AN ASSESSMENT OF THE COMPACTION SUSCEPTIBILITY OF FOREST SOIL IN OWO LOCAL GOVERNMENT; ONDO STATE, NIGERIA

BY

MALUMI, BARNABAS OMOLERE
MAT. NO/AGE/95/6933

SUBMITTED TO SCHOOL OF ENGINEERING AND ENGINEERING TECHNOLOGY IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF MASTER OF ENGINEERING (M.ENG) DEGREE

IN

AGRICULTURAL ENGINEERING
FEDERAL UNIVERSITY OF TECHNOLOGY, AKURE
ONDO STATE, NIGERIA

JULY, 2001

CERTIFICATION

This is to certify that this project was carried out by **MALUMI, Barnabas Omolere (AGE/95/6933)** as a Master of Engineering (M.Eng) Degree student in the Department of Agricultural Engineering, School of Engineering and Engineering Technology, Federal University of Technology, Akure (FUTA).

Prof.A.Y Sangodoyin
Project Supervisor
Agricultural Engineering Dept.
University of Ibadan
Ibadan – Nigeria

Date: JUNE 18, 2002

Dr. A.A Olufayo
Project Supervisor
Agricultural Engineering
Dept. Federal University
of Technology Akure

Date: 20TH JUNE 2002.

DEDICATION

This project is dedicated to the glory of God who granted me the strength and ability to carry out this research work. Moreover, this report is also dedicated to my dearly beloved father, Late Mr. N.A Malumi, and my mother, Mrs G.I. Malumi, for their love, patience and interest to see that I attain higher educational level in life.

ACKNOWLEDGEMENT

I thank God Almighty for His protection, guidance and love which He bestowed on me during this study. My thanks also go to my able supervisor, Dr. A.Y Sangodoyin, for his thorough and critical supervision and advice which enable the study to be properly executed and documented to the required standard.

I have deep and profound indebtedness to Engr. Manuwa, S.I for his Godly advice during the project. This also contributed to the success of the study. Others to be acknowledged are: Dr. A.A Olufayo and Engr. Alatise for their assistance and advice.

Persons, institutes and organizations whose materials or facilities were cited or used in the conduct of this study are acknowledged.

Also, my profound gratitude goes to my classmates, Mr. Johnson Fasinmirin, Mr. Kingsley Oni, Mr. Adeosun and Mrs Adegbemiro for their moral support, advice and hospitality.

Finally, I thank my wife, Mrs Bisi Malumi, and children, for their understanding and unquantifiable love.

ABSTRACT

This study was aimed at characterising and assessing the compaction susceptibilities of forest soils in Owo Local Government of Ondo State Nigeria. It was conducted in the perenial plantation of the study area. Forty five (45) samples were collected from fifteen (15) sites. Many experiments were carried out in the laboratory to determine the moisture content, bulk densities, porosities, soil texture, chemical properties and soil compaction. Soil temperature was the only data directly measured or observed on the field.

The study revealed that moisture content of soil in the Local Government varies from site to site. Emule forest soil has highest value of moisture content on average. Isuada and Ilale forest soil have the highest and the lowest soil temperature respectively.

Bulk density derived from samples collected directly from the field were plotted against the soil depth which revealed some useful information. The compaction test results are useful in advising foresters on the risk of soil compaction under diverse water regimes and soil conditions. The information presented in this study can be used as a guide on the relative importance of applied pressure and water content on the compaction process.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE

1.0. INTRODUCTION

Advancement in technology makes it imperative that more machines/vehicles are used both in crop production and in conveying logs from the forests. In a fully mechanised agricultural production system, different types of agricultural machinery are used for different operation. These include soil tillage, fertilizer application, planting, weeding, application of herbicides, pesticides and ameliorating chemicals, moving portable irrigation equipment, harvesting and moving primary processing equipment. The "unknown" traffic set up by these operations has been shown to cause soil deterioration, usually referred to as soil compaction (Brannack and Dexter, 1979, Soene *et al.* 1981, Hardas and Wolf, 1984). Such soil deterioration has been quantified with various parameters including changes in soil physical and hydraulic properties (Soene *et al.* 1981; IITA, 1984). These changes have been shown to cause reduced germination of crops, retarded root development and reduced crop yields for many soil types and condition. In developed countries, these problems are ascribed to the use of large and heavier agricultural machinery and heavy duty lorries. In Nigeria and other developing countries of the tropics, the mechanisation of agriculture is increasing. Although the intensity of traffic and weight of vehicles involves may be less, the low structural stability of tropical soils and the high erosivity of rainfall may make soil compaction problem more serious. Only few studies have been reported from this zone on soil compaction (IITA, 1984).

The development of large agricultural machinery in the last four decades has given rise to the question of maximum acceptable mechanical compressibility or trafficability of arable soils (Horn, 1993). Consequently, many studies have been carried out to predict the compressibility of arable soils and the effect on plant growth (Larson *et al.*, 1980). Soil compressibility is defined as the ease with which soil decreases in volume when subjected to a mechanical load (Gupta and Allmaras, 1987). Consolidation of saturated soils involves the reduction of soil volume by the expulsion of water from the soil pores. Compaction of unsaturated soils entails the reduction of soil volume by the expulsion of air from the soil pores. Soil compaction is more usual in agricultural soils since they are normally worked at unsaturated states (Gupta and Allmaras, 1987). Frankly speaking, the most common cause of agricultural soil compaction are trampling by livestock and pressures imposed by vehicles or tillage equipment (Bradford and Gupta, 1986).

Some researchers (Soane, 1975; Raghana *et al.* . 1990) used the fast rate (Proctor) stress loading method to study soil compaction, others (Larson *et al.*, 1980; Saini *et al.* 1984) used the slow rate loading technique of compressive machines. The proctor test gives the maximum soil density, the use of compression machines helps to define more clearly the amount of compression (volume reduction) of soils of given masses as well as the rate of increase of bulk density with stress (compression index).

There is the need to classify the forest soils in a given area especially those that have been abandoned for a long time. A step towards opening up new area for intensive farming could be a detailed characterization and mapping of the soil of the given area (Esu, 1987). This study had the following objectives:-

(1) To characterize the forest soils in Owo Local Government Area Ondo State, Nigeria, using texture, structure and other physical and chemical parameters.
(2) To assess compaction susceptibilities of the soils.

CHAPTER TWO

2.0 REVIEW OF PREVIOUS WORK

2.1. THE SCIENCE OF SOIL

To know the soil of a particular location or of a larger region is synonymous to an understanding of the diverse processes taking place in it and its interactions with other parts of the environmental system. Soil science is the foundation for agricultural productivity. It is also the key to sustainable development. Yet, soil science is a fairly young discipline, both with respect to the recognition of soil as an independent body in nature and to the applied aspects as surficial materials supporting plant growth and protecting land forms (Warkentin, 1992).

Despite the evident successes of soil science in increasing agricultural productivity, serious questions about its place and function have surfaced in recent years. A common trend in several articles in the special issue of soil science that celebrated its first 75 years of publication was the need to remove the public image of soil science and its standing in scientific community (Gardner, 1993, Greenland, 1991;Simonson, 1991). Gardner called for a re-direction of research in soil science in the US so as to improve image and to reverse the devaluation. Other appeals echoed similar sentiments (Tinker, 1985; Miller, 1993). The central point of this discourse is the recognition that "the paradigm has shifted", that improvement of soil productivity should no longer be the main focus of research in soil science. Some have called for more basic and earth science oriented research (Nielsen, 1987; Notohadiprowiro, 1993; Yaalon, 1993). Others have stressed mainly the global and regional environmental aspect or called for a re-orientation and intensification of soil survey to a more functional soil and landscape evolution based approach (Arnold, 1988; Jacob and Nordit; 1991).

2.2. SOIL COMPACTIBILITY

The passage of wheels of agricultural vehicles over soils is a common cause of soil compaction. Wheel traffic vehicle loads ranging from 9 to 18 Mg per single axle caused compaction in 20 – 30 cm depth of clay loam soils when the sub soil was near witting point. Similar loads increased bulk density in the 30 – 50 cm depth when the sub soil moisture was near field capacity (Voorhees, *et al.* 1986). The penetrometer is a common instrument for assessing compaction, mechanical impedance, or soil strength (Gill, 1968; Soene *et al.* 1981; Gerard *et al.,* 1982). Soil penetration resistance (SPR) readings can give an indication of compacted layer (pans) and relative resistance of root penetration (Volk, 1953). Soil penetrometer resistance values between 2.1 and 2.8 MPa impeded cotton root growth (Taylor, 1966). In Florida, SPR values greater than 1.7MPa impeded penetration of maize roots in coarse-textured soils (Fiskell *et al,* 1986). Generally, soil penetration resistance decreases as soil moisture content increases. Therefore, soil strength may fluctuate with soil water during the growing season (Rhoads and Wright, 1981; Robertson, 1984).

Compaction of tropical soils drastically reduces infiltration rate and consequently encourages runoff losses (Lal, 1979). In addition, even the little quantity of water that enters the soil is so tightly held in the resulting micropores that plant roots find it difficult to extract. A loose soil, on the other hand permits infiltration but the water may be lost to the plant through rapid drainage. In either case (compact soil or loose soil) plants may suffer moisture stress and reduced growth even though the right amount of water may be applied. This situation results in poor crop water use efficiency. Apart from this indirect effect, compaction also has a direct effect on plant growth by mechanically impending root growth and development (Taylor, 1966). This effect, however, can be amelioriated by maintaining a suitable soil moisture regime (Taylor *et al.* 1964; Taylor and Rattiff, 1969). A thorough understanding of the interactive effects of soil compaction and soil moisture regime is essential to improve crop water use efficiency.

More attention has been focussed on the effects of moisture stress on crop yield in Nigerian soils (Bababola, 1980; Fawusi and Agboola, 1980; Mbagwu and Lal, 1985) than those on soil compaction or the interaction between moisture stress and compaction. Information on the latter aspect is therefore very scanty and tends to show that the effects of both parameter are highly influenced by the soil type and crop use (Maurya and Lal, 1979; Mbagwu and Lal, 1985).

Sandy and Sandy loam soils are particularly susceptible to compaction of their upper layers when tilled. Compaction affects the quality of the soil because it reduces porosity, and hence permeability to both water and air (Kooistra, 1984; Bouma and Kooistra, 1987). Compacted layers occur after the application of low pressures and reappear quickly after digging of the plough pan (Soene, *et* *al.* 1981; Kooistra, 1987). These soils are generally considered to be susceptible to compaction owing to low organic matter and clay contents (Stengel and Douglas, 1984). Tests are used to analyse the response to compaction by determining the variation in bulk density at different pressures, water contents and structural state (Guerif, 1982).

Soene *et al.* (1981) have discussed the various parameters used to characterise soil compaction status. Many parameters frequently display a greater variability between soils than between non compacted and compacted variants of small soil. Hence, to permit comparison between different soil types, Soene *et al.* (1981) recommended using relative term e.g. by expressing the absolute values of, for example, dry bulk density, void ratio or pore volume, as a ratio of that in a reference state defined by some particular method of packing. Thus Pidgeon and Soene (1977) used, as an index of compaction status, the ratio of dry bulk density to the proctor maximum dry bulk density, referred to as relative compaction. O'Connnell (1975), reviewing data for critical bulk densities at which root growth is restricted, found a correspondence with the calculated bulk densities at 10% air-filled porosity and at a moisture content equal to their field capacity for soils in a moist state, and to approximately 90% of the proctor maximum dry bulk density for soils in a dry state. Thus, the ratio of dry bulk density to the calculated bulk density corresponding to a 10% air filled porosity and field capacity moisture content, may also be a useful index of soil compaction status. From a practical view point, soil compaction status becomes particularly important when root growth is restricted, and since moisture content has a marked influence on root elongation rates through its interaction with bulk density (Maurya and Lal, 1979). Moisture contents that are typical of field conditions should be used in the evaluation of soil compaction status. This is particularly important for imperfectly and poorly drained soils.

Soil compaction susceptibility is here defined as the vulnerability of a soil to compaction which depends only on relatively permanent factors such as soil properties and climate. This definition is analogous to that of erosion susceptibility as defined by Beek *et al.* (1965), and as such is an inherent characteristic of soils and their physical environment and is independent of management practices. This definition is different from that of Voorhees *et al* (1986) which suggested that soil compaction susceptibility can be evaluated from soil compactibility and compaction probability. The later is determined from long term weather or soil moisture data, machinery characteristics and management practices. There have been many studies on soil compactibility, that is, the quantitative prediction of compaction from applied stresses through modelling approaches (Blackwell and Soene, 1981; Gupta and Larson, 1982; Smith, 1995). Validation studies on these models have been very limited (Soene 1985). In contrast, the qualitative assessment and classification of soil compaction susceptibility for use in land evaluation studies have been largely ignored (Mc Cormack, 1987), despite the potential value of such information in tillage. McCormack (1987) suggested using information on the types of clay and organic matter contents, soil wetness during periods when cultivation is needed and frost action in the evaluation of compaction susceptibility.

Many research on the effects of tillage on soil compaction have dealt with structural porosity, that is, the pores related to biological activities and the arrangement of clods and cracks (Childs, 1969; Monnier, 1973; Stengel and Douglas, 1984; Kooistra, 1984). Textural porosity which is related to the fabric of individual soil particles, can also be affected by tillage of sandy, sandy loam and loamy-sand soils (Jaegger, 1983) but its variation for other soils under tillage has been debated on several occasions. Clay loam soil is susceptible to porosity variation when compacted, and demonstrated the difficulty in analysing the variation in textural porosity using sample collected in the field.

2.3. SOIL CHARACTERISTICS

Field definition have been devised (Soil Survey Staff, 1975) to relate the basic soil textural classes as felt with the fingers in the field to the proportions graphed on the textural triangle. Sand is loose and single-grained. The individual sand grain can be easily seen or felt. Loam is a soil having apparent relative even mixture of different grades of sand, silt and clay. Silt Loam (Soil Survey Staff, 1975) is a soil having amount of fine grades of sand and only a small amount of clay, with over 50% silt-size particles. Clay (Soil Survey Staff, 1975) is an extra-fine textured soil that usually form very hard humus or clods when dry; it is quite plastic and usually sticky when wet. From these definitions, other soil textures can be extrapolated from the textural triangle by relating the "feel" of the soils in the field to the textural triangle.

Loamy sand (Soil Survey Staff, 1975) which has about 85 – 90% sand, and the percentages of silt plus 1½ time percent of clay is not less than 15, sandy clay loam has 20 – 35 percent clay, less than 28% silt and 45% more sand. Sandy clay has 35% or more clay and 45% or more sand. Silt clay has 40% or more clay, and 40% or more silt (Soil Survey Staff, 1975). Measurements of soil variability are of tremendous help in understanding soils of each plot for each year, yields can then be related to each soil properties. Fly and Romine (1964) published a procedure for analyses of such experiments and the soil influences. Often, soil differences induce wider varieties yields than different treatments.

Beckett and Webster (1977) had published a review of many publications on soil variability and also had written an excellent comprehensive book on quantitative and numerical methods in soil classification and survey. Numerous authors (Pomerening and Knox, 1962; Powel and Springer, 1958) have investigated soil differences within Map Units. Smith (1982) has successfully classified soil in the field as shown in Table 1 below.

Table 1: **SOIL TYPES AND THEIR CHARACTERISTICS**

Soil types	Characteristics
Sand	Individual particles visible, exhibits dilatancy, easy to crumble when dry feels gritty, no plasticity
Clay	No particles visible, no dilatancy, hard to crumble when dry, feels smooth, plasticity.
Silt	Some particle is visible, exhibits dilatancy, easy to crumb when dry, feels rough, some plasticity.

2.4. EFFECTS OF SOIL PHYSICAL AND CHEMICAL PROPERTIES ON SOIL COMPACTION AND WEATHERING

Among the important soil properties reported to influence clay aggregation are organic matter and sesquioxides. Soil Survey Staff (1975) observed that in strong-weathered soils of the humid tropics, clay dispersion is not always complete if the aggregating effects of iron, aluminium, and organic matter are not removed. Ahn (1979) noted that many tropical soils, when dispersed in the laboratory reveal clay contents of more than 40%. Some authors working on the alfisoils of South Western Nigeria confirmed that organic matter has an effect on clay aggregation; hence its removal is necessary to achieve complete dispersion. They attribute increases in the clay values of pretreated soil sample to the removal of cemmenting agents such as organic matter and sesquioxides, which bind soil aggregates together.

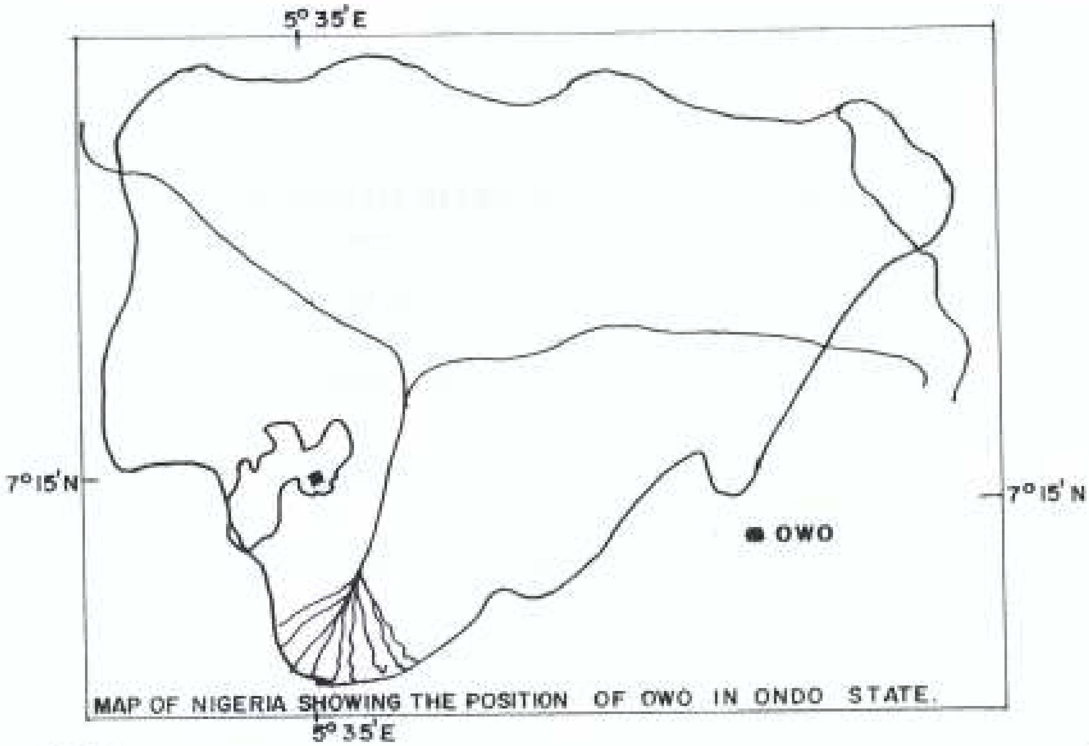
Many studies (Childs, 1969; Monnier, 1993; Kooistra, 1984) on the effects of tillage on soil compaction has dealt with structural porosity, that is the pores related to biological activities. However, its variation among soils under tillage has been debated on several occasions. Progressions to more rapid weathering coupled with stronger leaching potentials result to reduced Potassium (K) supplies in the soil of humid grassland and forest particularly on sandy soils. Intensive cropping on these lands usually requires input of Potassium fertilizers. The main minerals of Phosphorous (P) in soil is a Calcium (Ca) – Phospate minerals, appetite (Ca_2, PO_4 F_2) (Jackson, 1964). With continued weathering and the development of acidity, Progressively more phosphorous (P) becomes associated with aluminium (Al) and iron (Fe). In time the phosphate ions are present within the lattices of hydrous Fe and Al oxides; or are coated by them. Most grass land soils have about one half of their phosphorous associated with the relatively stable organic mater. The main sources of available phosphorous in the soils are from moderately inorganic forms, such as Phosphorous absorbed to amosphous minerals of Al and Fe and the mineralisation of organic P (Tiessen, 1984). A comparison of the amount and relative proportions of P fractions in the upper horizons of several mollisol soil along an environmental gradient yield information on weather processes (Westin and Buntley, 1967).

