will be discussed.

6.1 The relationship between infiltration and compaction in a laboratory experiment.

Typical soil samples were compacted at different moisture percentages in three rings of 20 cm in diameter, placed on a permeable subsoil. The soils were compacted in 3 layers of about 3 cm each at Standard Proctor energy equivalent. Therefore it is assumed that the dry bulk densities of the soil in the rings are equal to those obtained in the Standard Proctor Test, discussed in section 5.1 of this Chapter.



<u>Figure 12a</u>: Direct shear test, site 2 (90-110 cm)-Brasilia D.F.

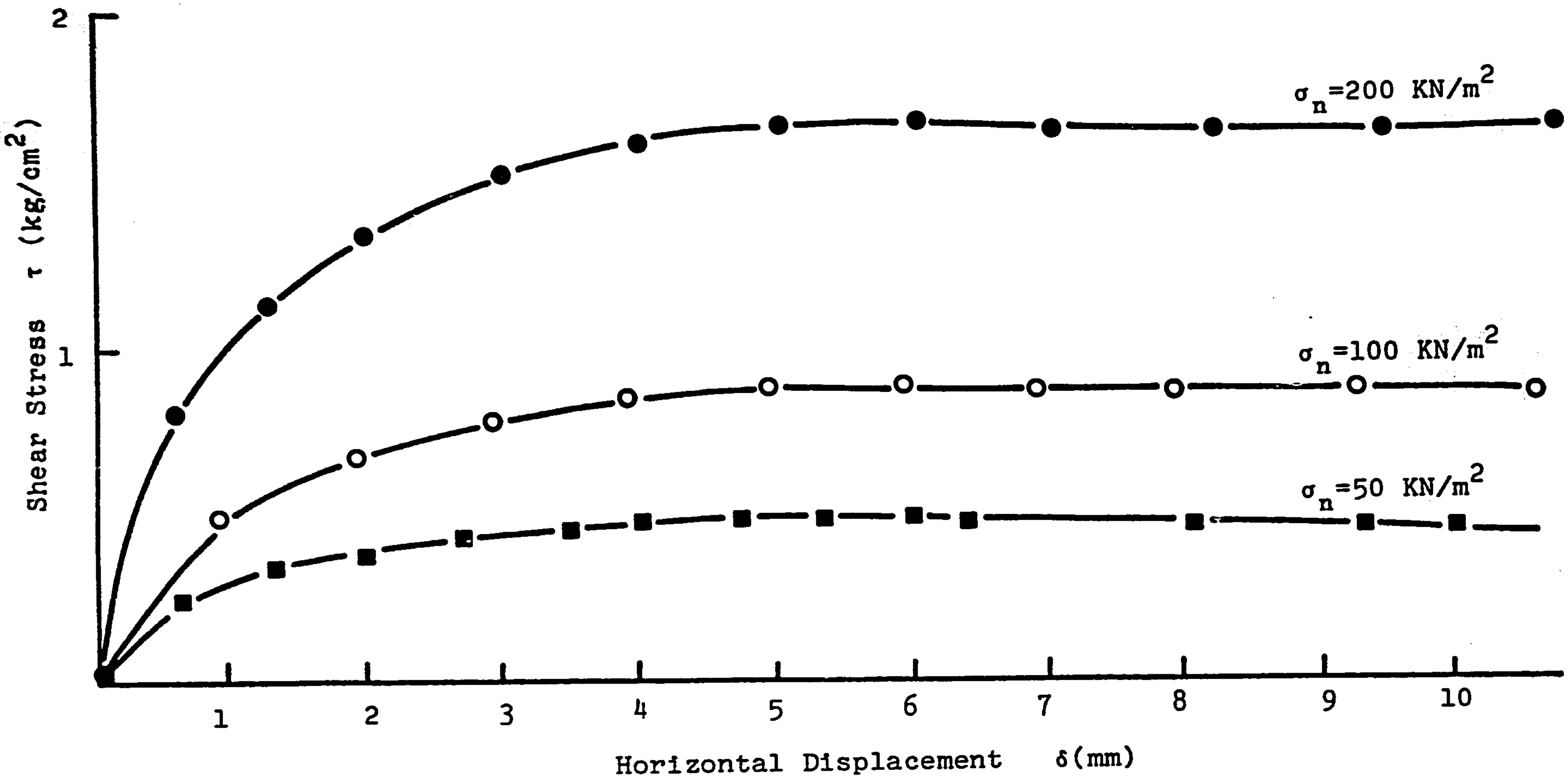


Figure 12b: Direct shear test, site 1 (70-90 cm)-Brasilia D.F.

