INFLUENCE OF PARENT MATERIALS ON COMPOSITION AND QUALITY OF PLINTHITE AS A RAW MATERIAL FOR THE BUILDING AND CONSTRUCTION INDUSTRY

BY

Stephen Garba ZARAFI

DEPARTMENT OF SOIL SCIENCE,
FACULTY OF AGRICULTURE,
AHMADU BELLO UNIVERSITY,
ZARIA, NIGERIA

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Stephen Garba ZARAFI,
B.Sc. (GEO.), M.Sc. (SOIL SCIENCE), AHMADU BELLO UNIVERSITY (ABU), ZARIA
PhD/Agric/03996/2008-2009

A DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY (SOIL SCIENCE)

DEPARTMENT OF SOIL SCIENCE,
FACULTY OF AGRICULTURE,
AHMADU BELLO UNIVERSITY,
ZARIA NIGERIA

JANUARY, 2018

DECLARATION

I declare that the work in this thesis entitled “Influence of Parent Materials on Composition and Quality of Plinthite as a raw material for the building and construction industry has been carried out by me in the Department of Soil Science, Ahmadu Bello University Zaria. The information derived from the literature has been duly acknowledge in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at this or any other institution.

Stephen Garba ZARAFI		
Name of Student	Signature	Date

CERTIFICATION

This thesis entitled: “**INFLUENCE OF PARENT MATERIALS ON COMPOSITION AND QUALITY OF PLINTHITE AS A RAW MATERIAL FOR THE BUILDING AND CONSTRUCTION INDUSTRY**” by Stephen Garba Zarafi meeting the regulations governing the award of the degree of DOCTOR OF PHILOSOPHY of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

Prof. B. A. Raji
Chairman, Supervisory Committee ______________________ ________________
Signature Date

Prof. A. C. Odunze
Member, Supervisory Committee ______________________ ________________
Signature Date

Prof. Y.D. Amartey
Member, Supervisory Committee ______________________ ________________
Signature Date

Dr. W. B. Malgwi
Member, Supervisory Committee ______________________ ________________
Signature Date

Prof. Ado A. Yusuf
Head, Department of Soil Science ______________________ ________________
Signature Date

Prof. A.Z Abubakar
Dean, School of Postgraduate Studies ______________________ ________________
Signature Date

DEDICATION

This thesis is dedicated to my Grand Father, Pastor Samaila Yarima Inusa Wushishi and to my parents Mr. and Mrs. Garba C. Zarafi who are his role models.