CHAPTER THREE

3.0. RESEARCH METHODOLOGY

3.1. THE STUDY AREA

Owo, the headquarter of Owo Local Government, is 48 kilometres east of Akure, the capital of Ondo state, Nigeria and 400 km north-east of Lagos. The town spreads over an area of about 12 km^2. The population of Owo and its environ, according to Nigeria census of 1991, is 160,286 and it is the fourth most thickly populated town in Ondo state. The town lies on latitude 7° 15′ N and longitude 5° 35′ E. It is about 150 metres above sea level and the lands towards Ikare are hilly. Owo Local Government enjoys abundant rainfall of over 1,500 mm annually and the South-Westerly winds blows most of the year. From the months of December to February, the cooler continental winds from the interior of the continent of Africa prevail. Fig. 1 shows map of Owo Local Government. Fifteen major sites were identified in the Local Government and are presented in Table 2.



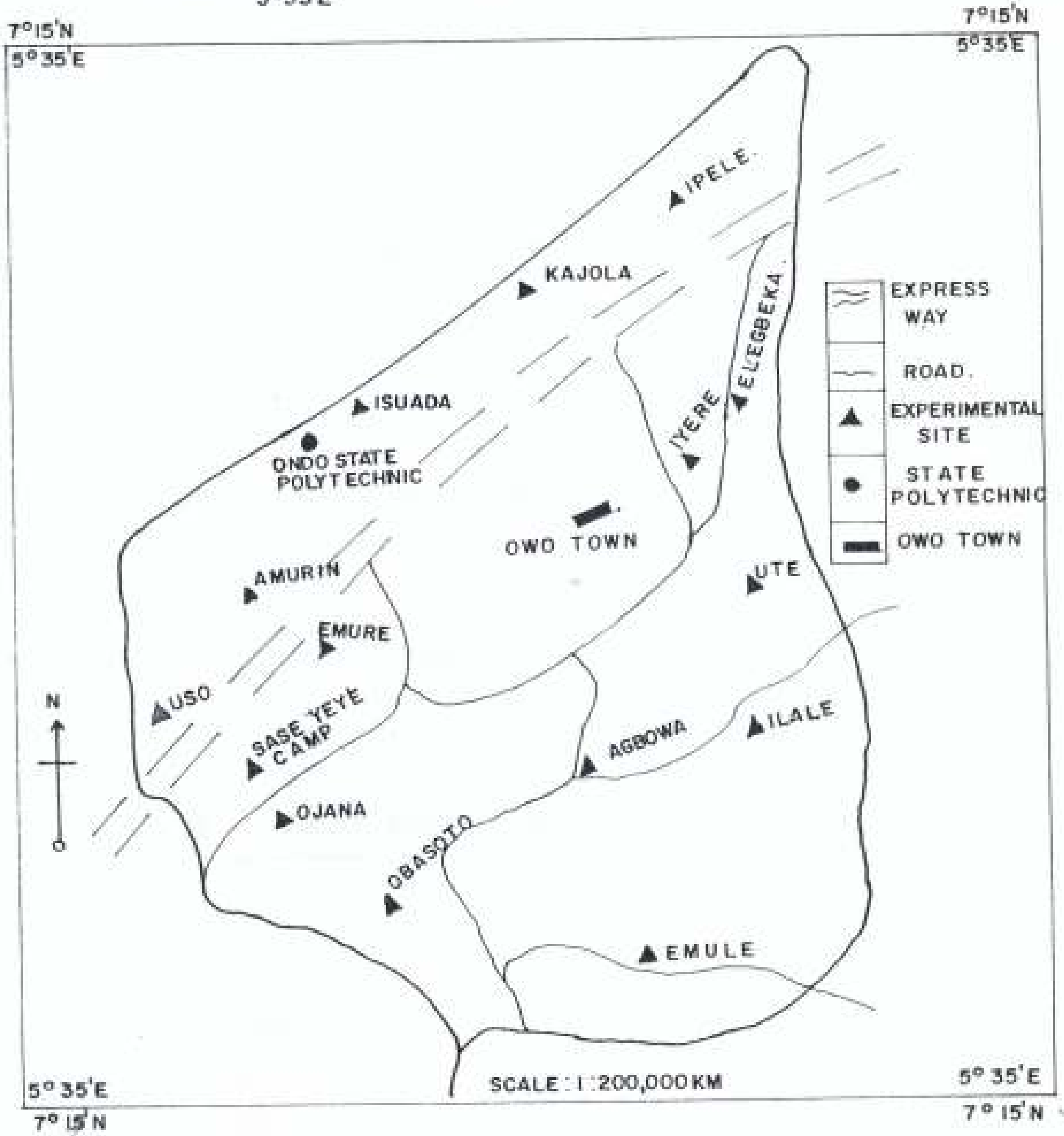


Fig I MAP OF OWO LOCAL GOVERNMENT.

Table 2: **LOCATION OF SITES AND THEIR SYMBOLS**

S/No	LOCATION OF SITE	SYMBOLS
1	UTE FOREST SOIL	U
2	IPELE FOREST SOIL	I
3	OBASOTO FOREST SOIL	0
4	USO FOREST SOIL	US
5	SASE YEYE FOREST SOIL	S
6	ISUADA FOREST SOIL	IS
7	AGBOWA IPELE FOREST SOIL	A
8	EMURE IPELE FOREST SOIL	E
9	AMURI FOREST SOIL	AM
10	IYERE IPELE FOREST SOIL	IY
11	KAJOLA FOREST SOIL	K
12	OJANA FOREST SOIL	OJ
13	ILALE FOREST SOIL	IL
14	ELEGBEKA FOREST SOIL	EL
15	EMULE FOREST SOIL	EM

3.2. SOIL SAMPLE COLLECTION

Forty five (45) soil samples were collected from fifteen (15) sites in the forest of Owo Local Government. In each of the site location, three samples were collected. The samples were collected mainly from the perennial plantation region of the study area. The soil samples were collected using soil auger at different soil depths. The sample collected were kept in a nylon and were transported to the laboratory for determination of moisture contents and other analyses.

3.3 MEASUREMENTS

3.3.1. MOISTURE CONTENT

Moisture content was determined at the three depths (10,20 and 30 cm) in each location by gravimetric method. The sample for the determination of the moisture content was collected during the wet season in the month of May 2000.

3.3.2 SOIL TEMPERATURE

Soil temperature was measured using mercury in glass thermometer at 10,20,30 cm soil depths. Three readings were taken randomly at each soil level and the average was recorded as the soil temperature.

3.3.3. BULK DENSITY

The determination of the bulk density was carried out using a core of known diameter and height to collect the samples and the volume of the soil was recorded applying the formula $\pi d^2 h/4$

Where d = Diameter

h = Height

3.4 COMPACTION TEST

The laboratory compaction test was carried out using universal compaction test machine. Soil samples were air dried and wetted to a range of water contents between saturation and wilting point. At a particular water content the samples were placed in steel cylinder 10.10 cm in diameter and 10.10 cm high. The cylinder was then placed on a 5.0 mm perforated metal base before the soil was added. The cylinder was gently tapped to allow settling of the soil particles.

The samples in the cylinder were then subjected to applied pressure of 100 kPa, 200 kPa, 300 kPa, 400 kPa, 500 kPa, 600 kPa, 700 kPa, 800 kPa and 900 kPa respectively. The pressure was applied through an hydraulic press consisting of an hydraulic ram connect to a piston. The pressure applied was maintained for a few seconds and then released. The samples were allowed to "rebound" before final heights were measured. Water and air could escape around the piston and through the perforated base plate. Weighing balance was used in measuring the weight of the cylinder and the soil before compaction and after compaction.

3.5. ANALYTICAL METHODS

3.5.1 SOIL TEXTURE

Soil samples were pretreated with hydrogen peroxide and the size fractions were determined by the pipette method (Day, 1965) after treatment with Calgon (Sodium hexemetaphosphate and sodium carbonate) and ultra sound. The thermometer reading were 27°C and 28°C for the first and second reading of the hydrometer. The room temperature was 20°C. The values of A and B in equations 1 and 2 represent the first and the second readings of the hydrometer. The formula below was used for the determination of silt, clay and sand.

$$\% \text{ silt} + \text{clay} = A + \frac{(0.36 \times 7)}{50} \times 100 = X \ldots\ldots (1)$$

$$\% \text{ clay} = B + \frac{(0.36 \times 8)}{50} \times 100 = Y \ldots\ldots (2)$$

$$\text{Silt} = X - Y$$

$$\text{Sand} = 100 - x$$

3.5.2. ORGANIC CARBON

Organic carbon was determined by wet-oxidation using the Walkley-Black Method (Walkley, 1974).

3.5.3. EXCHANGEABLE BASES

Exchangeable bases (Ca, Mg, N, K, and Na) were determined by ion exchange using 1m. PH7 ammonium acetate extract and using atomic absorption (Ca and Mg) and flame emission (K and Na) spectrophotometry.

3.6. TREATMENT OF DATA

The results obtained were subjected to appropriate statistical analyses such as ANOVA, regression and correlation.

CHAPTER FOUR

4.0. RESULT AND DISCUSSION

4.1. RELATIONSHIP BETWEEN SOIL PHYSICAL PROPERTIES

Figures 4 – 6 shows that the bulk densities at various depths vary from site to site. Observation shows that the Elegbeka, Ilale, Isuada, Kajola, Obasoto, Agbowa and Uso forest soils have parabolic curves leftward.

As the soil depth increases, the bulk density decreases especially for Obasoto, Uso and Agbowa forest soils. At soil depth 20 cm to 30 cm, the bulk density begins to decrease for Isuada, Kajola, Elegbeka and Ilale forest soils. Ute, Ojana, Iyere, Ipele, Sase Yeye, Emure forest soils have parabolic curves rightward and as the soil depth increases, the bulk density increases. The Emule forest soil presents a near linear relationship between soil depth and bulk density. Bulk density generally is higher in lower profile layers. This is due to the lower content of the organic matter, less aggregation, less root penetration and compaction caused by the weight of the overlying layers (Nyle and Brady, 1990). The system of crop and soil management employed on a given soil also influences it bulk density. Removal of trees or brushes greatly increases the surface soil bulk density. The addition of crop residues or farm manure in large amount tends to lower bulk density of surface soils, as does a blues grass sod (Nyle and Brady, 1990). Some authors have carried out some investigation that the land clearing (clear cut) has effect on the bulk density of soil at different depth. In exceptional cases, when the organic matter is high the bulk density