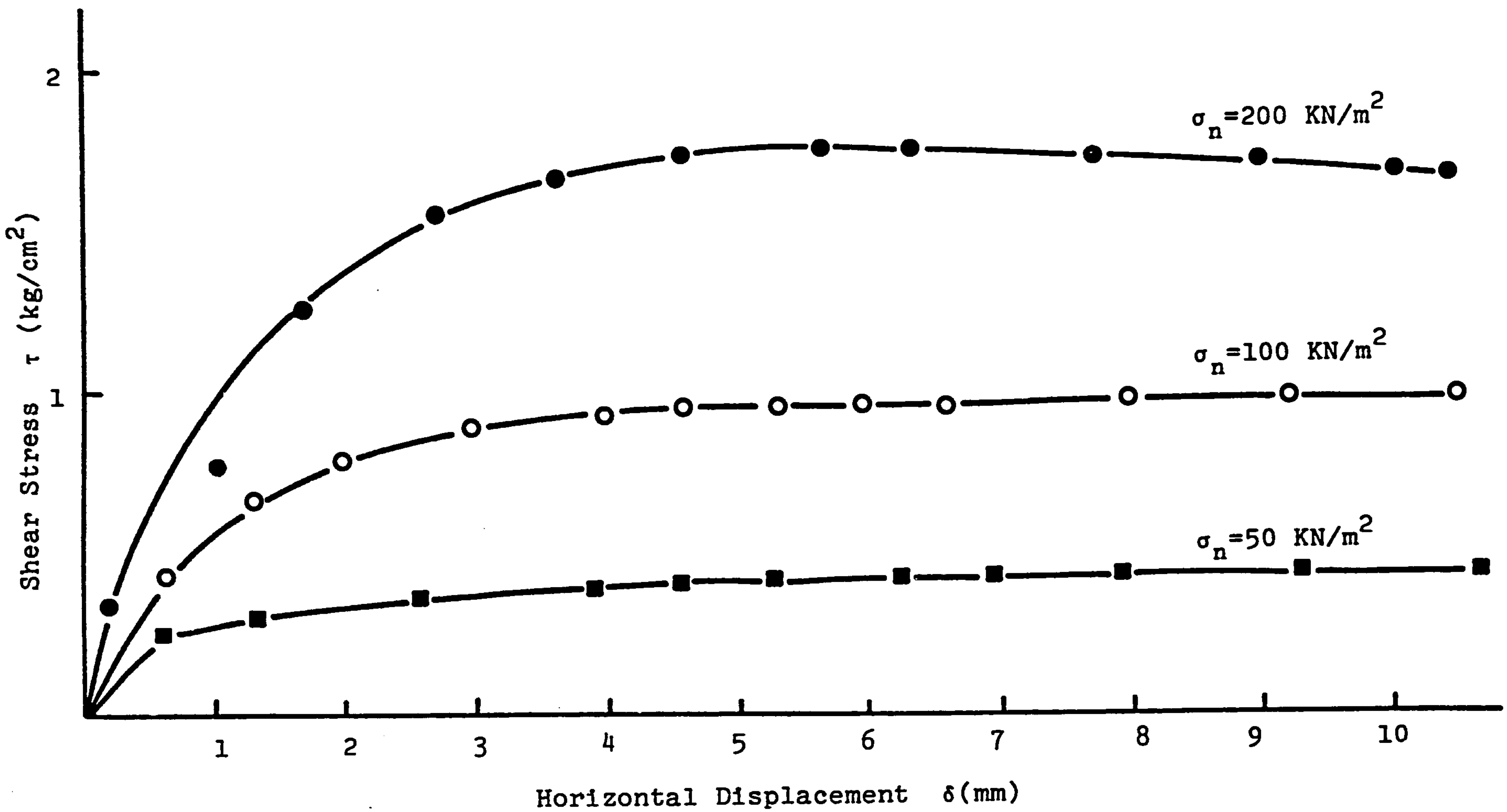


Figure 12c: Direct shear test, site 4 (80-100 cm)-Brasilia D.F.