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ABSTRACT

Pedogenic properties of plinthic (laterite) soils developed on two parent materials; basement complex and basaltic rock in Northern Guinea Savannah, Nigeria were studied with a view to determine the influence of composition and quantity of the soil (plinthite) as a raw material for the construction industry. Four pedons were dug on each parent material. Soil morphological, physico-chemical and mineralogical properties were examined and the soils were classified using USDA and WRB systems. Results indicated that soil morphological properties were generally similar, except for variation in depth and structure. The soils were generally deep to very deep. Dark brown colors dominated the soil surface layers, while red and reddish yellow and yellowish red colours dominated the subsurface horizons. Texture of surface soils were sandy loam, the subsurface soils had sandy clay loam in the plinthic layers and were dominated by subangular blocky structure throughout the eight pedons. Sand fraction dominated the soil separates. Particles density ranged between 2.02 Mg/m^3 (Pedon BS2, Btcv1) and 2.76 Mg/m^3 in (BS1, BCcv) at the surface and subsurface horizons of all the profiles. Bulk density values ranged from 1.31 to 1.80 Mg/m^3. Total porosity values ranged from 28 to 49%. Soil reaction of all the profiles indicated extremely acid to moderately acid throughout the soil depth with pH values ranging from 3.8 to 5.8. Cation exchange capacity (CEC-NH4OAc) values were low to high and moderate base saturation dominated the soils. Values of organic carbon were generally low (0.02 – 0.68 cmo1(+) kg^{-1}). Calcium was the dominant exchangeable base in all the profiles. Exchangeable magnesium (Mg) decreased regularly with soil depth while sodium content was irregularly distributed. Exchangeable sodium percent values decreased regularly with depth in the subsurface horizons of all the profiles except BS1 and BS2 which were irregularly distributed with depth. CBD extractable form of iron ranged from 1.27 to 3.79% in all the profiles studied, while oxalated extractable obtained 0.33 to 1.61% and pyrophosphate extractable recorded range 0.09 to 1.61% in all the soils. Active iron ratio ranged from 0.06 to 0.95 while clay/dithionite obtained ranged from 7.47 to 89.82 in all the profiles. Aluminum oxide (CBD) ranged from 0.01 to 0.10% with active ratio of ranged 0.01 to 0.17. Manganese oxide (CBD) ranged 0.01 to 0.10% with active ratio range 0.01 to 1.73. Total elemental oxides of silicon, aluminum and iron values dominated all the soils; silicon being most dominated, followed by Fe_2O_3 and Al_2O_3. Geotechnical properties and compressive strength of the soils revealed that soils developed on the basement complex parent material had the highest strength (1.87 Nmm^2) in pedon OL while the lowest strength of materials (0.53Nmm^2) in pedon BS2 in the Basaltic soils. The soils generally fell into two classes in both systems (AASHTO and USCS) used for the engineering classification. Using AASHTO, the Basement complex soils SC and OL were observed to fall into A-2-7 (O) group which was rated excellent to good, while OGR and YL were grouped as A-6(4) and A-7-6(7) in which were rated as fair to poor. However, all the Basalts also fell within A2 at group level, that is, A-2-6(0), A-2-7(1), A-2-7(0) and A-2-7(0) for BS1, BS2, BS3 and BS4 respectively and were rated excellent to good. For the USCS system, the soils were classified as SC, SC, SC, SC, SM, SC, SC, SC and SM respectively. All the pedons were classified as Alfisols except for BS1 as Ultisols using USDA soil taxonomy and plinthic Luvisols (WRB).

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CHAPTER ONE

1.0 Introduction

1.1 Background Information

The term plinthite was introduced in the early 1960s as a substitute for the term laterite and to depict a diagnostic feature in the soil. The term originates from the Greek word plinthos, meaning brick (Eswaran *et al.*, 1990). Plinthite is a relatively new terminology coined by Soil Survey Staff (1975) to describe soil materials that would later form or develop into ironstone or petroplinthite. It has a verbose definition (Soil Survey Staff, 2003), but is formed mainly from iron (Fe) and to some extent, aluminium (Al) and manganese (Mn) oxides in the B horizons of soils. When formed plinthite is soft; however, when exposed to the surface (through erosion) and/or subjected to alternating wetting and drying conditions, it hardens irreversibly into what is known as ironstone or petroplinthite (Daniels *et al*., 1978, dos Anjos *et al*., 1995).

Petroplinthite constitutes a barrier to both water and air movements and root penetration (Carlan *et al*., 1985; Blume *et al*., 1987; Stolt *et al*., 1993). The exposure of plinthite to the surface and its subsequent hardening into petroplinthite may render the soil anything from very shallow to bare, thus greatly reducing the agricultural value of the land (Yaro *et al.*, 2006).

It has long been recognized that parent material has a major influence on the physical and chemical properties of soils. It is one of the five traditionally accepted factors of soil formation, the others being climate, topography, organic material and time (Gray and Murphy 2002). Several definitions and perceptions about soil parent material exist. In general, parent material is the initial state of soil formation (Jenny, 1941). It is considered to provide the primary raw material upon which the other influencing factors will serve to modify (Gray and Murphy 2002).