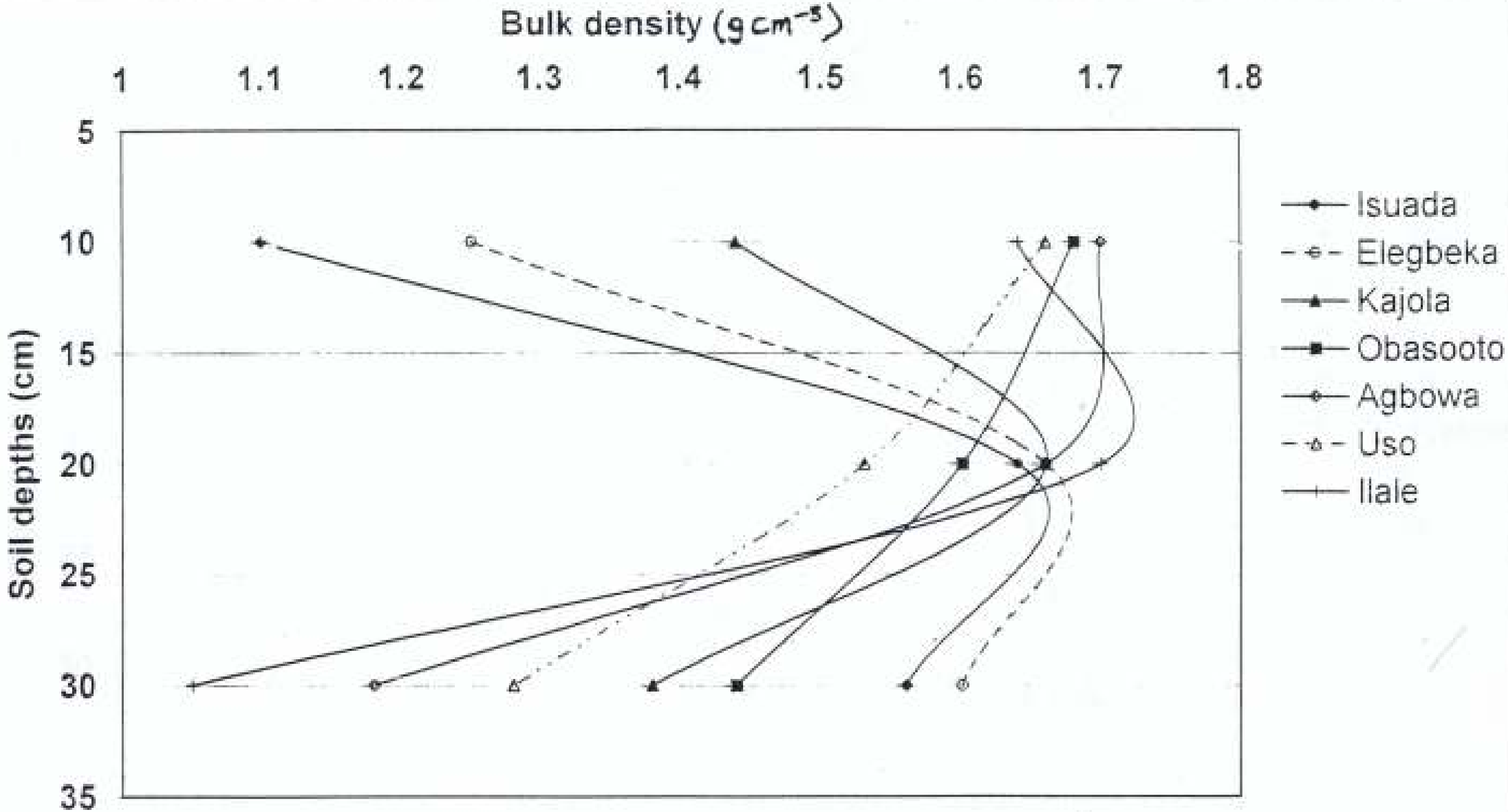


Fig 4 Bulk density at different soil depths of the experimental site

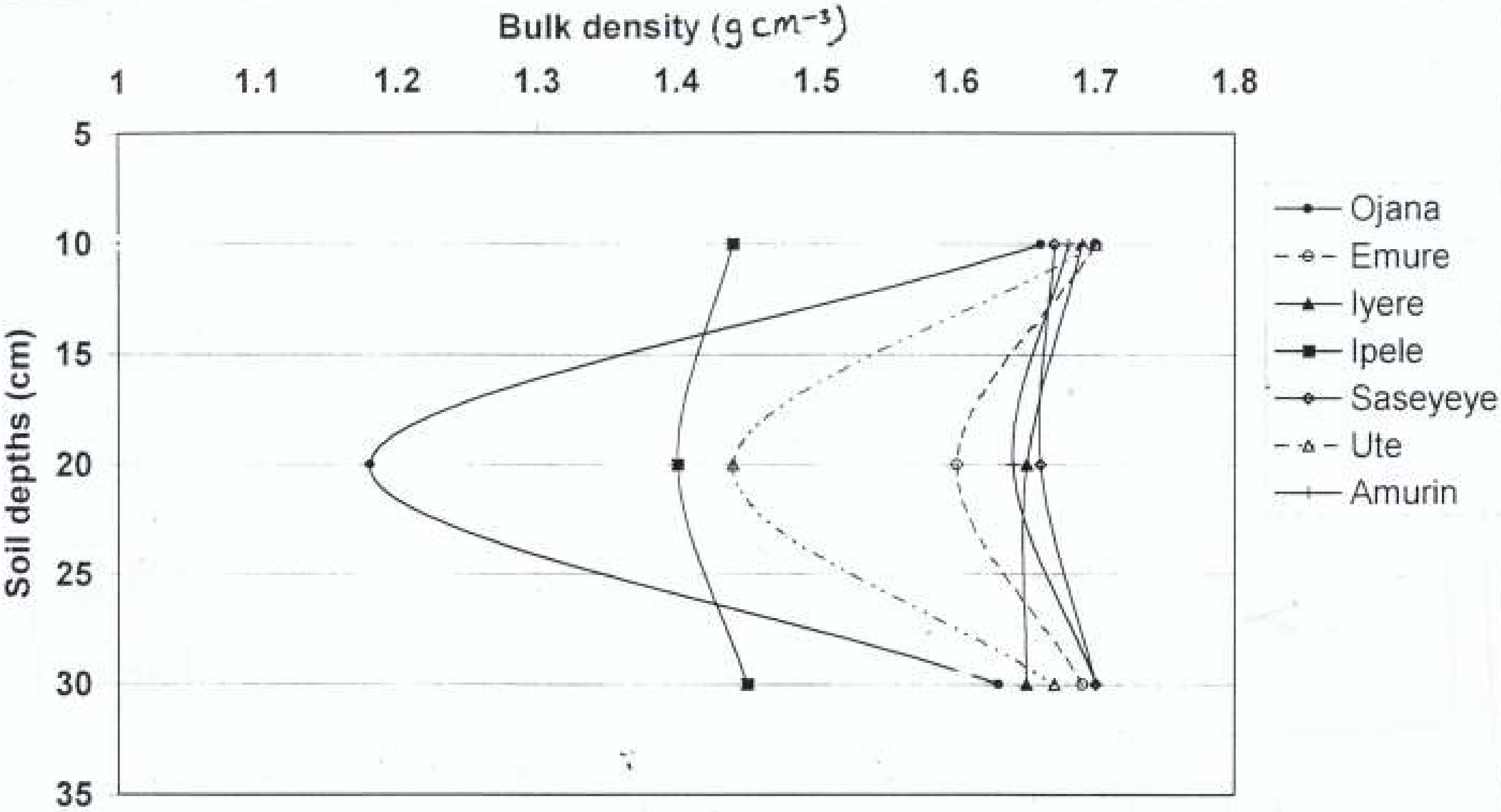


Fig 5 Bulk density at different soil depths of the experimental site

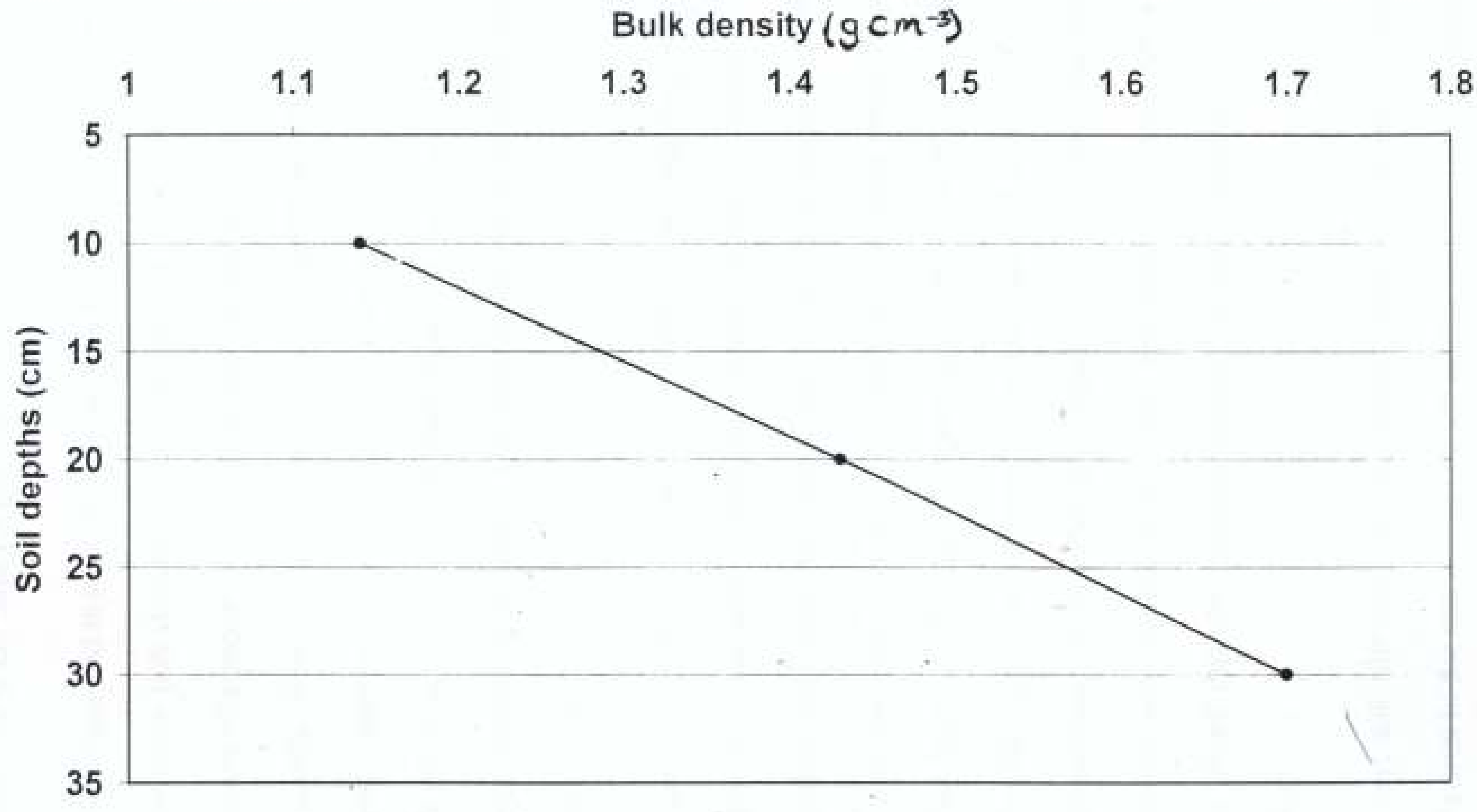


Fig. 6 Bulk density at different soil depths at Emule site

will be low and vice versa. Generally, in most soils the values of the bulk density ranges between 1 gm/ cm^3 and 1.7 gm/ cm^3 (Abitoye, 1997).

According to Nyle and Brady (1990), soils with high proportion of pore space to solids have lower bulk densities than those that are more compact and have less pores space. Consequently, any factor that influences soil spore space will affect bulk density. Fine textured surface soils such as silt loam clays and clay loams generally have lower bulk densities than sandy soils. It was observed from Table 4 that Emule forest soil had the highest and the lowest values of pore space and bulk density respectively. This agreed with the explanation given by Nyle and Brady (1990).

The particles of the fine textured soils tend to be organized in porous grains or granules especially if adequate organic matter is present. This condition assures high total pore space and a low bulk density. The bulk densities of clay, clay loam, and silt loam surface soils normally range from 1.00 mg/m^3 to as high as 1.60 mg/m^3, depending on their conditions. A variation from 1.20 to 1.80 mg/m^3 may be found in sand and sandy loams. Very compact top subsoils may have bulk densities of 2 mg/m^3 or even greater. The graph of moisture content was plotted against the soil depth as shown in fig. 2. Observations shows that the moisture content increases generally from depth 10cm to 30cm.

Emule forest soil site (EM) has the highest value of moisture content on average compared to the rest of the soil site locations. The moisture content of

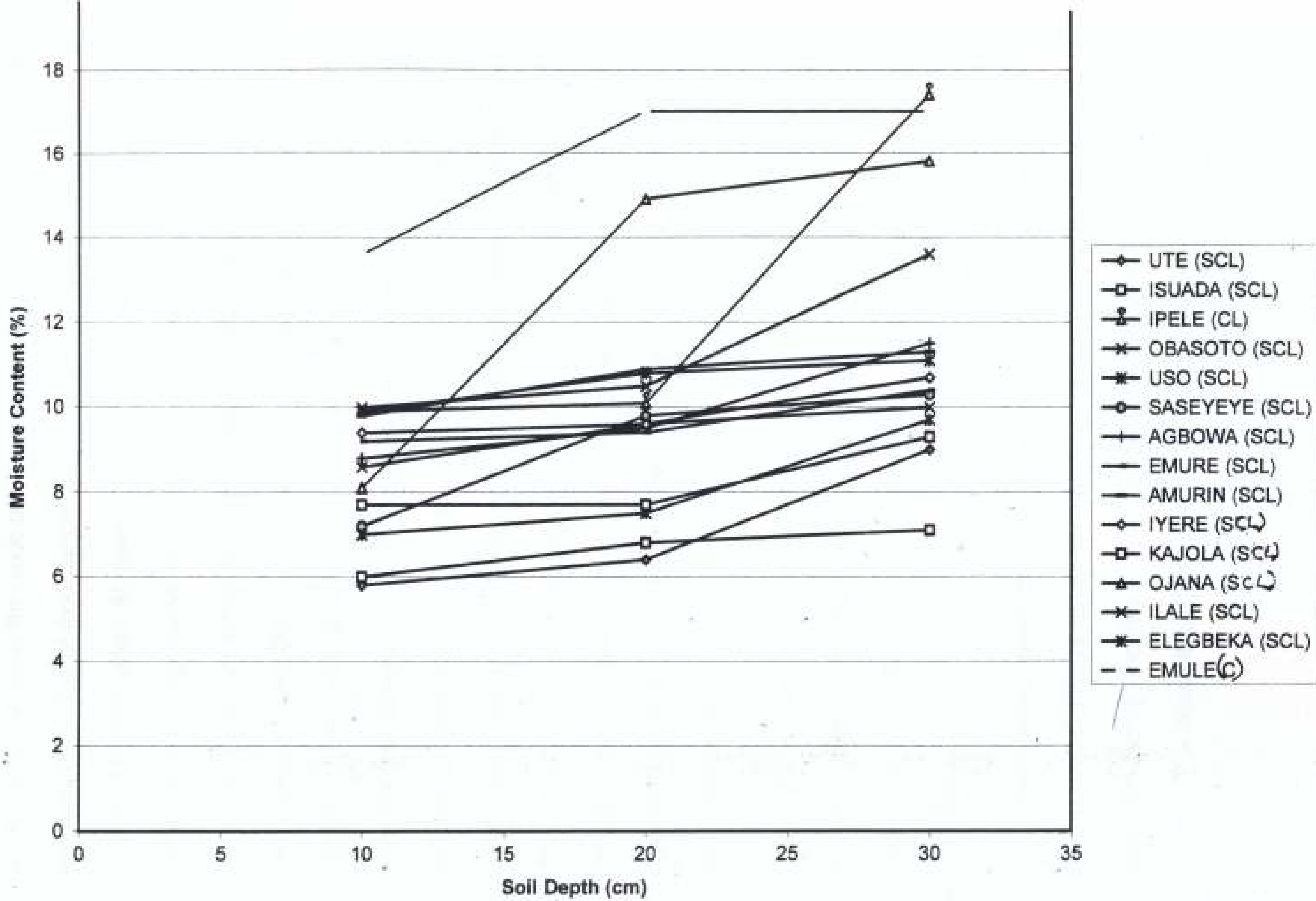


Fig. 2. Moisture Content versus the Soil Depth of Individual Experimental Site

Emule forest soil site at the range of 10 cm to 30 cm is 15.9%. This shows that the higher the value of moisture content, the lower the bulk density as revealed in Table 4 in most cases. At depth 30 cm, the soil site with the highest moisture content is Ipele soils, having value of 17.4% as indicated in Table 3 and 4. Ute forest soil (U) has the lowest moisture content especially at depth 10 cm and 20 cm respectively, and has a higher moisture content at depth 30 cm than Isuada soil (IS) at the same depth. It was observed that as the depth of the soil increases, the moisture content of the soil also increases downward. At the two extremes as indicated in Table 3, the colour of the soil at Ute soil site is dark brown, which indicates the presence of some organic matters, while that of Emule is pure yellowish to red clay. A yellowish red colour is an indication that the soil is rich in hydrated iron oxides. The yellowish red soil extended further down the soil profile. Table 3 shows the description of the colour of various soil sites investigated.

The plot of moisture content and the soil temperature revealed that as the moisture content is increasing, the soil temperature is decreasing between the range of 10 cm to 30 cm soil depth of the sites investigated as shown in fig 3 and Table 3.

Observations shows that Ilale forest soil has the least values of soil temperature at different moisture content and soil levels recorded; with Isuada forest soil having the highest soil temperature compared to the rest site locations. It is desirable to have temperature measurements at the same depth

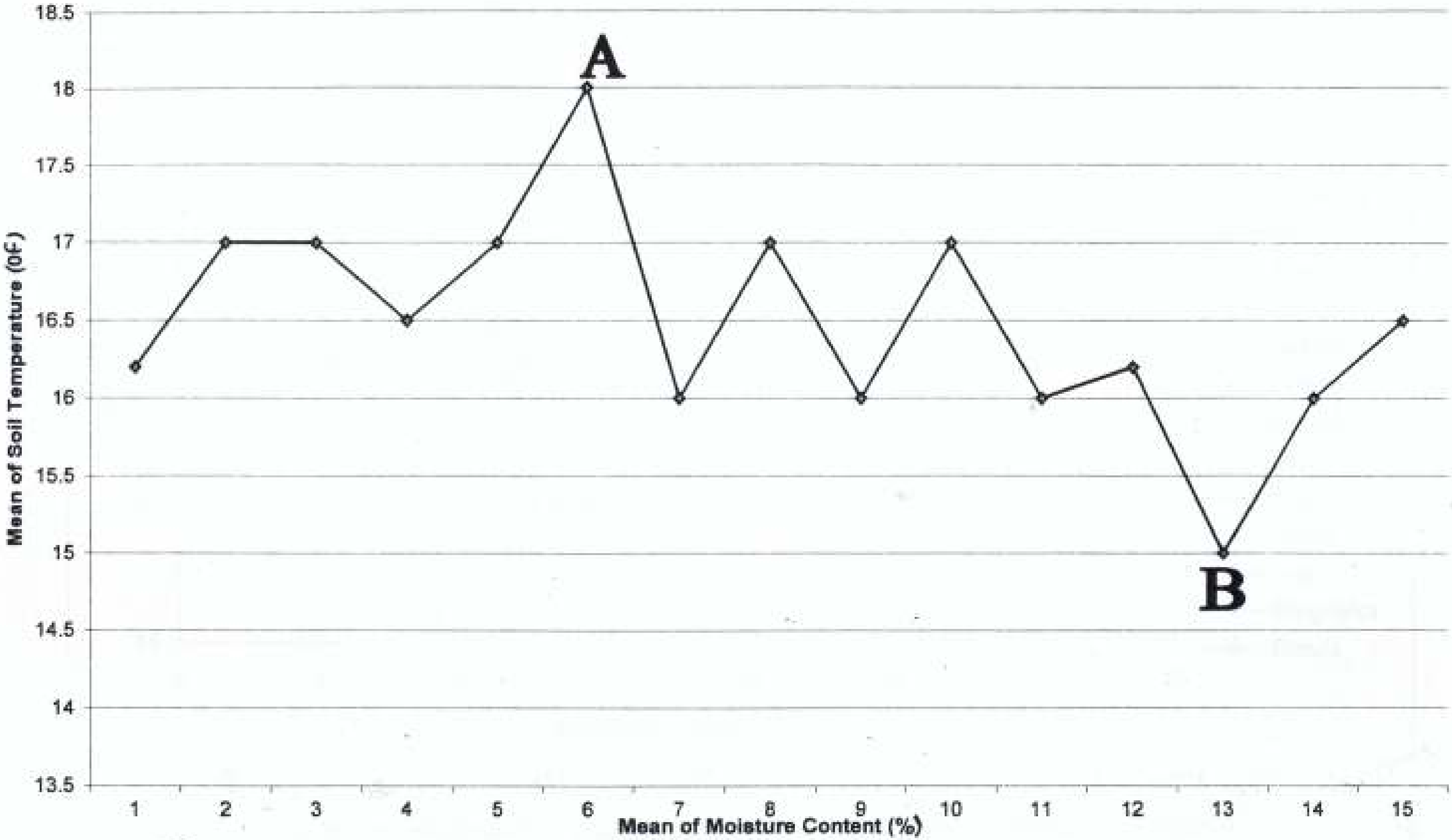


fig 3a Mean of the Soil Temperature and Moisture Contents of the 15 Experimental Sites.

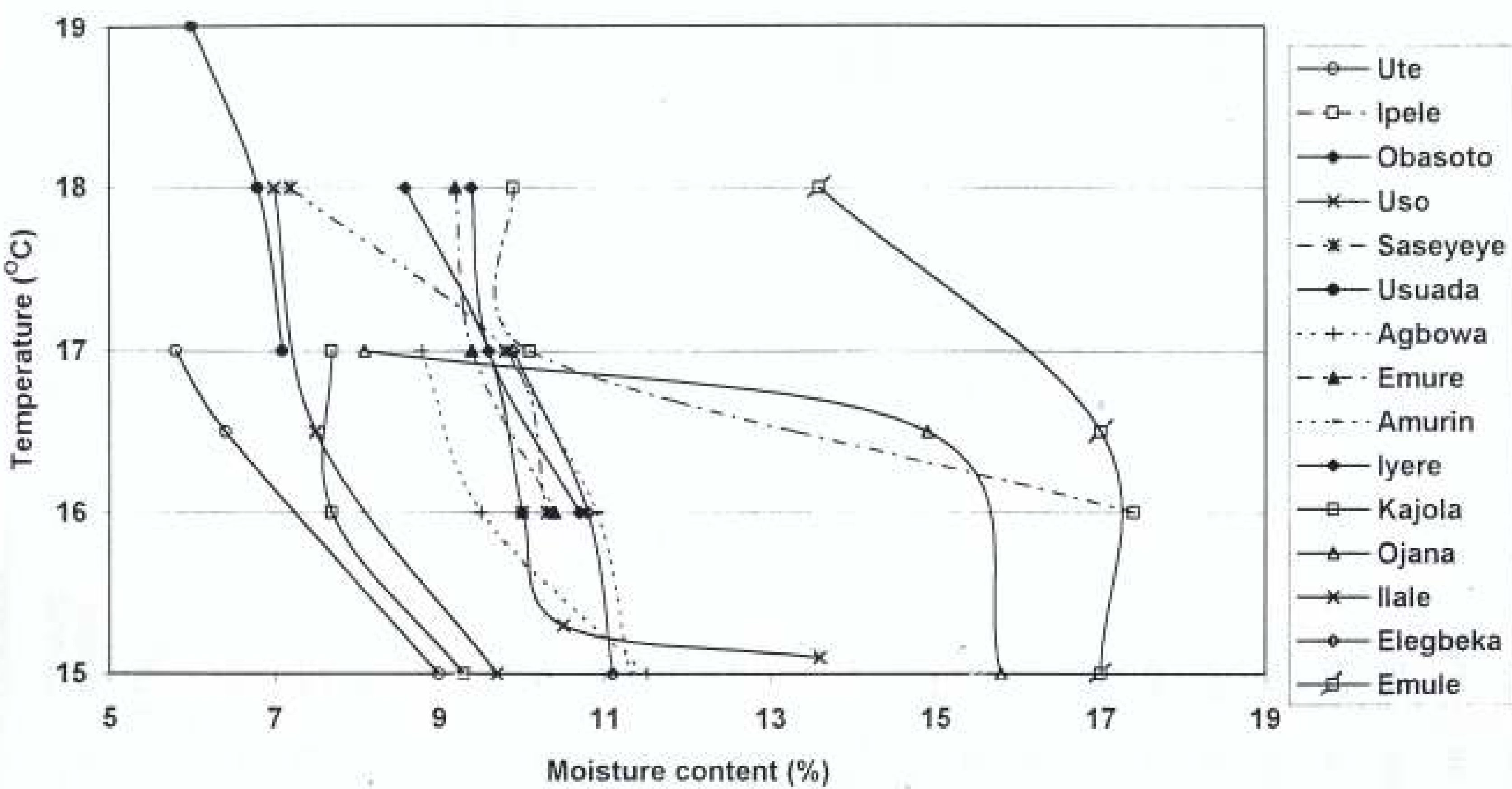


Fig. 3b Moisture content and Soil temperature of soil sites at different soil depths