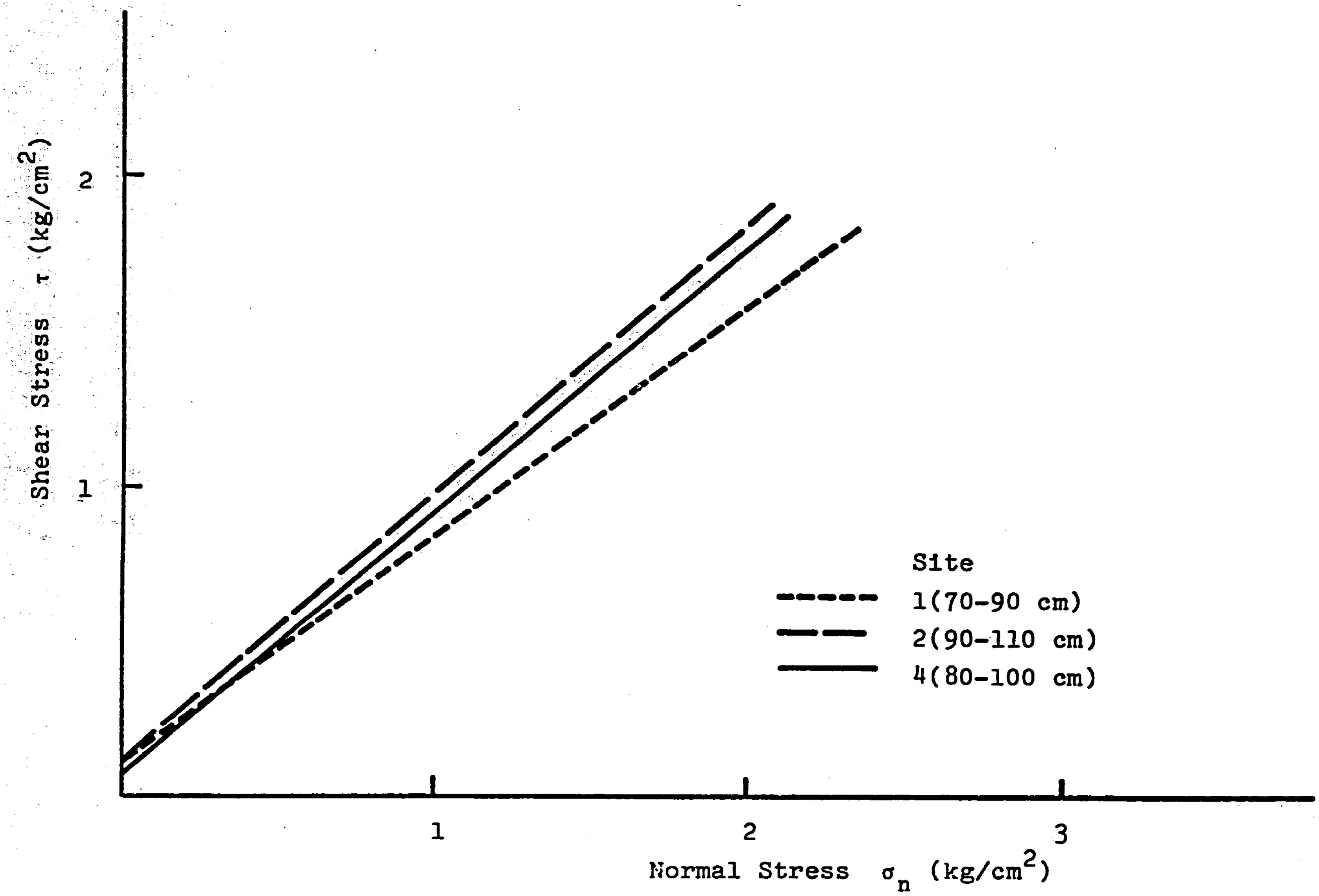


Figure 13: Shear stress vs. normal stress -Brasilia D.F.

A water depth of 15 cm was maintained throughout the test. The infiltration rates were measured as described in section 4.4.1 of Chapter V.