Plinthite is reported to develop more commonly in gently sloping to flat lying topography (McFarlane, 1976) and at the foot slopes of landscape (Theng, 1980; Esu *et al*., 1987; dos Anjos *et al*., 1995) which are more suitable for mechanized agriculture. The danger is the long-term reversal of topography as the petroplinthite caps the surface of the flat lying land rendering it almost useless for agriculture (Macleod *et al*., 1971), as erosion undermines the non-plinthitic soil circumventing the petroplinthite cap, eventually producing landforms known as mesas (Higgins, 1961). Mesas are more or less obstacles to agriculture. Even when not converted into petroplinthite, the formation of plinthite depletes the soil of bases (Magnien, 1966; Ibanga, 1980) due to desilication. Thus, plinthitic soils are generally poor in agricultural value.

The formation of the principal mineral components of laterite, the hydrated oxides of iron and aluminium, are mostly confined to the humid tropical and sub-tropical zones of the world, including Africa, India, South-East Asia, Australia, Central and South America. It should be emphasized that, because of shifts of climatic zone in the geological past, important areas of laterite can be found in areas now outside the tropics (Charman, 1988). In Nigeria, Lateritic and non-lateritic tropical soils occur abundantly and they are widely used for various earthwork engineering constructions such as pavements, embankments, earth dams. The degree of success in each case may be attributed to the geotechnical characteristics of the soils, design techniques, construction procedures, environmental factors and the specific function of the structure e.g. traffic in the case of roads.

Laterite being a major resource in the tropical, humid parts of the world by its varied uses contributes to the general economy: as mineral ore - possible source of aluminum (Africa), iron (Goa and Canara), and nickel (Indonesia), as substrate in aquatic structures like ponds and reservoirs, as alternative building material for low cost housing (stabilized brick using laterite soil), in road construction - as road substrate stabilized with fly ash and lime, and as a masonry material like other stones (Gidigasu, 1976).

1.2 Problems Statement

Despite the long-term use of Laterite in building applications worldwide, only few countries have scientifically documented its engineering properties and standards (Kasthurba and Santhanam, 2005). Non-availability of standards and lack of scientific data on laterite are the main issues for its building application in various countries especially in Burkina Faso, Africa (Lawane *et.al.*, 2011). Indian standards code IS 3620-1979 provides specifications and standards for laterite masonry construction in India (IS 3620-1979). Extensive studies on laterite masonry blocks (LMB) undertaken at the Indian Institute of Technology Madras (IITM) demonstrated the deficiencies in the IS code specifications on testing procedures which was favorably considered for amendments (Kasthurba and Santhanam, 2010). However, unique material properties and regional variations have rendered laterite stone as subject of controversy. Often this material faces uncertainties and reluctance to use by engineers for its building applications due to the ambiguity of behaviour, local variations and lack of standards. Standardization and optimal use of laterite is highly essential for its efficient utilization and for economic, energy and environmental benefits. Unique issues of laterite need to be addressed to formulate appropriate procedures for its evaluation and develop suitable standards for its building applications with future outlook.

Building sector is responsible for more than 50% of CO_2 emissions and energy consumption due to production of building materials and construction operations (Lawane *et al.*, 2012). The International Conference on Eco-materials for Construction held at 2iE, Ouagadougou, Burkina Faso, Africa, discussed the challenges linked with building construction on the environment impact caused by the manufactured materials in African countries (Tsobnang, 2013). The technical discussions at this conference emphasized the need for using local materials, especially laterite, to achieve sustainable construction. In Africa, priority has been given to laterite amongst the locally available masonry materials, as resource to housing to resolve the economic and environmental problems, compared to concrete or cinder block construction (Lawane *et al*., 2012).

1.3 Justification

Utilization of local materials is an important step to sustainable construction by reducing transportation cost, embodied energy and environmental protection (Baker, 1987).

In many countries, the need for locally manufactured building materials can hardly be overemphasized because there is an imbalance between the demands for housing and expensive conventional building materials coupled with the depletion of traditional building materials. To address this situation, attention has been focused on low-cost alternative building materials.

Economic growth has inevitably led to increasing demands for housing needs in developing countries and building materials play a significant role in this. Several technical organizations across the world have developed guidelines for assessment of environmental quality (e.g., LEED, BREAAM, and HQE) that combine material characteristics with their evaluation (Kibort, 2013). The popularity of laterite uses in current construction projects in India and Africa (Burkina Faso) was discussed from the technical studies presented (Tsobnang, 2013). Therefore, it is highly important to develop a future standpoint for efficient and optimal utilization of laterite in building applications for economic and environmental benefits.