Table 3: **MOISTURE CONTENT, TEMPERATURE AND COLOUR DESCRIPTION OF THE 15 EXPERIMENTAL SITE**

S/N	Site Location	Depth of soil	Moisture content (%)	Average in moist. content (%)	Soil Temp. (°c)	Average soil temp.	Soil colour description
1	U_1	10 cm	5.8		17		
2	U_2	20 cm	6.4	7.1	16.5	16.2	Brownish dark soil
3	U_3	30 cm	9.0		15		
4	I_1	10 cm	9.9		18		
5	I_2	20 cm	10.1	12.5	17	17.0	Red Brownish gravelled soil
6	I_3	30 cm	17.4		16		
7	0_1	10 cm	8.6		18		
8	0_2	20 cm	9.6	9.4	17	17.0	Light brownish dark soil
9	0_3	30 cm	10.0		16		
10	US_1	10 cm	7.0		18		
11	US_2	20 cm	7.5	8.1	16.5	16.5	Brown redish Gravelled soil
12	US_3	30 cm	9.7		15		
13	S_1	10 cm	7.2		18		
14	S_2	20 cm	9.8	9.1	17	17.0	Dark Brownish soil
15	S_3	30 cm	10.3		16		
16	IS_1	10 cm	6.0		19		
17	IS_2	20 cm	6.8	6.6	18	18.0	Gravelled brownish soil
18	IS_3	30 cm	7.1		17		
19	A_1	10 cm	8.8		17		
20	A_2	20 cm	9.5	10.1	16	16.0	Dark soil
21	A_3	30 cm	11.9		15		
22	E_1	10 cm	9.2		18		

23	E_2	20 cm	9.4	9.7	17	17.0	Red dark soil
24	E_3	30 cm	10.4		16		
25	AM_1	10 cm	9.8		17		
26	AM_2	20 cm	10.9	10.7	16	16.0	Red Brownish gravelled soil
27	AM_3	30 cm	11.3		15		
28	IY_1	10 cm	9.4		18		
29	IY_2	20 cm	9.6	9.9	17	17.0	Dark brownish soil
30	IY_3	30 cm	10.7		16		
31	K_1	10 cm	7.7		17		
32	K_2	20 cm	7.7	8.2	16	16.0	Light dark soil
33	K_3	30 cm	9.3		15		
34	OJ_1	10 cm	8.1		17		
35	OJ_2	20 cm	14.9	12.9	16.5	16.2	Light brownish soil
36	OJ_3	30 cm	15.8		15		
37	IL_1	10 cm	10.0		16		
38	IL_2	20 cm	10.5	11.4	15.3	15.0	Light dark soil
39	IL_3	30 cm	13.6		15.1		
40	EL_1	10 cm	9.9		17		
41	EL_2	20 cm	10.8	10.4	16	16.0	Deep Brownish Darl soil
42	EL_3	30cm	11.1		15		
43	EM_1	10 cm	13.6		18		
44	EM_2	20 cm	17.0	15.9	16.5	16.5	Red Clay soil
45	EM_3	30cm	17.0		15		

Table 4: **THE TABLE OF THE AVERAGE MEAN OF MOISTURE CONTENT, BULK DENSITY AND TOTAL POROSITY BETWEEN THE RANGE OF 10 CM TO 30 CM SOIL DEPTH**

S/N	Site Location	Soil Depth (cm)	Moisture content (%)	Bulk density gm/cm^3	Total Porosity (%)	Moisture content range between 10 cm – 30 cm	Bulk Density between 10 cm – 30 cm	Mean su of the to Porosity
1	U_1	10 cm	5.80	1.70	10.68			
2	U_2	20 cm	6.40	1.44	9.86	7.10	1.60	12. 36
3	U_3	30 cm	9.00	1.67	16.56			
4	I_1	10 cm	9.90	1.44	15.81			
5	I_2	20 cm	10.10	1.40	15.78	12.50	1.43	13. 92
6	I_3	30 cm	17.40	1.45	10.18			
7	0_1	10 cm	8.60	1.68	15. 73			
8	0_2	20 cm	9.60	1.60	16. 98	9.40	1.57	16. 25
9	0_3	30 cm	10.00	1.44	16. 03			
10	US_1	10 cm	7.00	1.66	12. 42			
11	US_2	20 cm	7.50	1.53	12. 42	8.10	1.49	12. 78
12	US_3	30 cm	9.70	1.28	13. 81			
13	S_1	10 cm	7.20	1.67	12..99			
14	S_2	20 cm	9.80	1.66	18. 04	9.10	1.68	16..92
15	S_3	30 cm	10.30	1.70	19.74			
16	IS_1	10 cm	6.00	1.10				
17	IS_2	20 cm	6.80	1.64	6. 60	6.60	1.43	10..37
18	IS_3	30 cm	7.10	1.56				
19	A_1	10 cm	8.80	1.70	16. 69			
20	A_2	20 cm	9.50	1.55	16. 29	10.10	1.48	16.34

21	A_3	30 cm	11.50	1.18	16. 03			
22	E_1	10 cm	9.20	1.70	17.23			
23	E_2	20 cm	9.40	1.60	16. 69	9.70	1.66	17. [illegible]
24	E_3	30 cm	10.40	1.69	19.74			
25	AM_1	10 cm	9.80	1.68	18.28			
26	AM_2	20 cm	10.90	1.64	29.59	10.70	1.67	23..[illegible]
27	AM_3	30 cm	11.30	1.70	21..94			
28	IY_1	10 cm	9.40	1.69	17. 48			
29	IY_2	20 cm	9.60	1.65	17. 48	9.90	1.66	17. 0
30	IY_3	30 cm	10.70	1.65	17.19			
31	K_1	10 cm	7.70	1.44	12..02			
32	K_2	20 cm	7.70	1.66	13. 81	8.20	1.49	13. 3
33	K_3	30 cm	9.30	1.38	14.26			
34	OJ_1	10 cm	8. 10	1.66	14. 63			
35	OJ_2	20 cm	14. 90	1.18	20. 70	12. 90	1. 49	21. 9[illegible]
36	OJ_3	30 cm	15. 80	1. 63	30. 55			
37	IL_1	10 cm	10. 00	1. 64	18. 28			
38	IL_2	20 cm	10. 50	1.70	20. 04	11.40	1. 46	18. 2[illegible]
39	IL_3	30 cm	13. 60	1. 05	16. 56			
40	EL_1	10 cm	9. 90	1.25	13. 75			
41	EL_2	20 cm	10. 80	1. 66	20. 11	10. 04	1. 50	17. 9[illegible]
42	EL_3	30 cm	11. 10	1. 60	20. 04			
43	EM_1	10 cm	13. 60	1. 14	18. 04			
44	OJ_2	20 cm	17. 00	29. 47	15. 90	1. 42	27.62	
45	OJ_3	30 cm	17. 00	35. 36				

so that the data from place to place can be directly compared. It is suggested that whenever possible, soil temperature be measured at 10, 20 and 30 cm soil depths (Blane and Milton, 1958). The type and amount of ground cover, as well as the soil moisture status have a marked effect on soil temperature (Singh, 1980).

4.2. THE EFFECT OF ORGANIC CONTENT, SOIL WATER CONTENT, SOIL TYPE AND VARIATION ON COMPACTION

Ute (U) forest soil has the highest organic matter compared with the other soils. As the compressibility of the soil increased the maximum dry unit weight of compaction will decrease. Franklin *et al.* (1973) studied the effect of organic contents on the strength and compaction characteristics of mechanical mixtures of inorganic soils and peat and natural soil samples with the same organic content. He drew a conclusion that if the organic content in a given soil is more than about 10%, the maximum dry unit weight of compaction decreases considerably. The optimum moisture content increases with the increase of organic contents of soil.

The shearing resistance to relative movement of the soil particles was large at low water contents. As the water content increased, it become progressively easier to disturb the soil structure, and the dry density achieved with a given compactive effort increased. However, if the dry density was plotted against the water content for a given compactive effort, it would be seen that the dry density would reach a peak, after which any further increase in water content would result in a smaller dry density. The reason for this can be readily seen if lines were plotted on the same diagram representing the relation between dry density and water content for complete saturation, and for various air void ratios. From the dry density and water content curve, two parameters can be determined. Viz: the maximum dry density and the optimum water content at which this maximum dry density is achieved. Both the maximum dry density and the optimum water content were found to depend on the compactive effort used. Increasing the compactive effort increases the maximum dry density, but reduces the optimum water content. The air void ratio at the peak density remained very much the same. It might be seen that at high water contents, there was little to be gained by increasing the compactive effort beyond a certain point. Since most natural soils in Owo community have water content above the optimum, for even the highest plant, and since "its" generally impracticable to dry the soil, little improvement in the dry density resulted from the use of heavier plant. Equally, extra passes of the equipment produce rapidly diminishing returns, once adequate compaction had been achieved. Heavy equipment was generally used, not because it greatly increased the dry density, but for the purely economic reason that it produced given compactive effort more cheaply.

From the compaction test carried out, it was observed that as the applied pressure increased, the bulk density decreases since most of the pore space were filled up with water. As the soil became wetter decreasing compaction was

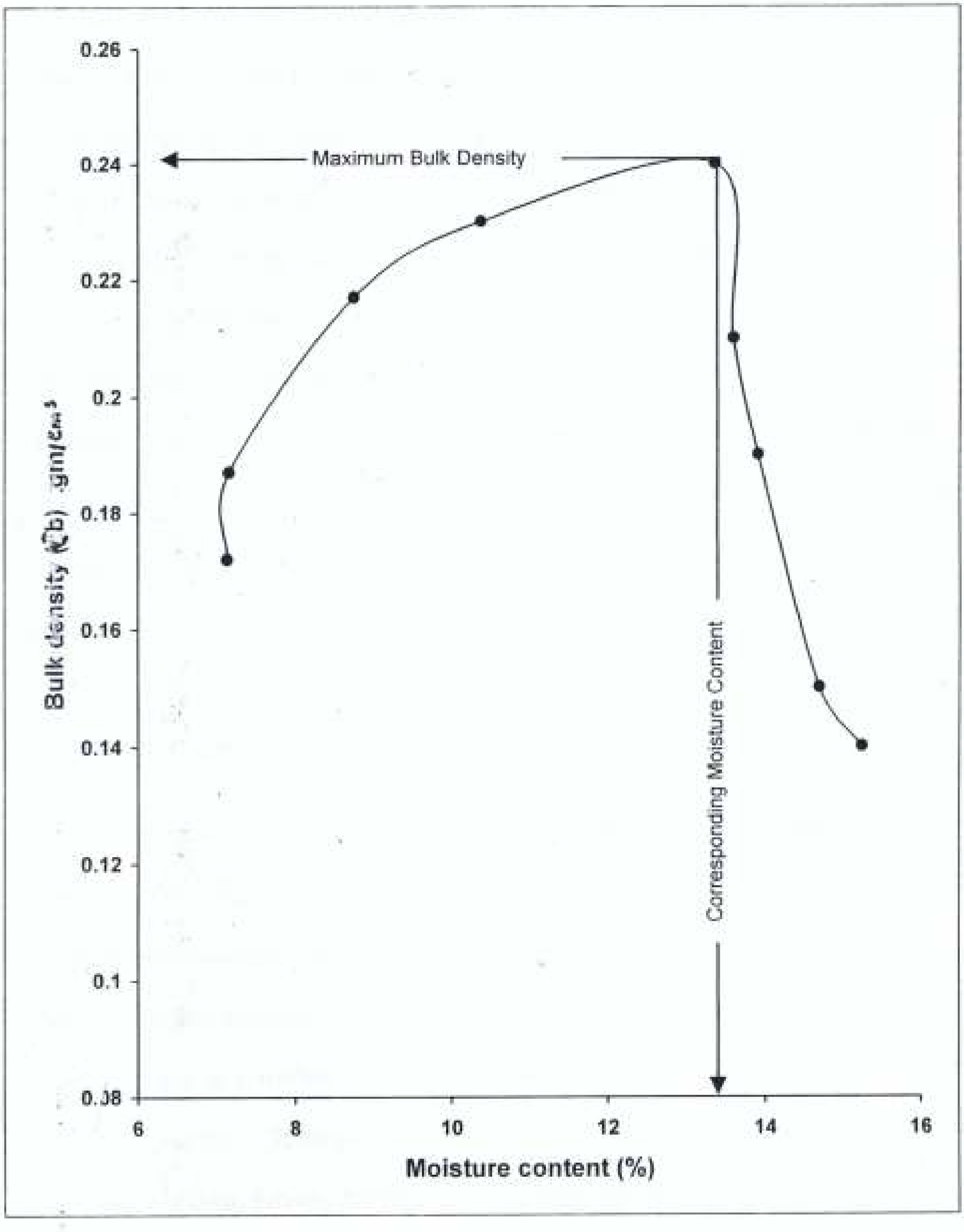


Fig.7.Soil water - applied pressure - bulk density

observed since the soil was less compressible as pores became increasingly filled with water. When the applied pressure was plotted against the porosity closely spaced lines indicating little change in soil volume across a range of water contents and applied pressures. Widely spaced lines indicated a rapid loss in porosity for incremental increases in applied pressure. Steep stress lines demonstrated strong dependence on soil water content at the time of compaction. Soehne (1958) express the relationship between porosity and applied pressure at a given soil water content as $\theta = K - C \ln \delta$, where θ is the porosity, δ is the pressure (bars), K is a constant and C is the compression index derived from the slope of the linear portion of the relationship between porosity or bulk density and the logarithm of applied pressure. This straight line is often termed the virgin compression line, or VCL. The overall relationship between bulk density and the logarithm of applied pressure is termed the virgin compression curve (VCC).

The soil compaction curves for 15 experimental sites are shown in figures 8a – 8o. The shape vary from site to site. The soil compaction curves represent typical soil behaviour with slight variation from one site to another. In all cases as the applied pressure increases, the bulk density increases up to peak point. At this point, any further increase in the applied pressure resulted in a decrease in bulk density. Thirteen experimental sites (Ute, Obasoto, Uso, Saseyeye, Isuada, Agbowa, Emure, Amurin, Iyere, Kajola, Ojana, Ilale and Elegbeka) in the major area of Owo Local Government had sandy clay loam. According to Smith (1995), Sandy Clay Loam (SCL) soils are difficult to manage because they are