The results of the tests are presented in Figure 14. The compaction curves show the relationship between dry bulk density and per cent soil moisture, compacting the soil under Standard Proctor Compaction conditions. The infiltration curves show the relationship between the moisture content at which the soil was compacted, and the resulting infiltration rates. The relationship between infiltration rate and dry bulk density can be obtained by reading the compaction curve at the corresponding moisture percentage. Arrows indicate how to use the graphs. For example, the Dark Red Latosol at site 1, compacted at a moisture per cent of 16 at the Proctor energy equivalent is expected to have a dry bulk density of 1.5 g/cm^3. The infiltration rate is 0.62 cm/hr. The compaction curves show a decrease in maximum dry bulk density and an increase in optimum moisture percentage from medium to heavy textured soils. The maximum dry bulk density of the Humic Gley Soil is lower than of the Dark Red Latosols, at a higher optimum moisture per cent.

Infiltration rates drop with increasing compaction and are in the order of 0.2 to zero cm/hr, at optimum moisture percentage. Beyond the point of optimum moisture for compaction, corresponding to lower maximum dry bulk densities,

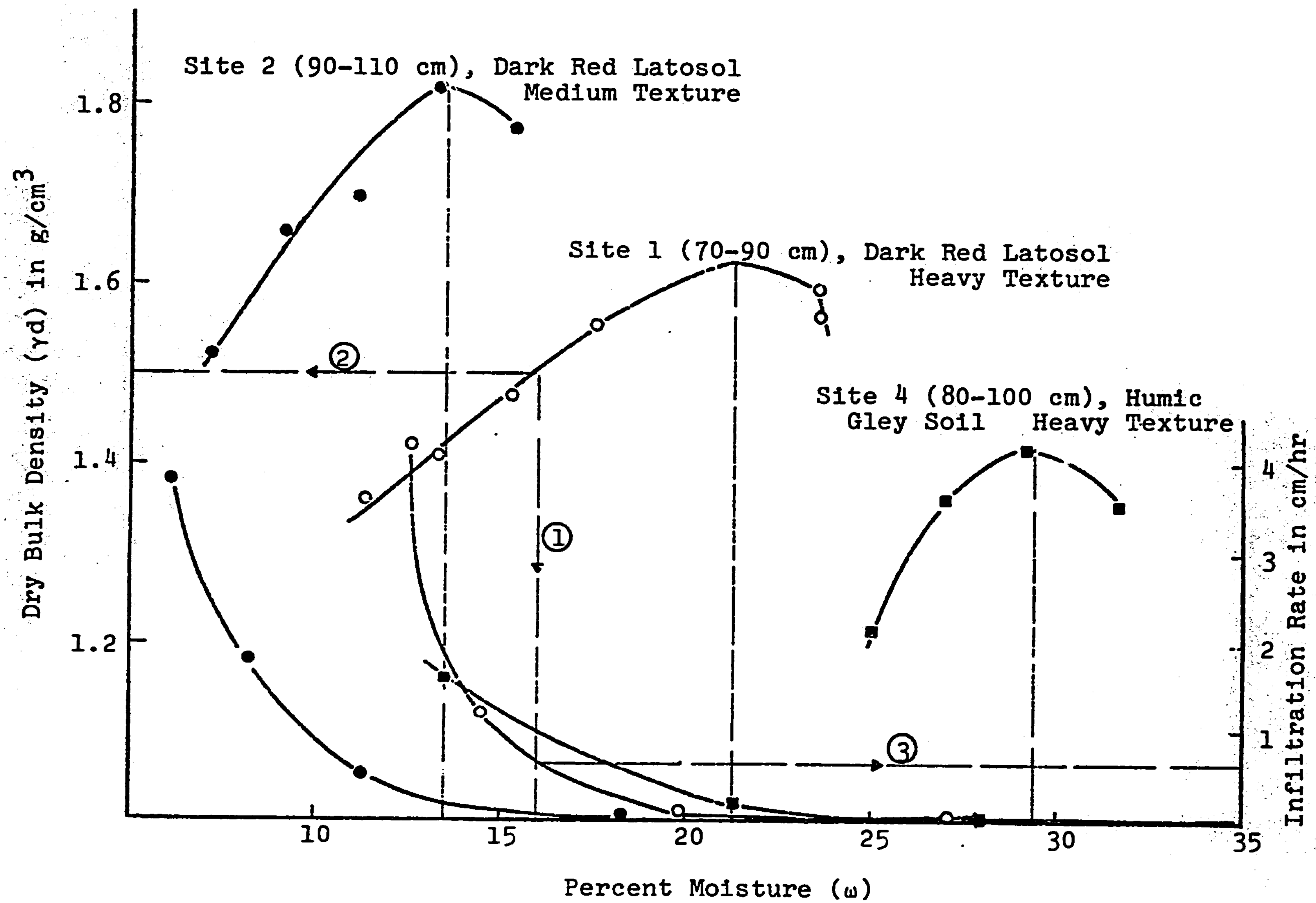


Figure 14: Relation between compaction and infiltration-Brasilia D.F.

the infiltration rates do not increase. This is due to a puddling effect in the soil. It is recommended that compaction be made close to optimum moisture to obtain high dry bulk densities corresponding with low seepage losses and a high stability of the structure.