In the Northern part of Nigeria, abundant lateritic soil deposits exist which can be harnessed for brick production. Compared to sandcrete blocks, it is economic to use laterite for brick production because very little cement is required and the cost of transportation is eliminated as production takes place on site. Compared to fired clay bricks, the production of laterite bricks does not involve the firing process. To cure the laterite bricks, they are covered with tarpaulin and waterproof devices thereby making the process to be more environmental friendly. Laterite bricks are fire resistant and bulletproof.

From experience, laterite bricks of 330 × 150 × 150 mm have proved to be economic and can be easily laid. It is an improvement on the fired clay bricks of 250 × 150 × 100 mm because 22 bricks are required per meter square of wall as against the 33 required for fired clay bricks. Consequently, the mortar required for jointing per square meter of wall is reduced significantly (Agbede and Joel, 2008)

Good laterite bricks were produced from different sites in Kano when laterite was stabilized with 3 to 7% cement. The study showed that particle size distribution, cement content, compactive effort and method of curing are factors which affect the strength of the bricks Aggarwal and Holmes (1983).

Laterite bricks were made by the Nigerian Building and Road Research Institute (NBRRI) and used for the construction of a bungalow. From the study, NBRRI proposed the following minimum specification as requirements for laterite bricks: bulk density of 1810 kg/m^3, water absorption of 12.5%, compressive strength of 1.65 N/mm^2 and durability of 6.9% with maximum cement content fixed at 5% (Madedor, 1992).

Several researchers have reported that cement-stabilized laterite can be used in road and building construction (Osula, 1996). In Nigeria there are few reports on the composition and quality of plinthite as raw material for building and construction industries.

1.4 Objectives

This study aims at examining the composition and quality of plinthites as raw materials for building and construction industries. The specific objectives of this study are:

1. To determine the morphological, physico-chemical and mineralogical properties of plinthic materials on two (2) different parent materials (Basement Complex and Basaltic rocks).
2. To determine the compressive strength of the plinthites from the various plinthic layers of all the pedons.
3. To determine the geotechnical properties of the plinthites in the various pedons for the purpose of interpreting the variations observed in the compressive strength and for engineering soil classification for construction.
4. To determine relationship between the nature of soil properties in the various plinthic layers and their quality for building and construction use.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin and Development of Plinthite

The term laterite first appeared in the scientific literature more than 200 years ago (Maignien, 1966) and seems to have been first used by Dr. Francis Buchanan-Hamilton to denote a building material used in the Malabar district of India. (Buchanan, 1807). Its appearance was described as “that of a ferruginous deposit of vesicular structure, apparently unstratified, and occurring not far below the surface”. Moreover, Buchanan observed that “when fresh, it can readily be cut into regular blocks with a cutting tool. However, on exposure to the air, it rapidly hardens and becomes highly resistant to weathering”. Thus, the unusual feature of the material first described by Buchanan under the name laterite, from the Latin word later, which means a brick, was that it had a soft consistency in situ but hardened rapidly on exposure – a phenomenon which led to the use of this material as a building brick. Modern pedological terminology would now perhaps describe Buchanan’s laterite as plinthite (Netterberg, 2014).

Kasthurba *et al.,* (2014) stated that Lateritic soils are highly weathered and altered residual material formed by the in-situ weathering and decomposition of rocks in tropical regions of all over the world having heavy rainfall. They are formed by intensive and long-lasting weathering of the underlying parent rock due to leaching of silica over a long period of time leaving a soil, rich in iron oxides, hydroxides and alumina. When such lateritic soils are exposed to atmosphere, the iron hydroxides lose the moisture quickly to form iron oxides, which develop a good bond with other particles in soil to form the concretionary laterite. Lateritic soils are rich in sesquioxides (Fe_2O_3, Al_2O_3 or both) and low in bases and primary silicates but may contain appreciable amounts of quartz and kaolinite. Due to the presence of iron oxides, lateritic soils are red in color ranging from light through bright to brown shades. They are composed essentially of hydrated aluminum and iron oxides and they can be used as a good building material (Varghese and Byju 1993).