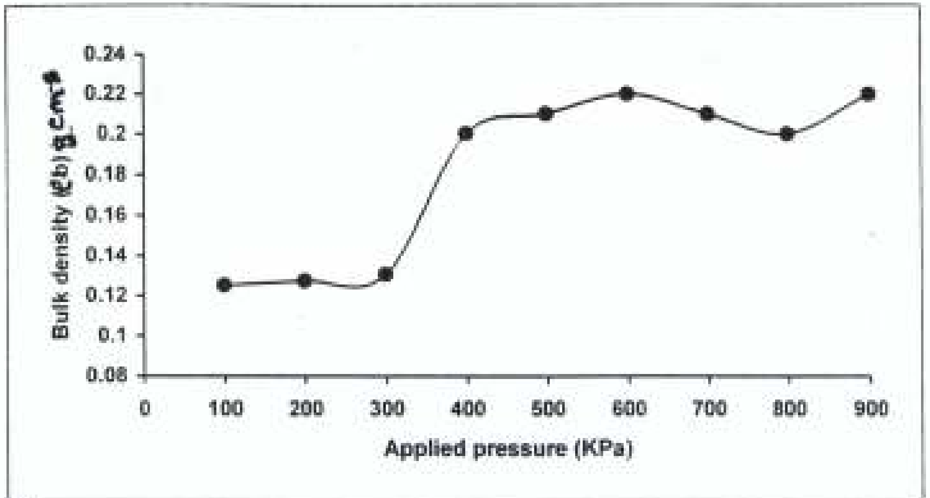


Fig.8a: EMULE FOREST SOIL

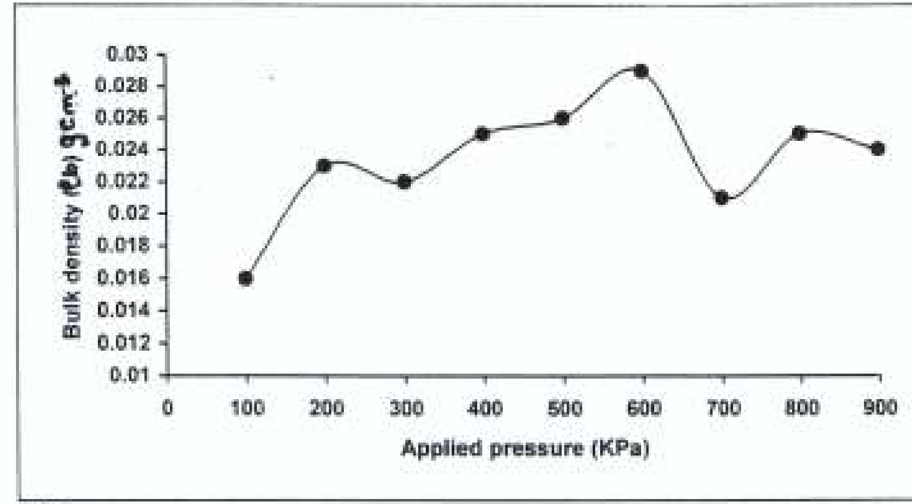


Fig.8b: UTE FOREST SOIL

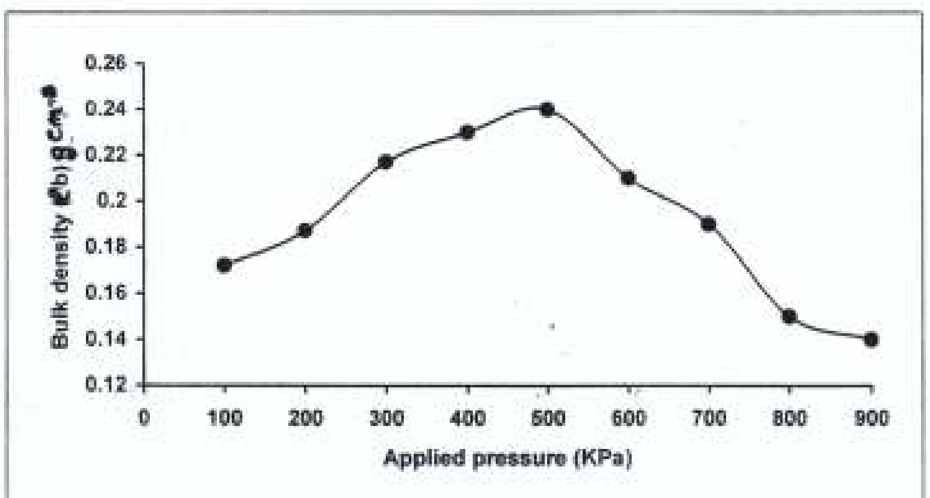


Fig.8c: AGBOWA FOREST SOIL

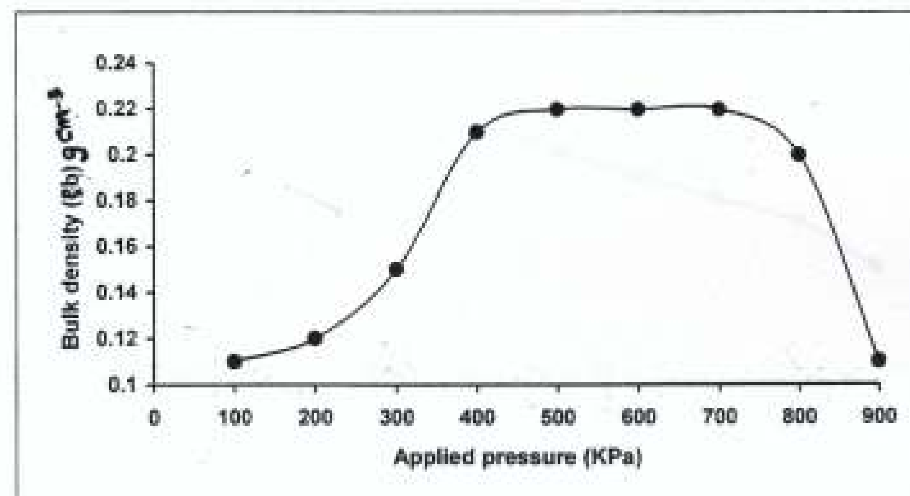


Fig.8d: OBASOTO FOREST SOIL

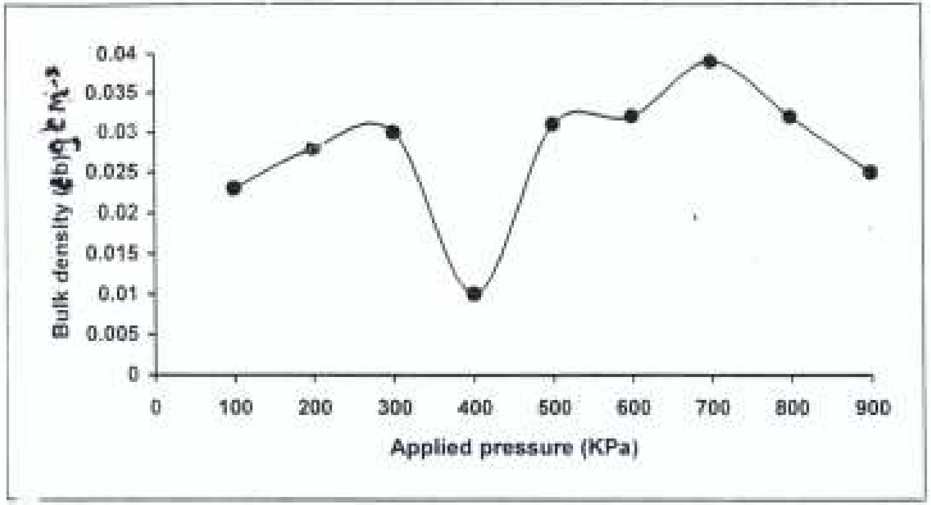


Fig.8e: ISUADA FOREST SOIL

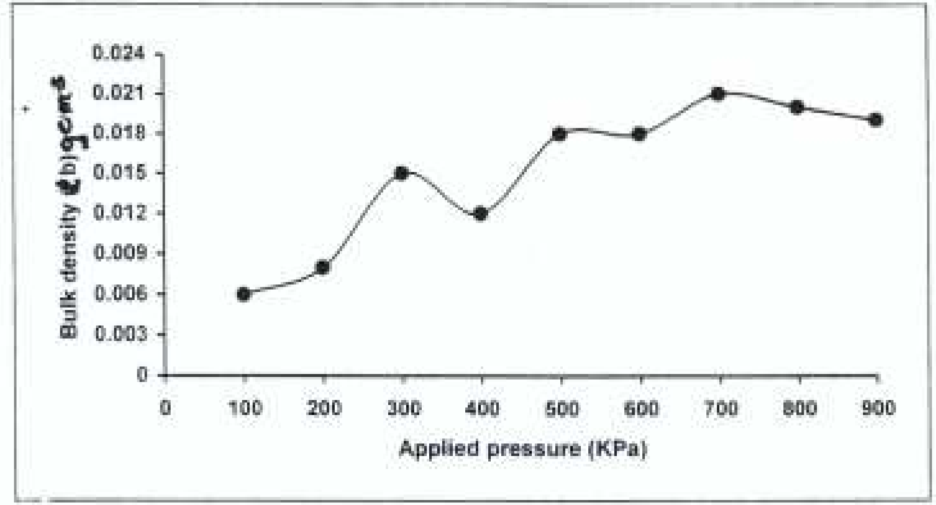


Fig.8f: IYERE FOREST SOIL

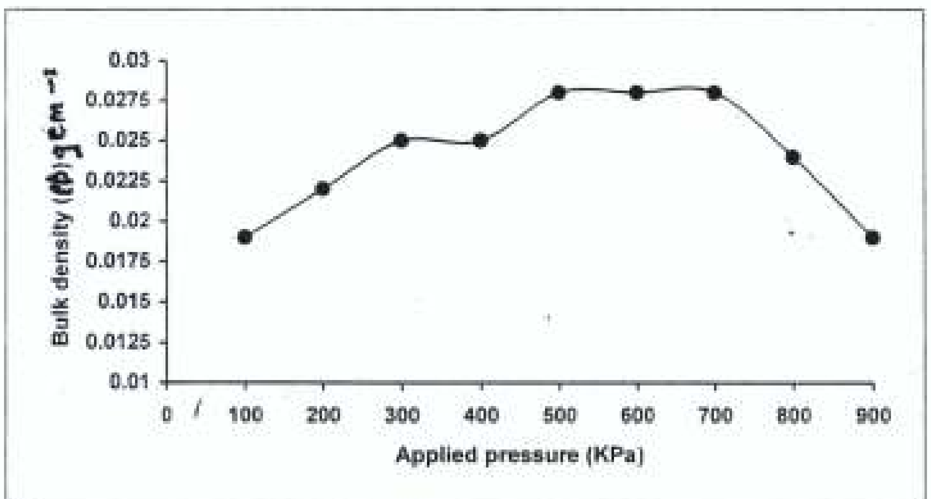


Fig.8g: EMURE FOREST SOIL

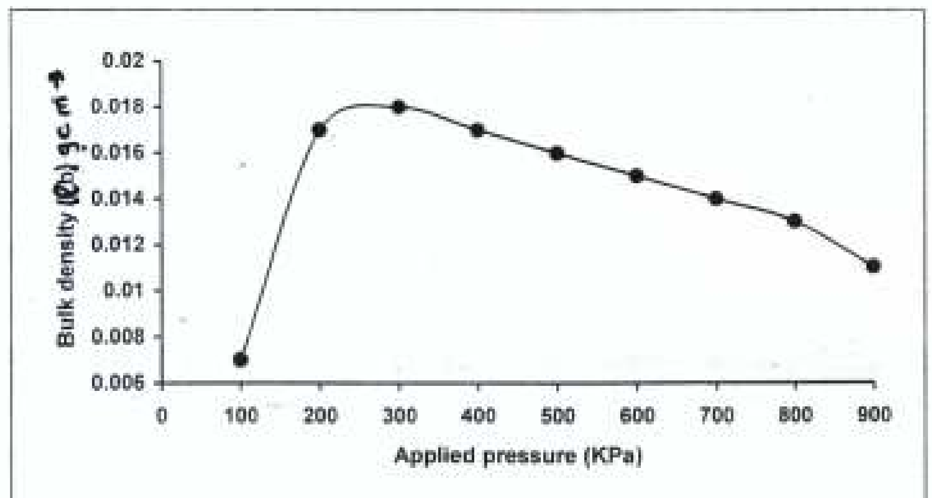


Fig.8h: KAJOLA FOREST SOIL

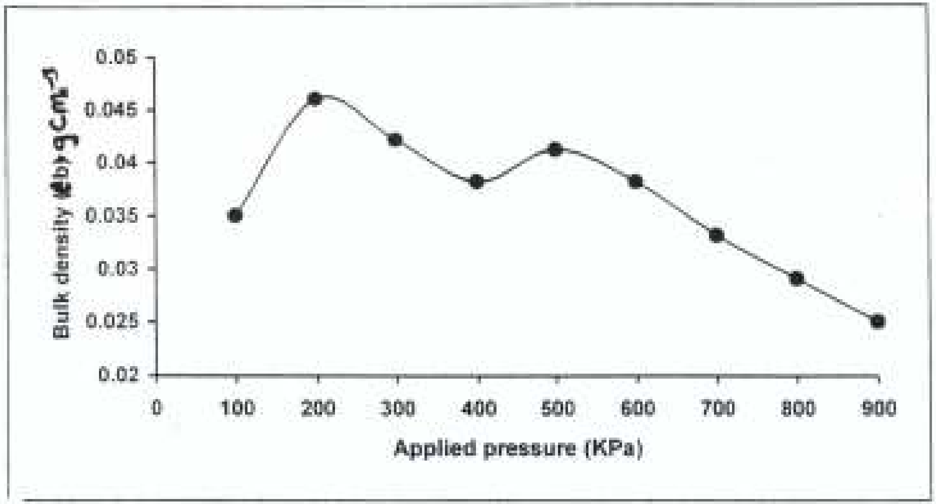


Fig. 8i: IPELE FOREST SOIL

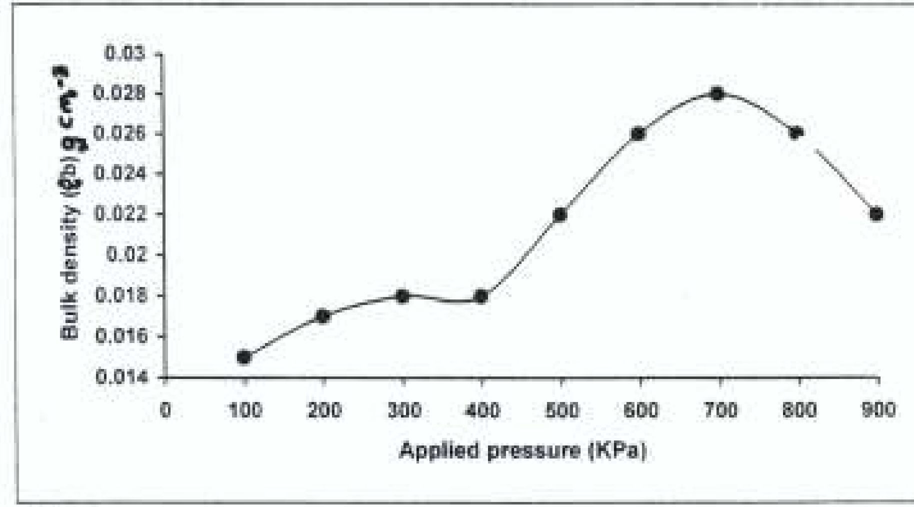


Fig. 8j: USO FOREST SOIL

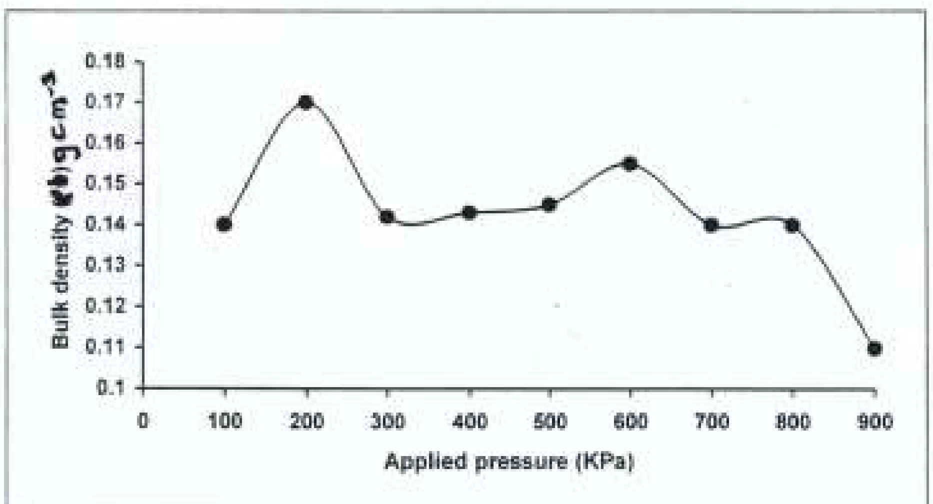


Fig. 8k: SASE/YEYE CAMP FOREST SOIL

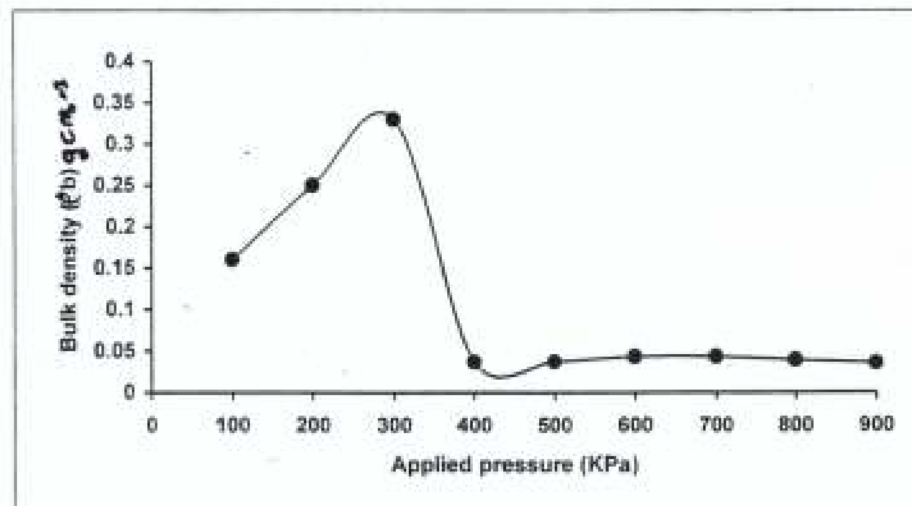


Fig. 8L: AMURIN FOREST SOIL

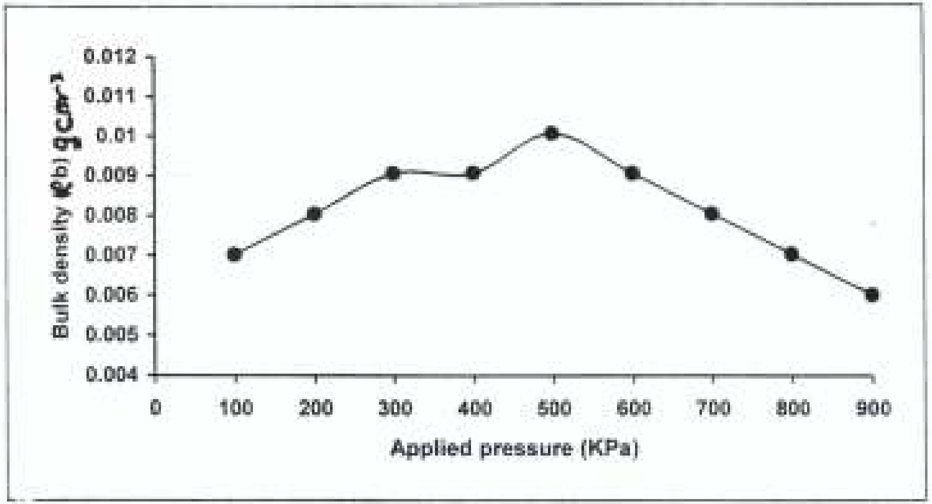


Fig. 8m: OJANA FOREST SOIL

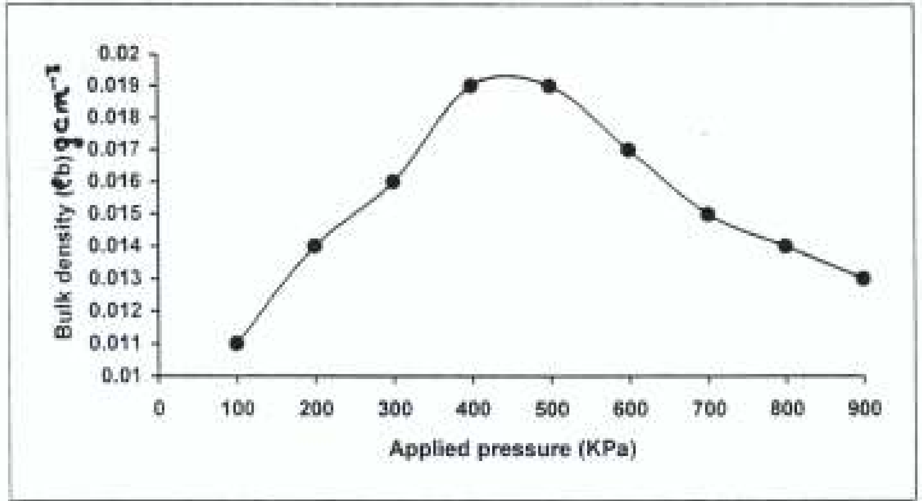


Fig. 8n: ELEGBEKA FOREST SOIL

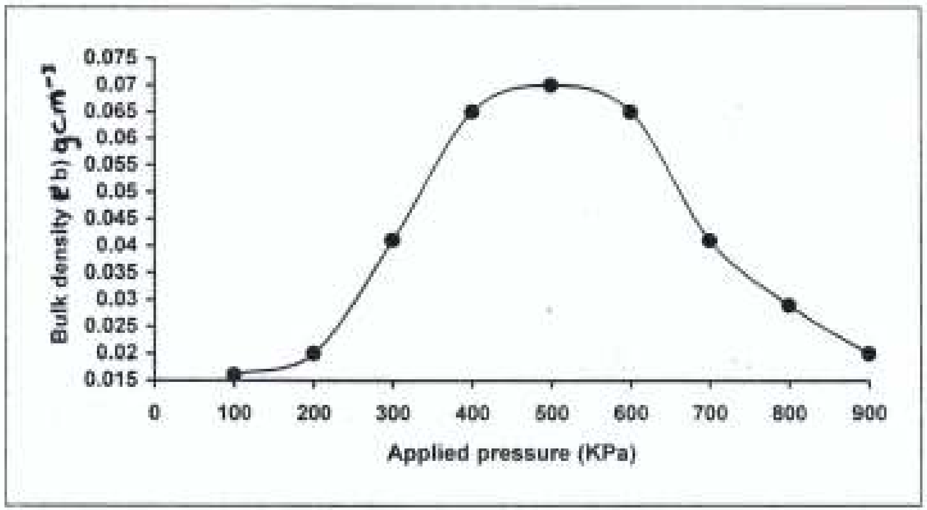


Fig. 8o: ILALE FOREST SOIL

susceptible to compaction with small fluctuation in water content. The compaction curves of these soils are similar. The practical implication of this is that when moisture is high especially during rainy season the soils are susceptible to compaction. The forest soils of Obasoto and Amurin have different compaction curves compared to the rest of the curves of the forest soils. The compaction curves of Obasoto forest soils shows a "domy shapes". Any further increment in applied pressure from 400 kPa to 700 kPa revealed a linear relationship at the top of the curve. As for Amurin forest soils, the curve revealed a constant linear relationship from 400 kPa to 900 kPa. From this, it can be deduced that there are similarities in soil strength at these levels. There was a sharp drop of the compaction curve of Amurin forest soil at 300 kPa indicating a rapid decrease in bulk density. Emule forest soil is pure clayey soil. The compaction curve shows that the soil is highly compressible. As the applied pressure increases the bulk density also increases. In the study area, Emule forest soil is muddy and marshy especially during the rainy season.