6.2 The relationship between hydraulic conductivity and compaction.

The same representative samples , used in the experiments described in section 6.1 were subjected to permeability determinations.

A metal cylinder, diameter 6.2 cm, was loosely packed with soil, brought to its optimum moisture content for compaction, and at both sides enclosed by sandfilters. The initial height of the sample was 4 to 5 cm.

Before testing, the cylinder was submerged in a water bath, until completely saturated. The cylinder was connected to a pressure system. Water was forced through the sample at a differential pressure head of 50 cm. The discharge was measured. Using Darcy's law, the permeability factor (K) could be calculated.

After each run the saturated soil sample was exposed to a static load. This reduced the height of the sample. Thus increasing the density of the soil. The final height of the sample was 2.0 to 2.5 cm.

The results of the tests are presented in Table 16. Real densities may be slightly less than indicated in

Table 16: Measurements of hydraulic conductivity and compaction - Brasilia D.F.

Site	Sampling depth cm	Run	Dry density g/cm^3	Permeability K cm/hr
1	70- 90	1	1.13	0.92
		2	1.22	0.88
		3	1.41	0.17
		4	1.80	0.02
2	90-110	1	1.24	0.94
		2	1.46	0.65
		3	1.63	0.54
		4	2.02	0.08
4	80-100	1	0.75	1.71
		2	0.85	0.95
		3	1.03	0.70
		4	1.15	0.18
		5	1.50	0.003

Table 16, because of failure to account for compaction of the sand filters.

In Figure 15, the relation between the coefficient of permeability or hydraulic conductivity (K) and dry bulk density is presented.

Permeabilities decrease sharply with increasing densities. The Humic Gley Soil shows the largest reduction of permeability with increasing density.

If the soils are compacted to Proctor densities, the conductivity drops to 0.05 cm/hr for the Humic Gley Soil, 0.10 cm/hr for the heavy textured Dark Red Latosol, and 0.20 cm/hr for the medium textured Dark Red Latosol, at sites 2, 1 and 4 respectively (see Figure 15).

6.3 The relationship between infiltration and hydraulic conductivity.

Infiltration rates and hydraulic conductivities have been compared at different dry density levels. The infiltration rates, discussed in section 6.1, were determined on samples, 10 cm thick, with a water depth of 15 cm on top. Using a head difference of 25 cm between the top and the bottom of the sample, the pressure gradient through the sample was $25 \div 10 = 2.5$.

Using Darcy's law the infiltration rates can be transformed into a conductivity rate (k) in the following way:

$$Q = k.i.A$$

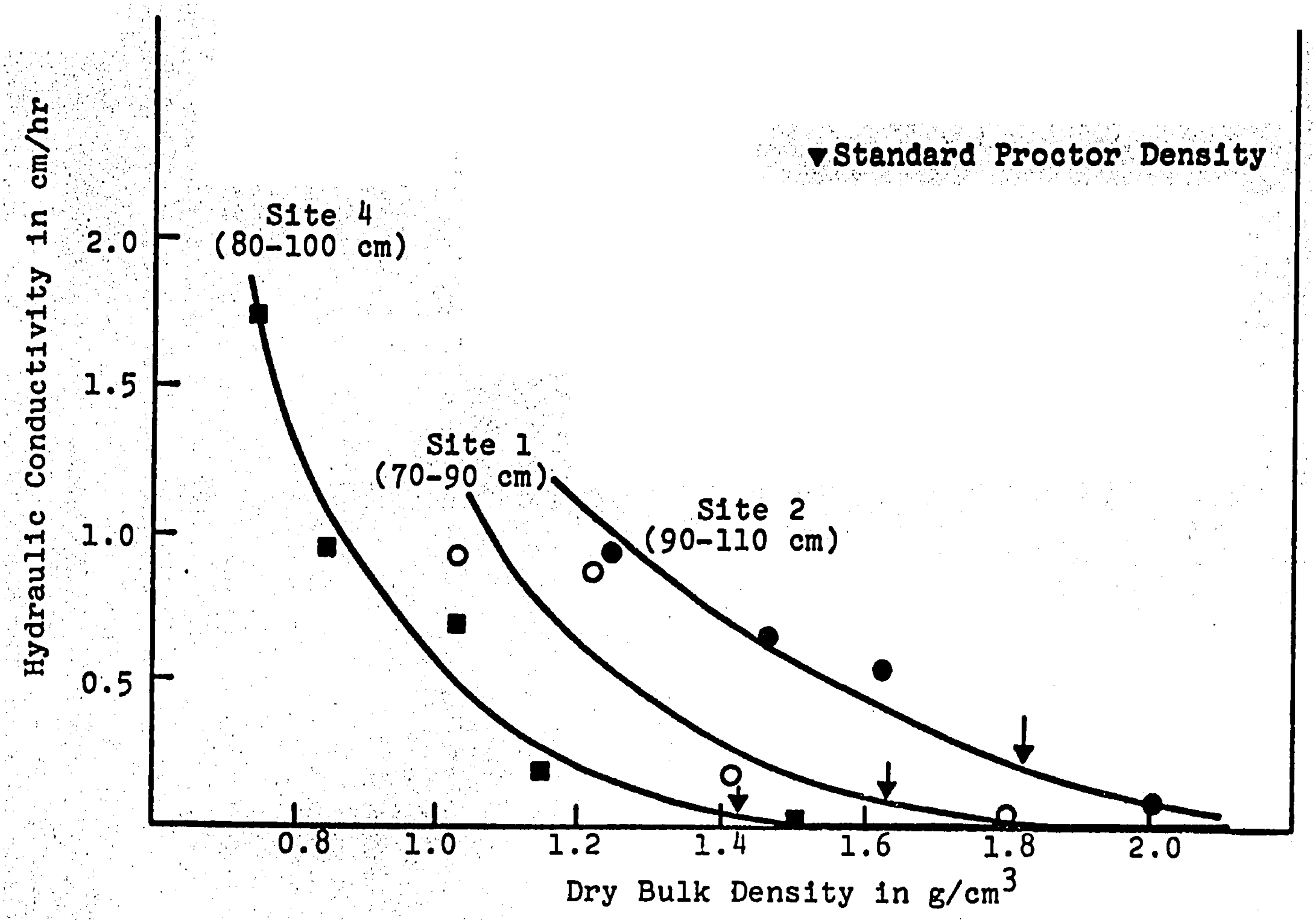


Figure 15: Relation between hydraulic conductivity and dry bulk density-Brasilia D.F.

or:

permeability k = infiltration rate ÷ 2.5

In Table 17 the permeability rates obtained by the two different methods are compared at various dry bulk density values.

Table 17: Comparison of dry bulk density and permeability, calculated by different methods - Brasilia D.F.

Dry density g/cm^3	Site 1		Site 2		Site 4	
	Inf.(k) cm/hr	Perm.(K) cm/hr	Inf.(k) cm/hr	Perm.(K) cm/hr	Inf.(k) cm/hr	Perm.(K) cm/hr
1.2	-	-	-	-	0.04	0.20
1.3	-	-	-	-	0.02	0.10
1.4	1.00	0.25	-	-	0.02	0.05
1.5	0.26	0.15	1.08	0.55	-	-
1.6	0.08	0.10	0.65	0.50	-	-
1.7	0.04	0.05	0.32	0.35	-	-
1.8	-	-	0.08	0.25	-	-

Both methods of measurements give low conductivities at densities approaching the densities obtained in the Proctor Compaction Test.

6.4 Seepage losses from farm ponds.

At a number of farm ponds in the Alexandre de Gusmao project, mostly coinciding with sampling sites, seepage losses were measured. Most of the ponds had been dug by bulldozer and no additional compaction had taken place. The seepage losses were measured with the ponds filled to maximum capacity. All inflow and outflow was stopped for a number of hours and the fall in water level was recorded. The results of the measurements are presented in Table 18.

Table 18: Measurements of seepage losses in farm ponds at the Alexandre de Gusmao project - Brasilia D.F.