2.2 Distribution of Plinthite in Nigeria

Laterite/Plinthite and associated soils are widely distributed in the tropics and subtropics of Africa, Australia, India, South-East Asia, and South America (Kasthurba *et al.*, 2014). The first global synthesis of the distribution of laterite prepared by Prescott and Pendleton in 1952 is presented in figure 1. (Pearson, 1970). One of the major difficulties to develop an integrate database of worldwide laterite research is lack of consistent terminology and information exchange. Laterite is known with different names in different countries and even in different parts of the same country (Kasthurba *et al*., 2014). The names of laterite in different countries are listed in Table 1 (Aleva, 1994).

In Nigeria, Finelib, (2017) reported that Lateritic clay deposits are often cheaply or freely found in any market centre in Nigeria and in most states of the country. Nigeria is one of the laterite producing country, but not effectively utilized. Fig. 2 shows some states in Nigeria where laterite materials are abundant.

Laterite has been used in most Nigerian construction works because it is fairly cheap and retains water. In as much as the mining of this mineral resources is beneficial, it is good to know that it leads to severe land degradation and erosion, loss of agricultural farmlands, groundwater contamination etc., as the land coverings including grasses and plants are removed during the quarrying process.

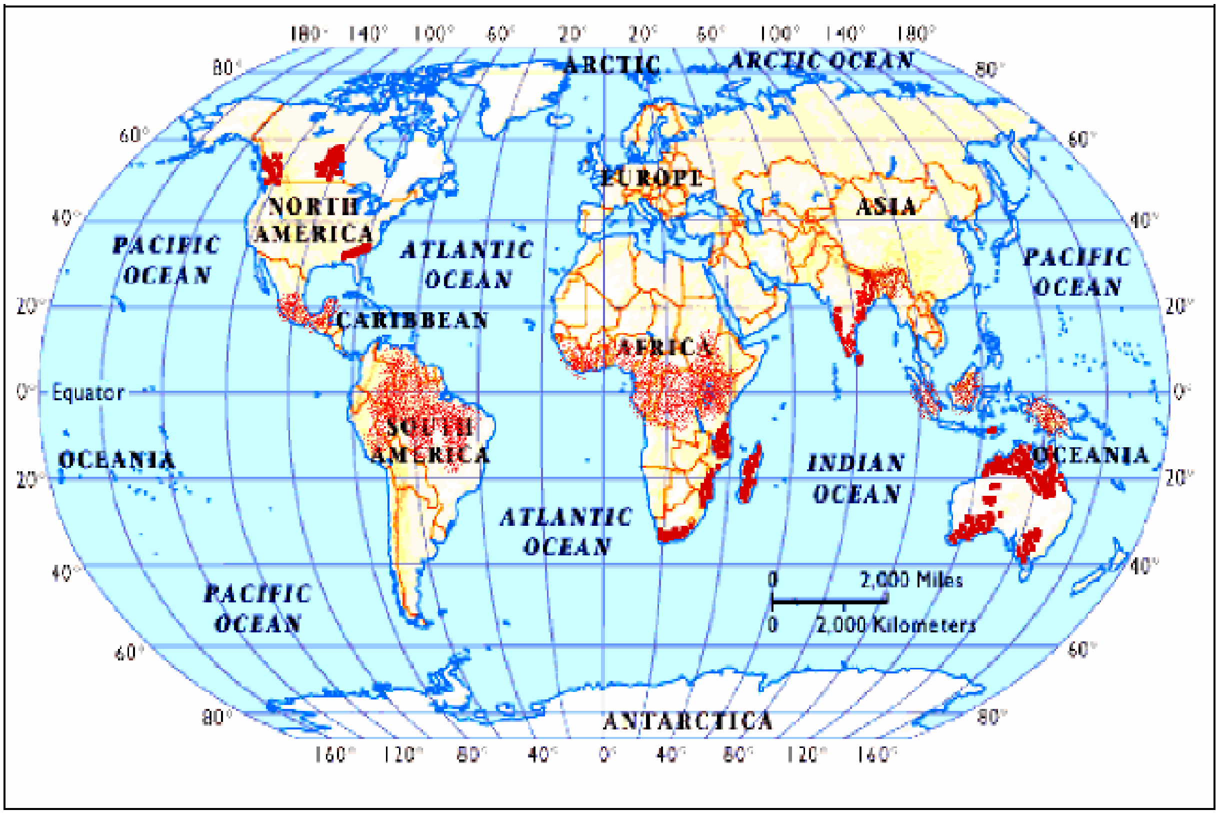

Fig 1: Worldwide distribution of Laterite (Pearson, 1970)

Table 1: Different names of Laterite in different Countries

Name Given	Country
Laterite/Brick stone	India
Ittica kallu/vettu kallu	India (Kerala)
Cabook	Ceylon
Canga	Brazil
Carapace	France
Eisenkruste	Germany
Iron clay	India
Ironstone	Nigeria
Krusteneisensteine	Germany
Mantle rock	Ghana
Moco de hierro	Venezuela
Murram	East Africa
Picarra	Brazil
Ferricrete	South Africa
Pisolite	Australia
Plinthite	USA

Source: (Aleva, 1994)