The bulk density continued to increase until the maximum bulk density was reached and thus the equation above does not apply at very high stresses. If the soil has a previous compaction history and a further stress was applied, the bulk density-applied pressure relationship would continue along a line with a slight slope until it joined the VCC. This is termed the secondary compression and is of great practical significance as it indicates that there is very little change in bulk density for increasing applied pressure until the secondary compression line joins VCL. The applied pressure required for secondary compression had been termed residual pressure by Amir et al (1976) who defined it as the pressure which when added to the applied pressure results in residual compaction.

It should be noted that the compaction curves in the 15 sites vary in shape. The steepness of stress lines of both the loam and clay loam illustrated a resistance to compaction when dry. Such behaviour reflected a rapid change for the soil. The steep stress lines of the sandy clay loam demonstrates the dependence of compaction behaviour on water content. This soil was extremely hard below a water content of 0.1kg/kg and thus relatively in compressible. As the soil water content increased, the soil rapidly lost its strength and the compaction behaviour changes sharply to an increase in water content of less than 0.014kg/kg. Both soils demonstrated the hardsetting nature of some forest soils (Mullins et al., 1980). Soil such as the loam derived from glacial tillite and the sand clay loam derived from sand stone are difficult to manage due to a combination of moderately high compressibility and rapid strength changes with small fluctuation in water content. The loam sand exhibited considerable resistance to compression, illustrated by the relatively level and closely spaced Iso-stress lines. For a given incremental load only small increases in compaction were noted. These results are consistent with those of

Mullins et al (1980) who showed that sandy soils are much less compressible than more finely textured soils. The loamy sand achieved higher bulk densities when it was very dry or approaching saturation but this is a feature of the unique particles rearrangement of sands with changing water content rather than the effect of an applied pressure at intermediate water contents. Ponayiotopolous and Mullins (1985) found that air dry and nearly saturated sands always packed more closely under a given load than at intermediate water contents and suggested this was related to annular bridges being formed between sand particles which act like elastic bonds when the soil is moist but are lost when the soil is saturated or air-dry and hence the soil at these two extremes collapses.

An empirical model was fitted to the data of the 15 forest soils studied in order to compare the influence of applied pressure and water content on compaction behaviour between soils.

The bulk density continued to increase until the maximum bulk density was reached and thus the equation above does not apply at very high stresses. If the soil has a previous compaction history and a further stress was applied, the bulk density-applied pressure relationship would continue along a line with a slight slope until it joined the VCC. This is termed the secondary compression and is of great practical significance as it indicates that there is very little change in bulk density for increasing applied pressure until the secondary compression line joins VCL. The applied pressure required for secondary compression had been termed residual pressure by Amir et al (1976) who defined it as the pressure which when added to the applied pressure results in residual compaction.

It should be noted that the compaction curves in the 15 sites vary in shape. The steepness of stress lines of both the loam and clay loam illustrated a resistance to compaction when dry. Such behaviour reflected a rapid change for the soil. The steep stress lines of the sandy clay loam demonstrates the dependence of compaction behaviour on water content. This soil was extremely hard below a water content of 0.1kg/kg and thus relatively in compressible. As the soil water content increased, the soil rapidly lost its strength and the compaction behaviour changes sharply to an increase in water content of less than 0.014kg/kg. Both soils demonstrated the hardsetting nature of some forest soils (Mullins et al., 1980). Soil such as the loam derived from glacial tillite and the sand clay loam derived from sand stone are difficult to manage due to a combination of moderately high compressibility and rapid strength changes with small fluctuation in water content. The loam sand exhibited considerable resistance to compression, illustrated by the relatively level and closely spaced Iso-stress lines. For a given incremental load only small increases in compaction were noted. These results are consistent with those of

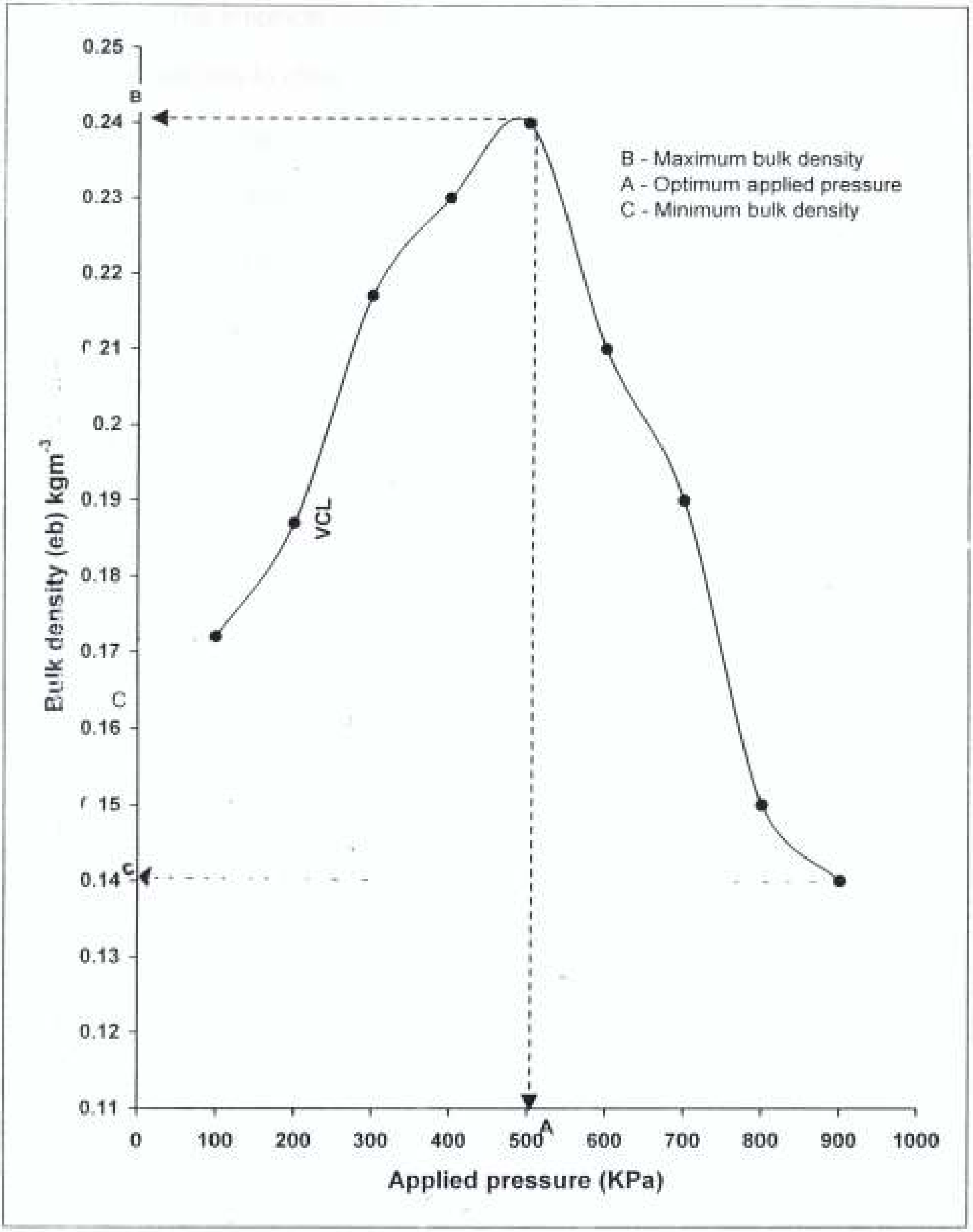


Fig9 A Typical Compaction Curve for Agbowa Soil

The empirical model equation established in this study which relates the bulk densities to other parameter are:

$$Pb = a(\theta m - \theta mr) + C \log(\delta r - \delta) + Pbk \quad (3)$$

Where

Pb - Bulk density in mg /m^3

A - Constant (slope of ℓ against water content for a given applied pressure)

θmr - Residual mass water content (The least w.c)

θm - Mass water content

C - Compression index (slope of linear portion of ℓ against pressure)

δ - Applied pressure (particular pressure)

δr - Pressure (when compression curve becomes a straight line

usually at 100 kPa

Pbk - Constant (bulk density at 100 kPa).

Table 5: **RESULT OF THE EQUATION OF MODEL DEVELOPMENT**

Site locations	A	θmr %	θm %	C	δ kPa	δr kPa	Pbk	Pb gcm^{-3}
U	4.00	16.67	168.35	3.5440	200	27272.70	0.125	1.53
I	0.25	8.14	146.18	3.7×10^5	200	12500.00	0.035	1.51
0	5.00	2.99	74.89	3.0×10^5	200	54000.00	0.110	1.42
US	2.00	7.44	93.62	3.4×10^5	200	8695.65	0.015	1.34
S	0.75	7.24	105.63	0.4×10^6	200	6818.18	0.140	1.53
IS	0.11	0.96	91.31	4.1×10^5	200	13636.00	0.023	1.26
A	0.60	7.13	104.14	4.0×10^5	200	3333.00	0.172	1.40
E	1.60	13.70	102.57	4.0×10^5	200	50000.00	0.019	1.87
AM	17.25	5.41	111.61	4.5×10^6	200	25000.00	0.160	1.98
IY	0.05	7.26	98.83	2.4×10^5	200	37142.85	0.006	109
K	0.21	6.19	86.50	516663	200	123330	0.007	1.29
OJ	0.05	7.07	126.57	2.1×10^5	200	73684.20	0.007	1.09
IL	0.23	7.51	113.44	4×10^5	200	3000.00	0016	1.38
EL	0.16	3.95	100.82	3×10^5	200	80000.00	0.011	1.47
EM	0.14	7.23	167.10	4.4×10^5	200	1250.00	0.125	1.33

4.3. PRACTICAL INTERPRETATION OF COMPACTION BEHAVIOUR

On harvesting operations in Owo Forest soil, harvesting foresters are constantly being advised against the risk of soil compaction occuring under diverse water regimes and soil conditions. The information presented in this study can be used as a guide as to the relative importance of applied pressure and water content on the compaction process. However, the value for applied pressure should be regarded in a relative sense since it has been note that the pressure required in uni-axial tests to produce the same bulk density in the fields is considerably higher (O'Connell, 1992). A clayey soil is always water logged during the rainy season because most of the pores space has been filled with water. Under this condition, heavy tyred lorries will sink into the soil. For a sandy loam soil, increases in compaction are almost independent of water content. Increases in soil compaction are almost entirely due to increasing ground pressure. The principal factor influencing compaction of silty clay is applied pressure rather than water content at the time of compaction. The minor role of water content in affecting compaction is indicated by the very low value of 'a' (the slope of bulk density against water content for a given applied pressure).

Soils with high 'a' values such as the sandy clay loam are extremely sensitive to water content at the time of compaction. Smith (1995), noted that the percentage increase in soil compaction for the sandy clay loam is related more to changes in water content than to applied pressure. A ground pressure of only 200 kPa when the soil is wet results in a similar increase in compaction (60%) to a ground pressure of 600 kPa when the soil is moist. Scheduling harvesting operations on these soils to drier periods will have the greatest benefit in lowering soil compaction. Soil possessing both high average compression index (Cmod) and value 'a' such as clay should be trafficked in dry periods and with as low a ground pressure as possible. Applying moderate ground pressure of 400 kPa when the soil is moist results in an increase in compaction of more than 60%. This increases to nearly 80% when the soil is wet. It is no coincidence that many granite and gneiss derived soils, particularly sandy clays, sandy clay loams and clays, are known to posses severe compaction problems despite their relatively high clay contents (Smith, 1995). It has been clearly shown that Ute, Obasoto, Uso, Sasayeye, Isuada, Agbowa, Emure forest soils are sandy clay loam and Emule forest soil is purely clay as shown in Table 6. These soils posses severe compaction problems according to the investigation of Smith (1995).

The summary of the statistical analysis of the bulk density, moisture content and porosity derived from the raw data in Tables 7a –7c is presented in Table 8.

Table 6: **TABLE SHOWING THE PARTICLE SIZE DISTRIBUTION AND CHEMICAL PROERTIES OF THE 15 SITE LOCATIONS**

	PARTICLE SIZE DISTRIBUTON %			CHEMICAL PROPERTIES							
SITE	SAND	SILT	CLAY	ORGANIC MATTER %	NITROGEN %	PHOSPHORUS ppm	POTASSIUM meq/100g	SODIUM mgL^{-1}	CASSIUM mgL^{-1}	MAGNESSIUM mgL^{-1}	SOIL TEX
U	69	8	23	1.53	0.21	2.24	0.17	0.26	1.50	0.97	SCL
I	51	14	35	2.08	0.09	1.53	0.17	0.27	2.07	1.47	CL
O	70	7	23	1.76	0.07	3.89	0.22	0.21	2.30	1.37	SCL
US	62	12	26	1.82	0.10	2.55	0.12	0.27	2.63	0.83	SCL
S	63	10	27	1.53	0.07	4.32	0.32	0.33	1.30	1.07	SCL
IS	70	8	22	2.52	0.12	3.34	0.19	0.24	2.87	1.23	SCL
A	67	7	26	1.76	0.08	2.88	0.07	0.27	1.30	0.73	SCL
E	63	13	25	2.05	0.08	2.88	0.22	0.28	2.07	1.73	SCL
AM	55	14	30	1.69	0.07	0.27	0.16	0.39	2.80	0.90	SCL
IY	68	8	24	1.26	0.06	4.17	0.46	0.76	2.23	1.97	SCL
K	68	8	24	2.23	0.12	1.84	0.26	0.58	2.47	4.33	SCL
OJ	57	14	29	2.69	0.34	2.88	0.32	0.34	2.11	1.27	SCL
IL	61	11	28	2.98	0.14	4.86	0.78	0.57	3.07	2.67	SCL
EL	66	9	23	3.54	0.07	3.42	0.78	0.57	3.07	2.67	SCL
EM	34	11	55	3.28	0.15	2.71	0.32	0.26	2.80	2.20	C

SCL - **Sandy clay loam**

CL - **Clay loam**

C - **Clay**

TABLE 7a: THE TABLE OF BULK DENSITY DERIVED FROM COMPACTION TEST OF THE STUDY AREA (gcm^{-3})

S/N	U	I	O	US	S	IS	A	E	AM	IY	K	OJ	IL	EL	EM
1	0.016	0.035	0.11	0.015	0.140	0.023	0.172	0.125	0.160	0.006	0.007	0.007	0.016	0.011	0.01
2	0.023	0.046	0.12	0.017	0.170	0.028	0.182	0.129	0.250	0.008	0.017	0.008	0.020	0.014	0.0
3	0.022	0.042	0.15	0.018	0.142	0.030	0.217	0.130	0.330	0.015	0.018	0.009	0.041	0.016	0.0
4	0.025	0.038	0.21	0.018	0.143	0.031	0.230	0.200	0.036	0.012	0.017	0.009	0.65	0.019	0.0
5	0.026	0.041	0.22	0.022	0.145	0.031	0.240	0.210	0.037	0.018	0.016	0.010	0.070	0.017	0.0
6	0.029	0.038	0.22	0.026	0.155	0.032	0.210	0.220	0.048	0.018	0.015	0.009	0.0065	0.011	0.0
7	0.025	0.033	0.21	0.028	0.140	0.039	0.190	0.220	0.043	0.021	0.094	0.008	0.041	0.009	0.0
8	0.024	0.029	0.22	0.026	0.140	0.032	0.150	0.200	0.039	0.020	0.013	0.009	0.029	0.006	0.0
9	0.022	0.025	0.190	0.022	0.110	0.025	0.140	0.220	0.035	0.019	0.011	0.006	0.020	0.005	0.01

TABLE 7b: THE TABLE OF MOISTURE CONTENT DERIVED FROM COMPACTION TEST OF THE STUDY AREA (g/g %)

S/N	U	I	O	US	S	IS	A	E	AM	IY	K	OJ	IL	EL	EM
1	16.67	8.14	2.99	7.44	7.24	0.96	7.13	13.7	5.41	7.26	6.19	7.07	7.51	3.95	7.23
2	17.08	16.31	7.81	9.09	6.08	7.15	14.0	8.36	7.61	7.57	8.94	8.94	8.94	8.91	7.36
3	18.01	16.36	6.85	7.91	10.65	7.22	6.74	14.4	8.84	9.90	8.13	9.78	10.81	8.99	10.2
4	18.47	16.38	7.98	8.51	11.64	8.98	10.37	19.6	13.17	10.86	8.14	12.35	12.24	9.41	10.3
5	18.78	16.39	8.88	10.41	12.09	10.79	13.35	20.7	14.20	12.23	10.25	14.09	13.25	12.34	12.8
6	19.30	17.52	9.44	10.81	13.41	11.04	13.59	20.60	14.20	12.36	10.79	15.00	14.19	13.15	13.0
7	19.35	17.78	10.34	12.03	13.44	11.73	13.90	20.90	14.81	12.69	11.33	18.24	14.51	13.89	13.3
8	19.61	18.44	11.30	12.57	13.99	13.51	14.68	21.10	16.03	12.86	11.68	19.23	15.48	14.91	13.8
9	21.08	18.66	11.94	16.13	14.08	21.05	15.23	22.10	16.59	13.06	12.42	21.87	16.51	15.27	14.2

TABLE 7c: THE TABLE OF POROSITY DERIVED FROM COMPACTION TEST OF THE STUDY AREA (%)

S/N	U	I	O	US	S	IS	A	E	AM	IY	K	OJ	IL	EL	EM
1	0.32	0.25	0.03	0.15	0.11	0.20	1.44	0.15	0.09	0.13	0.04	.06	0.13	0.04	1.90
2	0.54	0.89	0.01	0.14	0.18	018	1.28	0.17	0.25	0.07	0.14	.08	0.20	0.14	2.84
3	0.48	0.79	0.38	0.14	0.18	0.0-9	2.08	0.28	0.32	0.19	0.16	.09	0.50	0.15	2.18
4	0.21	0.75	0.19	0.17	0.15	0.10	2.30	0.30	0.44	0.24	0.18	.13	0.90	0.20	0.47
5	0.18	0.79	6.33	0.25	0.24	0.09	3.17	0.21	0.36	0.26	0.16	.42	1.00	0.24	0.33
6	0.15	1.07	8.38	0.32	0.22	0.06	2.77	0.31	0.27	0.12	0.15	.17	1.098	0.16	0.67
7	0.13	0.60	1.67	0.38	0.20	0.09	2.08	0.07	0.30	0.07	0.10	.17	0.70	0.15	0.90
8	0.11	0.53	1.58	0.37	0.17	0.10	2.25	0.06	0.31	0.06	0.09	.16	0.28	0.10	0.71
9	0.06	0.49	2.18	0.42	0.14	0.11	2.52	0.06	0.29	0.03	0.14	.14	0.38	0.09	0.98

TABLE 8; **THE RANGE, MEAN , MEAN DEVIATION, STANDARD DEVIATION AND VARIANCE OF THE BULK DENSITY, MOISTURE CONTENT AND POROSITY OF THE EXPERIMENTAL SITE**

	Range	Mean	Mean Deviation	Standard Deviation	Variance
Bulk density (mg/m^3)	0.23	0.07	0.01	0.09	0.01
Moisture content . (%)	21.14	14.16	1.73	22.20	4.71
Porosity	8.35	0.58	0.13	1.13	1.06

TABLE 9: ANOVA FOR COMPLETELY RANDOMISED DESIGN (EQUAL SAMPLE SIZE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean squares	F. Ratio
Treatment	2	5760,65	2880,33	278,07
Error	42	435,05	10,39	
Total	44	6195,70		

It could be observed from the table that the values for the range, mean, mean deviation and variance of Bulk density are low compare to those of moisture content an porosity. This is because the soils investigated have higher proportion of pore space to solid. The bulk density must be lower which agreed with the explanation given by Nyle and Brady (1990). The higher the values of moisture content the lower the values of bulk density. This agreed with the finding in Table 4.