Site nr.	Parcel nr.	Year of constr.	Seepage losses cm/hr*)	Remarks
6	2-197	1971	1.2	
7	3-300	1971	1.6	
	3-304	1974	0.0	Plastic lining
10	2-244	1974	0.7	
20	2-207	1972	0.2	Used as swimming pool

*) Ponds measured at full capacity.

Usually losses in farm ponds remain high, even 3 years after construction. The seepage losses were reduced considerable as a result of compaction and puddling through human activity. This is illustrated by the case of a farm pond being used as a swimming pool. In addition, in at least one case a plastic lining was used to reduce seepage. The susceptibility of the plastic to damage is unknown. The costs involved are relatively high.

The author decided to construct and compact a farm pond at optimum moisture content. The test was executed in cooperation with the management of the Alexandre de Gusmao project and one of the settlers. The pond is located at site 20, parcel no. 2-207. Soil characteristics are presented in Tables 9, 10 and 13, in this Chapter. The soil is a Dark Red Latosol, typical for the soils in the Federal District. The maximum dry bulk density at Proctor Compaction is 1.48 g/cm^3 at 27 per cent moisture. The dimensions of the bottom of the pond were 8.5 x 16 m. The maximum water depth is 1.30 m. The capacity is 220 m^3, at side slopes of 1 : 1. The pond was constructed by a hydraulic bucket loader. The dry soil was brought to its optimum moisture content with spraying equipment and mixed with a small rotovator. The soil then was tamped by hand in two layers of 10 cm each. The compaction tools consisted of 2 liter tins filled with concrete, with a stick in the center. A total of 20 man days was spent to compact the soil close to Proctor density. The costs of sealing the pond through compaction are about one tenth that of a plastic lining. The seepage losses were reduced.

7. Summary and conclusions.

Physical properties of typical soils with agricultural potential were determined for an evaluation of the soil as a construction material.

The location of the sample sites is indicated in Figure 2 of Chapter II. Characteristic soil properties are presented in Tables 9, 10 and 13 of Chapter V.

No correlation is found between soils and the geological formations from which those soils originated.

Most of the sample sites are on Dark Red Latosols, less on Red Yellow Latosols, and few on the Humic Gley Soils. After complete dispersion soils show a high percentage of clay sized particles. The per cent water dispersable clay is low, especially in the subsoil, indicating strong structural stability.

Specific gravities are high, especially for the Dark Red Latosols, caused by a high iron content.

Infiltration rates are extremely high, with an average of about 30 cm/hr for the Dark Red and the Red Yellow Latosols. The average for the Humic Gley Soils is 10 cm/hr. Characteristic infiltration curves are presented in Figure 6. These high infiltration rates can result in high percolation losses in gravity irrigation systems: in reservoirs, canals and on the field. Compaction of the soils is one of the methods that can be applied to reduce water losses. Compaction tests (Standard Proctor Compaction) revealed that the soils are easily compactable. The maximum dry bulk density of a Dark Red Latosol increased, through compaction, from 1.0 to 1.6 g/cm^3. This is an increase in density of 60 per cent over the original material. Clay percentage is negatively correlated to maximum bulk density. The optimum moisture percentage for compaction increases with the clay percentage.

Optimum compaction can be obtained at moisture levels of the soil close to field capacity. This characteristic endangers mechanical compaction of the surface soil of agricultural land after rains or irrigation, but is favorable for the compaction of irrigation canals and farm ponds.

The plasticity index (Atterberg) for the Dark Red and Red Yellow Latosols is low and ranges from 3 to 10 per cent. Relationships were found between plasticity indices and clay percentage.

The Unified Soil Classification System, evaluating engineering soil properties, and developed for the soils of the temperate regions does not appear to apply to the soils of the Federal District.

The degree of aggregate water stability of the Brazilian Oxisols is high, especially for the topsoils. A consequence of the high aggregate stability may be the high infiltration rates and low water holding capacities, reported for these soils (63).

Effective stress strength parameters: internal friction angle and cohesion intercept, were obtained from direct shear tests. Typical samples show high friction angles of around 40° and negligible cohesion intercepts. The low cohesion implies that the resistance to shear is derived from the friction between grains and the interlocking of grains (30). In this particular case the grains consist of small iron coated aggregates with a high water stability. The high friction angles indicate a high effective shear strength, and permits steep side slopes in earth structures, such as canals and dams.