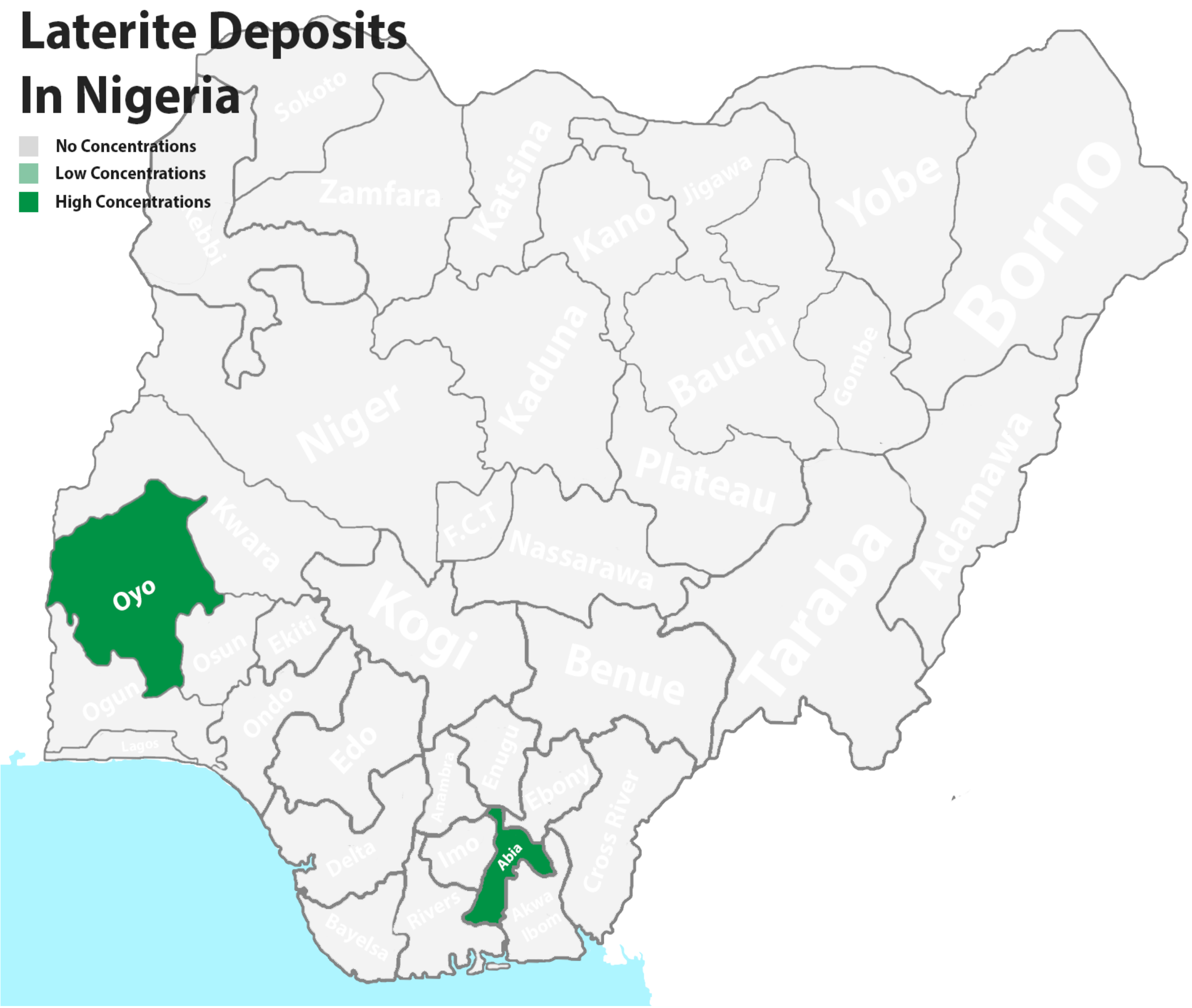

Fig 2: Laterites Deposit in Nigeria States

Laterite bricks were made by the Nigerian Building and Road Research Institute (NBRRI) and used for the construction of a bungalow (Madedor, 1992). From the study, NBRRI proposed the following specifications as requirements for laterite bricks: bulk density of 1810kg/m^3, water absorption of 12.5%, compressive strength of 1.65N/mm^2 and durability of 6.9% with maximum cement content fixed at 5%. Good laterite bricks were produced from different sites in Kano, Nigeria when laterite was stabilized with 3 to 7% cement and the study showed that particle size distribution, cement content, compactive effort and method of curing are factors, which affect the strength of bricks (Aggarwaal and Holmes, 1983).

2.3 Importance of Plinthite

Plinthite/Laterite is a stone of a thousand uses. Many are well known to the modern engineer yet many still lie buried beneath green vines, shifted sands, or cracked stucco. Mukerji and Bahlmann (1978) indicated that laterites are difficult to use in road construction as their properties vary considerably and this variability makes their use difficult. They do note the fact that the materials achieve relatively high strengths and water resistance on drying. Similarly, when excavated in "vertical cuts, highly laterized soils can be self-stabilizing (after hardening on exposure to the air). Nogami and Villibor (1991) reported that fine grained lateritic soils were used only for subbase (or stabilized with cement for base) until the early 1970s when trial sections were done with neat soils. Routine use of such lateritic soils for base for low to medium traffic in Sao Paulo State started in the 1980s. In many cases they were blended with gap-graded crushed stone for more heavily trafficked roads. The area has rain in all months with between 1000 and 2000 mm annually (Thornthwaite 5 – 100). Although Charman (1988) suggested their use for low volume road bases only, they are used in Brazil for up to 1500 vpd and 5 MESA

(Villibor, 2006) – their use clearly not being limited to low volume roads. Apart from Laterite uses in construction, they are also use in medical, architectural industry, Commercial uses include oil and gas reservoir, source of bauxite, used in aquariums. According to the Laterite features like texture, appearance, hardness, streak, toughness, resistance etc., it is used for various antiquity uses. Antiquity uses of Laterite include Artifacts, Monuments and Sculpture.

2.4 Factors of Plinthite Formation

Tropical weathering (laterization) is a prolonged process of chemical weathering which produces a wide variety in the thickness, grade, chemistry and ore mineralogy of the resulting soils (Dalvi *et al*., 2004). The initial products of weathering are essentially kaolinized rocks called Saprolites (Bellan *et al*., 2007).