ANOVA Table was constructed from the analysis data derived from Laboratory test of the moisture content, Bulk density and porosity which were selected randomly in the study area as revealed in Table 4. The summary of the ANOVA analysis is stated in Table 9.

The assumed level of significance is $\alpha = 0.05$. Since F 0. 05, 2, 42 = 3.23, the computed value in Table 9 exceeds this critical value, the null hypothesis is rejected. It shows that the results of the data obtained may not be 100% because there may be some minute experimental error. Two variables were used to model the relationship between the results of the data obtained from the experimental test carried out in the laboratory. The variables are moisture content (x) and Bulk density (y) in the 15 site location. The Y-intercept and the slope of the linear graph are 2.56 and 0.002 respectively. The co-efficient of correlation revealed that there is a stronger relationship between Y and X variables because the sign of the coefficient of correlation is minus. Equation (2) was used to obtained a straight line using lest square method.

$$Y = \beta_0 + \beta_1 X \quad \text{.......} 3$$

Where y - dependent variable to modelled

X - independent variable use as a predict of y

β_0 - y – intercept of the line

β_1 – slope of the line or gradient

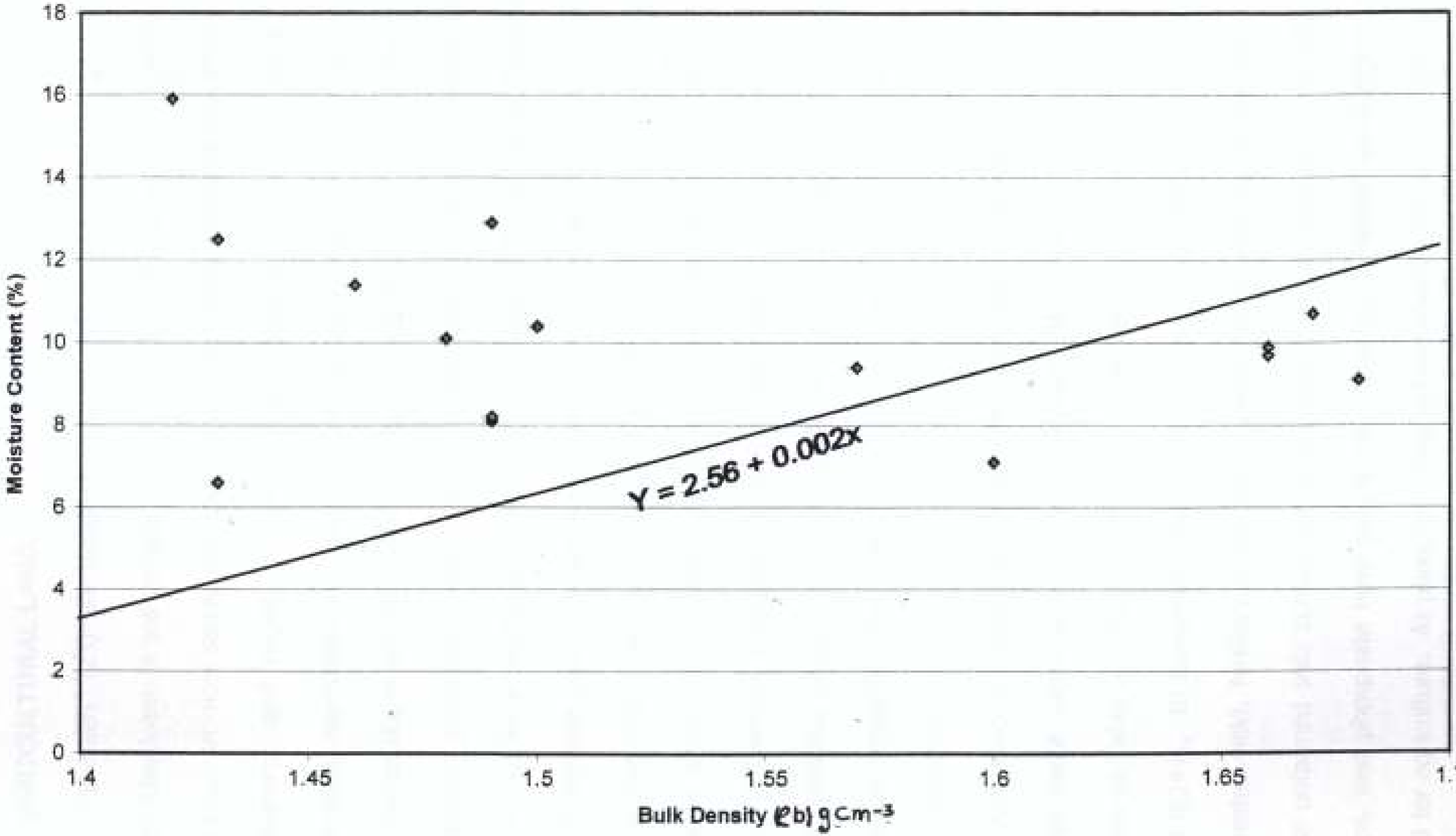


Fig.9 Scattered Diagram and Least - Square Line for Bulk Density and Moisture Content Datas of Fifteen Experimental sites

4.4. THE EFFECT OF CHEMICAL PROPERTIES ON CROPS AND AGRICULTURAL LAND

Thirteen (13) site locations used for the experiment in this study have sandy clay loam as soil texture. (that is U, OJ, 0, US, S, IS, K, A, E, AM, IL,IY and EL). In most sandy clay loam soils, it has been observed that potassium, phosphorus and organic matter is low (Steward, 1978). In slopy land, experiment has shown that potassium, phosphorus and organic matter are less on steeper slopes and pH is higher, indicating loss of nutrient and weathered soil by erosion (Steward 19780). Some of the locations where experiment were carried out were undulated. Practically, the values of the Nitrogen, Phosphorus and Potassium (NPK) decreases downward but in exceptional cases it may not follow that pattern because of leaching and other particles (like roots) in the soil samples which may increase the values. From Table 10, it could be observed that the chemical properties decreased with depth. The mean result of the entire chemical properties are shown in Table 6. These represents the various chemical properties from soil depth 10 cm to 30 cm for the whole area experimented.

According to Cooke 1982, organic Nitrogen have small values which agreed to the result obtained from the experiment conducted in the study areas as shown in Table 6. The highest value of Nitrogen average is Ojana forest soil with 0.34%. In temperate climates Nitrogen is usually deficient and because it regulates yield, fertilizer is needed to make the amount up to the maximum. Most unfarmed soils contain too little phosphorus for good yields of cultivated crops, and phosphate have usually been the first fertilizers used in improving land for agriculture. As phosphate does not move easily in soil being precipitated in forms with only slight solubilities, crop roots never reach more than ¼ or 1/3 of a dressing of phosphate fertilizer in a single year. The forest soil with the highest value of phosphorous is Sase/Yeye Camp with 4.32%. With much total K in soils, it may seem surprising that potassium salts are important fertilizers. Many clay soils have 1% or more of total K; some clays steadily release K and supply enough for crops for many years, but other clay soils, and most sandy soils, can supply little. In the experiment conducted Elegbeka forest soil has the highest value of potassium with 1.78%. Some clay soils, contain large reserves of calcium carbonate. In temperate climates calcium is leached by percolating rain and soils becomes acid unless they have large reserves. Elegbeka forest soil have the highest value of calcium from the result obtained from the experiment conducted in the study area. Phosphate and potassium ions are not mobile in soil. It is believed that much of the supply of K and nearly all P that reaches plants moves by diffusion. As rates of diffusion depend greatly on soil.

TABLE : 10: TABLE SHOWING THE CHEMICAL PROPERTIES AT DIFFERENT SOIL DEPTHS OF OWO FOREST SOIL

Site	Organic Matter %	N %	P	K	Na	C	Mg
U_1	2.03	0.10	2.62	0.26	0.20	1.10	1.80
U_2	1.98	0.10	2.18	0.19	0.28	2.80	0.80
U_3	0.60	0.03	1.92	0.07	0.31	0.60	0.30
I_1	2.03	0.10	2.62	0.26	0.20	0.10	1.80
I_2	2.02	0.10	0.98	0.12	0.28	2.70	1.90
I_3	1.49	0.08	0.98	0.12	0.32	2.40	0.70
O_1	1.38	0.07	6.86	0.17	0.28	3.10	1.20
O_2	2.05	0.07	3.92	0.11	0.16	1.70	0.70
O_3	1.46	0.06	0.88	0.38	0.19	2.10	2.20
US_1	1.58	0.10	3.92	0.14	0.29	4.00	0.60
US_2	1.90	0.10	3.92	0.14	0.26	2.20	1.00
US_3	1.98	0.10	1.78	0.09	0.25	1.70	0.90
S_1	1.94	0.10	3.92	0.14	0.29	4.00	0.60
S_2	1.20	0.06	3.50	0.32	0.41	1.00	1.30
S_3	1.46	0.05	2.88	0.31	0.34	1.60	1.20
IS_1	2.97	0.15	3.50	0.28	0.19	1.70	1.90
IS_2	2.12	0.11	3.42	0.15	0.26	1.70	0.40
IS_3	2.46	0.10	3.10	0.13	0.27	5.20	1.40
A_1	1.38	0.09	1.75	0.12	0.17	1.10	1.10
A_2	1.86	0.08	0.86	0.10	0.27	1.30	0.80
A_3	2.05	0.07	0.24	0.09	0.23	1.70	0.80
E_1	1.57	0.10	3.80	0.08	0.26	1.90	1.00
E_2	3.68	0.08	2.94	0.07	0.33	1.10	0.20
E_3	0.90	0.05	1.90	0.03	0.22	0.90	1.00
AM_1	2.05	0.10	2.94	0.26	0.33	3.00	1.90
AM_2	1.16	0.06	2.94	0.26	0.27	1.20	2.20
AM_3	1.86	0.05	0.90	0.14	0.23	2.00	1.10
IY_1	1.68	0.08	1.96	0.24	0.19	0.80	0.60
IY_2	0.90	0.05	1.94	0.12	0.27	1.20	2.20
IY_3	1.20	0.04	0.88	0.12	0.71	0.90	1.70
K_1	1.40	0.16	3.92	0.21	0.30	4.30	2.50
K_2	4.28	0.11	0.98	0.14	0.23	1.80	2.80
K_3	1.00	0.09	0.62	1.04	1.74	0.60	0.60
OJ_1	3.40	0.18	2.94	0.30	0.17	3.00	1.70
OJ_2	3.08	0.15	2.94	0.25	0.28	2.70	2.40
OJ_3	1.60	0.68	2.76	0.22	0.38	1.70	0.70
IL_1	2.50	0.23	5.88	0.49	0.32	3.90	1.30
IL_2	2.05	0.10	4.90	0.28	0.36	1.60	0.80
IL_3	4.39	0.10	3.80	0.20	0.33	1.10	1.70
EL_1	1.76	0.08	4.38	0.58	0.20	2.20	2.10
EL_2	4.32	0.07	2.94	0.17	0.28	3.50	2.20
EL_3	4.39	0.10	3.80	0.20	0.33	1.10	1.70
EM_1	3.54	0.18	2.94	0.34	0.26	1.20	3.40
EM_2	2.83	0.14	2.94	0.32	0.22	2.00	0.90
Em_3	3.47	0.13	2.25	0.31	0.29	5.20	2.30

CHAPTER FIVE

5.0. CONCLUSIONS AND RECOMMENDATIONS

The results derived from the data can be used to evaluate the relative importance of water content and applied pressure in the compaction process for a wide range of forest soils using a standard technique. Nevertheless, the evaluation of the relative importance of water content and applied pressure in the compaction process is of practical significance since it allows harvesting planners to decide whether water sensitivity of a particular soils or over all load is more important in order to minimise soil compaction. The use of bulk density as an independent variable in the compression tests is useful since correlations of bulk density with soil physical quality for particular soils are acheiveable (Smith, 1995). Moreover, bulk density is an easily measured and widely used soil physical parameter. This study also shows that soils which are rich in iron oxides can have a wide range of compaction behaviour. This would suggest that grouping these soils together as suggested by Mullin *et al.* (1980) is at best a first approximation.

Having conducted the physical and chemical properties and the compaction test of the forest soil in Owo Local Government of Ondo state (Nigeria) the following recommendations are suggested:

- The farmers should ensure that crops that can do well in sandy clay loam (SCL) and other type of textural classes should be planted for more production of yield.
- The experiment carried out shows that there were variations in the values of soil moisture content in the area. The farmers are advised and should be educated to cultivate land that have been

been indicated to have high moisture content for crops that need much water for their development, and vice versa.

- It should be pointed out that the lodgers and heavy tyred lorries should be restricted during the rainy season because of the risk of the lorry tyres entering into a marshy area. Emure forest soil which is purely red clayey soil, slippery and muddy during the rainy season should not be plied by heavy loaded timber lorries.
- For more yield to be provided, the farmers should be familiar with the results of this study and the Local Government Authority should provide fund for more investigation of this nature to protect the soil of the study area and to achieve good benefits from lodging operations.

REFERENCES

Abitoye, A.A 1997: Analytical Laboratory. Department of Crop Production, Federal University of Technology, Akure pp 18.

Ahn, P.M. 1979: Microaggregation in tropical soils: Its measurement and effects on maintenance of soil productivity. In Soil physical properties and crop production in the tropics R. Lal and D.J Greenland (eds). John Wiley and Sons, New York.

Amir, E; Raghaavan, G.S.V. Mckyes, E. Chasse M. and Broughton, R.S 1976: Prediction of soil compaction due to off road vehicle traffic. Trans. A.M. Soc. Agric. Eng. 19: 610 – 613.

Arnold, R. 1988: Soil survey: An example of applied research, Agrotechnology Transfer 7: 15.

Babalola, O. 1980: Water relations of three cowpea cultivars (Vigna Ungniculata) Plant Soil, 56: 56-59.

Beek, K.J, Bennema, J. and Carmargo, M. 1965: Soil survey interpretation in Brazil. Stiboka. Wageningen pp. 36

Beckett, G and Webster C 1977: Soil variability: A review, soil and fertilizers 34: 1-15.

Blackwell, P.S and Soane B.D 1981: A method of predicting bulk density changes in field soils resulting from compaction by agricultural traffic J. Soil Sci. 32: 51 – 65.

Blane, K and Milton, L 1958: The climatological investigation of soil temperature. World metreorological organization, Geneva, Switzerland. Technical Note 20.

Bouma, J and Kooistra, M.J. 1987: Soil Morphology and soil water movement. In: N. Fedoroff, L.M, Bresson and M.A County (Editors Soil Micromorphology, VII Reunion internationale de micromor phologic de sols, Paris, 1985 AFES, pp. 507 – 511.

Bradford, J.M. and Gupta, S.C: 1986, Compressibility. In Methods of Soil analysis. Part 1: Agronomy (2nd ed.) Klute. A. (ed), American Society of Agronomy, Madison, W.I., pp. 479 – 492.

Brannack, F. and Dextex A.R 1979: Compaction of aggregate beds. In: W.W Emerson, R.N. Bond and A.R Dextex (Editors), Modification of soil structures Wiley :New York, N.Y 120pp.

Childs, E. C. 1969: An introduction to the physical basis of soil water phenomena. Wiley Inter science, New York.

Cooke, G.W 1982: Fertilizer for yield soil and plant Nutrition Department Rothamsted experimental station. Agricultural Research Council.

Day, P.R 1965: Particle fractionation and particle size analyzes. In: C.A Black (Editor). Methods of soil Analysis. American Society of Argronomy. Madison, WI, pp. 562 – 566.

Draper, N.R and Smith, H. 1981: Applied Regression Analysis. 2nd Edition. Wiley, New York, 709 pp. 40.

Esu, I.E 1987: Morphology and classification of soils of the Nupe sandstone formation in Niger state, Nigeria. Dept. of Soil Science Ahmadu Bello University, Zaria. Samaru J. Agric. *Res.* Vol. 4, Nos 1 and 2 pp. 15.

Fawusi, O and Agboola A 1980: Soil Moisture requirements for germination of sorghum, millet, tomatoes and celosia. Agron, J. Vol. 3 pp. 353 – 357.

Fiskell, J.G.A, Carlisle, V.E., Kashirad, R. and Hutton, C.E 1986: Effect of soil strength on root penetration in coarse textured soils. Transactions of the 9th International Congress on Soil Science 1: 793 – 802.

Fly, D.L. and Romine, D.S 1964: Distribution, patterns of the weld-Raga soil association in relation to research planning and interpretations. Soil Sci. Soc. Am. Proc. 28: 125 – 130.

Franklin, A.F, Orozco, L.F, Semrau, R 1973: Compaction of Slightly Organic Soils. J. Soil Mech. Found. Div, ASCE, Vol. 99, No. SM 7, pp. 541 – 557.

Gardner, W.R 1993: A call for action, Soil Science Soc. Am. J. 57: 1403-1405.

Gerard, C.J.; Sexton, P. and Shaw, G.1982: Physical factors influencing soil strength and root growth. Agron J. 74: 875 – 879.

Gill, W.R.1968: Influence of compaction hardening of soil on penetration resistance. Trans Am. Soc. Agric. Eng. 11: 741-745.

Greenland,D.J. 1991: The contributions of soil science to society – past and future.Soil Sci. 151: 19-23.

Guerif, J. 1982: Compactage d'un massifd' aggrats: effet de a teneur en eau et de la pression applique. Agronomic 2: 287 – 294.