Compaction tests combined with infiltration and permeability measurements reveal that the high basic infiltration rates and high initial hydraulic conductivities can be reduced by compaction. A high maximum dry bulk density corresponds to a low infiltration rate and hydraulic conductivity. These relationships are shown in Figures 14 and 15.

A feasable solution to reduce seepage losses in irrigation canals and farm ponds would be through compaction techniques at optimum moisture.

In the Alexandre de Gusmao project in the Federal District a farm pond was constructed and compacted with manual labor. The results of the test are favorable: seepage losses were reduced greatly. The costs involved are about one tenth of those of a plastic lining.

VI CONCLUSIONS

One third of the precipitation goes to deep percolation. This water is gradually released from the groundwater reservoir and subsequently discharged by the rivers and streams.

Part of the water is potentially available for irrigation. During the wet season abundant quantities of water are available. Minimum river flows are 5 liters per second per square kilometer at the end of the dry deason. With the creation of storage facilities this amount could be doubled and would be enough to irrigate perhaps 5 to 10 per cent of the Federal District.

Groundwater could become an important irrigation water source, especially at high elevations. Water from springs is readily available and can be used for irrigation to a minor areal extent.

Surface runoff impoundment does not seem to be a viable solution for irrigation water supply, especially in the promising agricultural areas of the Federal District.

The quality of the water is excellent for irrigation.

Seepage losses from canals and farm ponds can be markedly reduced by compaction alone. The costs of compaction are one tenth of the costs of the use of plastic lining.

The findings in this thesis can be extrapolated to a large area of the Central Plateau. Local differences must always be taken into account.

VII RECOMMENDED FUTURE RESEARCH

Some important aspects of future water management research are:

- To study and compare various water storage systems.
- To determine the ground water potential for irrigation. Deep well data are available. Additional data could be collected from geo-electrical surveys.
- To study and compare different irrigation systems.

These subjects should be studied in combination with the agricultural and socio-economical aspects involved. Inter-disciplinary projects could be a satisfactory means of future research.

GLOSSARY

AASHO	American Association of State Highway Officials.
ACER-DF	Associação de Crédito e Assistência Rural; the association in charge of credit and rural extension, Brasilia D.F.
AIA	American International Association for Economic and Social Development.
ASTM	American Society for Testing and Materials.
BSB	Bombas Submergidas Brasília; a Brazilian private firm, constructing deep wells.
CAESB	Companhia de Água e Esgotos de Brasília; the water and sewage company of Brasilia.
CODEPLAN	Companhia do Desenvolvimento do Planalto Central; the company responsible for the development of the Central Plateau of Brazil.
CONTAP	Conselho de Cooperação Técnica da Aliança para o Progresso; the council for technical cooperation of the alliance of progress.
CPF	Centro de Pesquisas Florestais; the centre for silvicultural research.
DER-DF	Departamento de Estradas de Rodagem; the roads department of the Federal District.
ECEPLAN	Escritório Central de Planejamento e Controle; the bureau for planning and control.
EEB	Estação Experimental de Brasília; the agricultural experimental station of Brasilia, near Planaltina.
EMBRAPA	Emprêsa Brasileira de Pesquisa Agropecuária; the Brazilian institute for agricultural research.
EPFS	Equipe de Pedologia e Fertilidade do Solo; the soil and fertility institute.
ETAS/GEOS	Private Brazilian engineering firm.
GEOTECNICA	Private Brazilian engineering consultants.

ILACO	International Land development Consultants; a Dutch private firm engaged in agricultural development, mainly in the "third world".
INCRA	Instituto Nacional de Colonização e Reforma Agrária; the Brazilian national land reform institute.
MA	Ministério da Agricultura; the Brazilian Ministry of Agriculture.
NOVACAP	Companhia Urbanizadora da Nova Capital do Brasil; the company responsible for the development of the new capital of Brazil.
PLANIDRO	Hydraulic and sanitary consultants; a private Brazilian firm.
PROSPEC	Levantamentos, Prospeções e Aerofotogrametria S.A.; a Brazilian engineering firm.
SCS	Soil Conservation Service of the USDA.
SEITEC	Private Brazilian agro-industrial planning company.
USAID	United States Agency for International Development.
USDA	United States Department of Agriculture.

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