Gupta, S.C.and Allmaras,R.R.1987: Models to assess the susceptibility of soils to excessive compaction. In: Advances in soil science. ed. Steward B.A New York: Springer Verlag, Vol. 6, 65 -100

Gupta, S.C.and Larson, W.E.1982: Modelling Soil Mechanical behaviour during tillage. In: Punder (Editor) Predicting Tillage Effects on soil physical properties and processes. Proceedings of a symposium 30 Nov. – 5 Dec. 1980, at Detriot. MicChigan, U.S.A. As a special publication No. 44 Am. Soc. Agron, Madison, WI, pp 151-178.

Hadas, M and Wolf, C. 1984: Soil aggregates and clod strength dependence on clod size, cultivation and stress load rates Soil Sci. Soc. Am. J. 48: 1157 – 1165.

Horn, R. 1993: Mechanical properties of Structured unsaturated soils. Soil Technology 6: 47 – 75.

IITA, 1984: International Institute of Tropical Agriculture. Annual report for 1983.Ibadan, Nigeria, pp 218.

Jackson, M.L. 1964: Chemical components of soil. In:F.F.E Bear (ed) Chemistry of soil Reinhold Publ. New York pp. 71—134.

Jaegger, C. 1983: The characterization of microporosity in a plough plan by submicropic and Quatimet techniques. Geoderma 30: 277 – 283.

Jacob J.S and Nordt L.C 1991: Soil and landscape evolution. A paradigm for pedology. Soil Sci. Soc. Am. J. 55: 1194.

Kooistra, M.J. 1984: Physical and Micromorphological characterization of undisturbed and disturbed plough pans in a sandy loam AM 8: 151 – 157.

Kooistra, M.J 1987: The effect of compaction and deep tillage and soil structure in a Dutch sandy loam. In: N. Fedoroff, L.M. Bresson and M. A.Courty Soil Micromorphology, VII Reunion International de micromorphologie des solo Paris 1985 AFES. pp 445 – 450.

Lal, R. 1979: Physical characteristics of soils of the tropics: determination and management. In: R.Lal and D.J Greenland (Editors). Soil physical properties and crop production in the tropics. John Wiley, New York. pp. 7-44.

Larson, W.E; Gupta, S.C and Useche, R.A 1980: Compression of agricultural soils from eight soil orders. Soil Science Society of America Journal. 44: 450 – 457.

Maurya P.R and Lal, R. 1979: Effects of Bulk density and soil moisture of radicle elongation of some tropical crops. In: Lal and D.J. Greenland (Editors). Soil Physical properties and crop production in the tropics. Wiley, Chichester pp 339 – 348.

Mbagwu, J.S.C and Lal, R. 1985: Effect of bulk density and irrigation frequency on the root growth and dry matter yields of corn and cowpea for three Nigeria top soil and subsoil profiles. Beitr. Trop. Land wristsh. Verterinaermed, 23: 277-285.

McCormack, D.E 1987: Land evaluations that consider soil compaction. Soil Tillage Res. 10:21-28.

Miller, F.P. 1993: Soil Science: A scope broader than its identity. Soil Sci. Soc. Am. J. 564 – 999.

Monier, G. 1993: Une me-thode de measure dela densite apprarente de petists agglome-rat terreux. Application al 'analyse des systems de porosite du sol Annales Agronomiques, 24: 533 - 545

Mullins, E.C; Macleod, D.A; Northcote, K.H; Tisdal, J.M. and Young, I.M 1989: Hardsetting soils: behaviour, occurance, and management. Adv. Soil Sci. 10:37-108.

Nielsen, D.R 1987: Emerging Frontiers in Soil Science. Geoderma 40: 260 – 273.

Notohadiprawiro, T, 1993: Rethinking the soil science paradigm. In new ways in soil science ITC Publ. No. 4.ITC, Ghent Belgium, pp. 4-16.

Nyle, B. and Brady, L. 1990: The nature and properties of soils. Cornell University and United States Agency for International Development (USAID).

O' Connell, D.J. 1975: The measurement of apparent specific gravity of soils and its relationship to mechanical composition and plant root growth. In: Soil, Physical Conditions and Crop Production. Min. Agric. Fish. Food. Tech. Bull 29, HMSO, London pp. 298 – 313.

Olson, G.W 1977: A proposal to formula national procedures and guidelines for linking soil fertility evaluation to the soil survey in the U.S Cornell Argonomy Micro 77-34, Cornell University Ithaca. N.Y 19pp.

Panayiotoplouns, K.O. and Mullins, E.C 1985: Packing of sands J. Soil Sci. 36: 129 – 139.

Pidgeon, E. and Soane, B.D.1977: Effects of tillage and direct drilling on soil properties during the growing season in a long term barley monoculture system. J. Agric. Sci. 88: 431 – 442.

Pomerening, J.A and Knox, E.G 1962: A text for natural soils groups within the Willamette Cateria population. Soil Sci. Soc.AM. Proc. 22: 282 – 287.

Powell, J.C and Springer, M.E 1958: Composition and precision of classification of several mapping units of the Applying ceil, and Lloyd series in waltton county. Georgia.Soil Sci. Am. Proc. 29: 454 – 458.

Raghavan, G.S.V; Alvo, P.; and McKyes, E. 1990: Soil compaction in agriculture: a view toward managing the problem. In Advances in soil science, R. Lal and B.A Stewart (eds), New York, Springer – Verlag. 11: 1-36.

Rhoads, F.M. and Wright, O. 1981: Influence of soil moisture and compaction on energy for subsoiling with minimum tillage. University of Florida pp. 1-5.

Robertson, J. 1984: Crop rotation affect compaction. Solutions 28: 18 – 24. SAS Institute 1982a, SAS User's Guide:Statistics. SAS Institute Cary, NC.pp 22 – 123. SAS Institute, 1982b, SAS/ Graph, Technical Report P-121, pp. 56 – 63.

Saini, G.R; Chow, T.L. and Ghanew, I. 1984: Compactibility index of some agricultural soils of New Brunswick, Canada soil science. 137: 33 – 38.

Shaw, C.F 1928: A definition of terms used in soil literature. First international Congress of Soil Science preceding proceedings and papers V. 5.pp. 38 - 64.

Simonson, R.W.1991: Soil Science-Goals for the next 75 years Soil Sci. 151: 7-18.

Singh R.A.1980: Physical soil properties. Department of Agronomy Banaras Hindu University, Varanasi 221 – 005.

Smith, G.N.1982: Elements of soil mechanics for civil engineers Collin Professional Books William Collins Sons and Company Ltd. London.

Smith, C.W 1995: Assessing compaction susceptibility of forest soil, Unpublished Ph.D Thesis, University of Natal, Pieter Maritzbury.

Soane, B.D, 1975: Studies on some physical properties in relation to cultivation and traffic. In:MAFF Technical Bulletin 29, Soil Physical conditions and Crop Production. pp 160 – 182.

Soehne, W. 1958: Fundamentals of pressure distribution and soil compaction under tractor tyres. Eng. 39: 276 – 281.

Soene, B.D 1985: Traction and Transport systems as Related to cropping systems. Scottish Institute of Agricultural Engineering. Penicuit, Midlothin, Scotland, pp. 73.

Soene, B.D; Blackwell, P.S; Dickson, J.W and Painter D.J. 1981: Compaction by Agricultural Vehicles. A review Soil and Wheel Characteristics. Soil Tillage Res., I: 207 – 237.

Soene, G.C; Godwin M.J. and Spoor G. 1986: Influence of deep loosening techniques and subsequent wheel traffic on soil structure. Soil Tillage Res. 8: 231 – 237.

Soil Survey Staff, 1975: Soil taxonomy: A basic system of soil classification for making and interpreting soils surveys Handbooks No. 436, Washington.

Stengel, P. and Douglas, J.T 1984: Factors influencing the variation of some properties of soils in relation to their suitabilities for direct drillings. Soil Tillage Res. 4: 35 – 53.

Steward B.A 1978: Steward USDA Conservation and Production Research Laboratory Bushland. Texas 79102U.S.A

Taylor, H.M.;1966: Soil strength-root penetration relations for medium to coarse textured soil-materials. Soil Sci. 102: 18-22.

Taylor, H.M.; Locke, L.F and BOX J.E 1964: Paw in Southern plains soils III. Their effects on yield of cotton and grain sorghum Agron J. 56: 542 – 545.

Taylor, H.M. and Ratiff, L.F 1969: Root elongation rates of cotton and permits as a function of soil strength and soil water content. Soil Sci. 198: 113-119.

Tiessen, J.H.1984: Pathways of phosphorus transformations in soil of different pedogenesis. Soil Sci. Soc. Am J. 48: 853 – 858.

Tinker, P.B.H.1985: Soil Science in a changing world J. Soil Sci. 36: 1-8.

Volk, G.M. 1953: Formation of plow sole pans in Florida soils. Fla. State Hort Soc. Proc. 66: 138- 141.

Voorhees, W.B.; Nelson, W.W. and Landall, G.W.1986: Extent and persistence of subsoil compaction caused by heavy axle loads. Soil Sci. Soc. Am.J. 50: 428 – 433.

Walkey, A. 1974: A critical examination of a rapid method for determining organic carbon in the soils effect of variations in digestion conditions and of organic constituents. Soil Sci. 63: 255 – 264.

Warkentin, B.P. 1992: Soil Science for environmental quality How do we know what we know. J. environ Qual. 21: 163 – 166.

Westin, F.G and Buntley, G.I . 1967: Soil phosphorus in South Dakota III. Phosphorus fractions of some Boroll and Usolls. Soil Sci. Am Proc. 31: 521 – 528.

Yaalon, D.H.1993: Soil Science in the eyes of the beholder. Bull. Int. Soc. Soil Sci. 84: 13-14.

APPENDIX A

FORMULAE

Determination of Moisture Content (M.C %)

$$\frac{\text{Weight of wet soil} - \text{Weight of dry soil}}{\text{Weight of wet soil}} \times 100$$

Determination of Porosity (%)

$$\frac{\text{Weight of saturated soil} - \text{Weight of oven dry soil}}{\text{Volume of core or soil}} \times 100$$

Determination of Bulk Density (Mg/m^3)

$$\frac{\text{Oven dry soil}}{\text{Volume of dry soil}}$$

$$\text{Volume of Soil} = \frac{\pi d^2 \times h}{4}$$

where

π - constant

d - diameter of core

h - height of core

C - Clay

SL - Sandy Loam

SCL - Sandy Clay Loam

APPENDIX B

COMPACTION TEST

Relationship between Force, Pressure and Area

Force = Pressure x Area

KN = kPa x M^2

Area = $\frac{\pi d^2}{4}$ = $0.008M^2$

KN = kPa x $\frac{\pi d^2}{4}$

KN = kPa x $0.008M^2$

Table 11: **TABLE SHOWING METHOD USED IN DETERMINING THE COMPACTION TEST**

Applied Pressure kPa	100	200	300	400	500	600	700	800	900
Force (KN)	0.8	1.6	2.4	3.2	4.2	4.8	5.6	6.4	7.2
Sinkage	0.021	0.023	0.024	0.025	0.026	0.028	0.030	0.032	0.034
Height	0.080	0.078	0.077	0.076	0.075	0.073	0.071	0.069	0.067
Diameter of Mould (m)	0.101	0.101	0.101	0.101	0.101	0.101	0.101	0.101	0.101
Height of Mould (m)	0.101	0.101	0.101	0.101	0.101	0.101	0.101	0.101	0.101
Bulk density (ρ_b)	0.125	0.127	0.130	0.20	0.210	0.220	0.210	0.200	0.220

Weight of Mould and soil	3610.0	2665.1	2722.8	2768.4	2889.9	2964.2	2953.8	2834.2	2948
Weight of Mould and compressed soil	2609.8	2664.2	2711.0	2762.6	2881.8	2860.0	2853.0	2830.0	2944
Volume of Soil (m^3)	0.8	0.9	0.8	5.8	0.4	0.5	0.6	0.6	0.8

The above data is the compaction test data of Emule forest soil. The compaction test and the moisture content of the different sites were also determined using the above method.

APPENDIX C.

TABLE 12.TABLE SHOWING THE BULK DENSITY AND THE APPLIED PRESSURE OF THE RESULTS OBTAINED FROM THE COMPACTION TEST EXPERIMENT

EMULE FOREST SOIL

Bulk Density ($g\,cm^{-3}$)	Applied Pressure (KPa)
0.125	100
0.127	200
0.130	300
0.20	400
0.21	500
0.22	600
0.21	700
0.20	800
0.22	900

UTE FOREST SOIL

Bulk Density ($g\,cm^{-3}$)	Applied Pressure (KPa)
0.016	100
0.023	200
0.022	300
0.025	400
0.026	500
0.029	600
0.025	700
0.024	800
0.022	900

AGBOWA FOREST SOIL

Bulk Density ($g\,cm^{-3}$)	Applied Pressure (KPa)
0.172	100
0.187	200
0.217	300
0.23	400
0.24	500
0.21	600
0.19	700
0.15	800
0.14	900

OBASOTO FOREST SOIL

Bulk Density ($g\,cm^{-3}$)	Applied Pressure (KPa)
0.11	100
0.12	200
0.15	300
0.21	400
0.22	500
0.22	600
0.22	700
0.20	800
0.11	900

ISUADA FOREST SOIL

Bulk Density (gcm^{-3})	Applied Pressure (KPa)
0.023	100
0.028	200
0.030	300
0.010	400
0.031	500
0.032	600
0.039	700
0.032	800
0.025	900

IYERE FOREST SOIL

Bulk Density (gcm^{-3})	Applied Pressure (KPa)
0.006	100
0.008	200
0.015	300
0.012	400
0.018	500
0.018	600
0.021	700
0.020	800
0.019	900

EMURE FOREST SOIL

Bulk Density (gcm^{-3})	Applied Pressure (KPa)
0.019	100
0.022	200
0.025	300
0.025	400
0.028	500
0.028	600
0.028	700
0.024	800
0.019	900

KAJOLA FOREST SOIL

Bulk Density (gcm^{-3})	Applied Pressure (KPa)
0.007	100
0.017	200
0.018	300
0.017	400
0.016	500
0.015	600
0.014	700
0.013	800
0.011	900

IPELE FOREST SOIL

Bulk Density (g cm-3)	Applied Pressure (KPa)
0.035	100
0.046	200
0.042	300
0.038	400
0.041	500
0.038	600
0.033	700
0.029	800
0.025	900

USO FOREST SOIL

Bulk Density (g cm-3)	Applied Pressure (KPa)
0.015	100
0.017	200
0.018	300
0.018	400
0.022	500
0.026	600
0.028	700
0.026	800
0.022	900

SASE/YEYE CAMP FOREST SOIL

Bulk Density (g cm-3)	Applied Pressure (KPa)
0.140	100
0.170	200
0.142	300
0.143	400
0.145	500
0.155	600
0.140	700
0.140	800
0.110	900

AMURIN FOREST SOIL

Bulk Density (g cm-3)	Applied Pressure (KPa)
0.160	100
0.250	200
0.330	300
0.037	400
0.037	500
0.043	600
0.043	700
0.039	800
0.035	900

OJANA FOREST SOIL

Bulk Density (gcm-3)	Applied Pressure (KPa)
0.007	100
0.008	200
0.009	300
0.009	400
0.010	500
0.009	600
0.008	700
0.007	800
0.006	900

ELEGBEKA FOREST SOIL

Bulk Density (gcm-3)	Applied Pressure (KPa)
0.011	100
0.014	200
0.016	300
0.019	400
0.019	500
0.017	600
0.015	700
0.014	800
0.013	900

ILALE FOREST SOIL

Bulk Density (gcm-3)	Applied Pressure (KPa)
0.016	100
0.020	200
0.014	300
0.065	400
0.070	500
0.065	600
0.041	700
0.029	800
0.020	900

APPENDIX D

The equation for the graph in figures (4 & 5) is $Q^2 + Bx + C = 0$. Where Q,B and C is constant. In figure 6, the graph represent a linear relationship between soil depths (y) and Bulk density (x) and gives the equation $y = mx + c$, where m is the gradient and c is the Intercept on the y- axis. All the graphs of figure 8 are quadratic graphs in the form $Q^2 + Bx + C = 0$.

APPENDIX E

STATISTICAL ANALYSIS

Mean (x) = $\frac{\sum x}{n}$

Standard Deviation (S.D) = $\sqrt{\frac{\sum x^2}{n} - \left(\frac{\sum x}{n}\right)^2}$

Mean deviation = $\frac{\sum |x - \bar{x}|}{n}$

Variance (S^2) = square of S.D

$S = \sqrt{S.D}$

$\hat{y} = \beta_o + \hat{\beta}_1 x$

$\beta_1 = \frac{SSxy}{SSxx}$

$Ssxy = \frac{\sum xy - \sum x \sum y}{n}$

$SSxx = \sum x^2 - \left(\frac{\sum x}{n}\right)^2$

$r^2 = 1 - \frac{SSE}{SSyy}, \quad r = \frac{SSxy}{\sqrt{SSxx \, SSyy}}$

$Ssyy = \sum y^2 - \left(\frac{\sum y}{n}\right)^2$

ANALYSIS OF VARIANCE

SST - Sum Square for total

SSE - Sum Square for Error

SSTr - Sum Square for Treatment

SST - $\Sigma X^2_{ij} - C$

C - $\frac{\Sigma T^2}{KN}$

n = No on roll; k - No on column

$$SSTr = \sum \frac{Ti^2}{n} - C$$

$SSE = SST - SSTr$

Ti = The total of nth observations in the ith sample

T = The grand total of all Kn observations

Table 13: TABLE FOR ANOVA

Source of Variation	Degree of Freedom	Sum of Square	Mean Square	F-Ratio
Treatment	K – 1	SSTr	$MsTr = \frac{SSTr}{K-1}$	$\frac{MsTr}{MSE}$
Error	K(n-1)	SSE	$MSE = \frac{SSE}{K(n-1)}$	
Total	nK-1	SST		

APPENDIX F

Table 14: Field criteria for determination of soil consistence (adapted from Soil Survey Staff 1975)[a]

Consistence	Conditions	Stages	Results
Dry consistence	Air dry	Loose	Falls apart. Cannot pick ped.
		Soft	Can be picked up as a mass but Falls apart with slight pressure.
		Hard	Must exert strong pressure to break the ped.
		Very hard	Cannot be broken between thumb and finger.
Moist consistence	Half way between air dry and field capacity	Loose	Falls apart. Cannot pick up a ped.
		Friable	Indents finger when crushed but only gentle pressure is needed.
		Firm	Crushes only when deliberate pressure is applied. Deeply indents the fingers.
		Extremely firm	Cannot be crushed between thumb and forefinger.
Wet consistence	Slightly above field capacity	Stickiness	Press between thumb and finger
		Non stickiness	Almost none adheres to either finger.
		Sticky	Stretches noticeably before breaking and leaves materials on both fingers.
		Very sticky	Stretches as one exerts strong effort to pull fingers apart.
		Non plastic	Cannot form a wire by rolling in fingers.
		Slightly plastic	Can form a wire by rolling
		Plastic	Can form a wire that will bear to own weight must press to.

[a] Consistence expresses degree and kind of adhesion and cohesion, and is given for dry, moist and wet soil.