Tardy (1997) reported that plinthite are formed from the leaching of parent sedimentary rocks (sandstones, clays, limestones); metamorphic rocks (schists, gneisses, migmatites); igneous rocks (granites, basalts, gabbros, peridotites); and mineralized proto-ores which leaves the more insoluble ions, predominantly iron and aluminium. The mechanism of leaching involves acid dissolving the host mineral lattice, followed by hydrolysis and precipitation of insoluble oxides and sulfates of iron, aluminium and silica under the high temperature conditions (Whittington and Muir, 2000) of a humid sub-tropical monsoon climate (Hill *et al*., 2000).

An essential feature for the formation of plinthite is the repetition of wet and dry seasons. Rocks are leached by percolating rain water during the wet season; the resulting solution containing the leached ions is brought to the surface by capillary action during the dry season. These ions form soluble salt compounds which dry on the surface; these salts are washed away during the next wet season (Yamaguchi, 2004). Plinthite formation is favoured in low topographical reliefs of gentle crests and plateaus which prevents erosion of the surface cover (Dalvi *et al*., 2004).

Tardy, (1997) reported the mineralogical and chemical compositions of plinthite are dependent on their parent rocks. They consist mainly of quartz, zircon, and oxides of titanium, iron, tin, aluminium and manganese, which remain during the course of weathering. Quartz is the most abundant relic mineral from the parent rock.

Plinthite vary significantly according to their location, climate and depth. The main host minerals for nickel and cobalt can be either iron oxides, clay minerals or manganese oxides (Whittington and Muir, 2000) . Iron oxides are derived from mafic igneous rocks and other iron-rich rocks; bauxites are derived from granitic igneous rock and other iron-poor rocks (Yamaguchi, 2004). Nickel plinthite occur in zones of the earth which experienced prolonged tropical weathering of ultramafic rocks containing the ferro magnesian minerals olivine, pyroxene, and a mphibole (Dalvi *et al*., 2004).

2.5 Characteristics of Plinthite

Plinthite is an unusual soil which is rich in iron and alumina. Plinthite occurs in tropical humid regions within 300°N and 300°S of equator and these regions belong to less developed areas in economic and scientific terms (Kasthurba, *et al*., 2014). Plinthite and plinthite soils have been efficiently utilized in civil engineering applications like road base and low-cost housing (Madhu, 1977). Laterite cannot be placed in the triplet family of rocks, namely igneous, sedimentary or metamorphic. It is considered as metasomatic rock (Kasthurba and Santhanam, 2007). Metasomatism is a metamorphic process by which the chemical composition of a rock or rock portion is altered in a pervasive manner which involves the introduction and/or removal of chemical components as a result of the interaction of the rock with aqueous fluids (solutions). During metasomatism, the rock remains in a solid state. They are usually found in heavily rainfall regions formed by intensive and long-lasting weathering. Silica in the clay is usually leached out over a long period of time leaving the residual soil rich in iron oxides, hydroxides and alumina. When lateritic soils are exposed to atmosphere, the iron hydroxides lose the moisture quickly to form iron oxides, which develop a good bond with other particles in soil to form the plinthite blocks (Kasthurba, *et al*., 2014). This process of irreversible surface hardening known as induration is due to oxidation as a result of exposure to atmosphere. The progressive strengthening was due to mineral transformation from goethite to hematite which is a more stabilized form makes it suitable as a building material (Kamasew *et al.*, 2013). Plinthite vary in colour, texture, structure, morphology and engineering properties as they vary in their chemistry and mineralogy (Netterberg, 2014).

Plinthites are essentially two-component mixtures of the original host or parent material and the authigenic cementing, replacing or relatively accumulated minerals (mostly sesquioxides but also certain clay minerals). As the plinthite develops, so the authigenic mineral content increases until it may constitute almost the whole material. Thus, hardpan plinthite can be expected to have a higher content of sesquioxides ($Al_2O_3 + Fe_2O_3$) than a nodular plinthite (Netterberg, 2014). Table 2 shows the typical chemical composition of materials described as plinthites (or ferricretes in southern Africa) (Netterberg, 1985) and Table 3 shows the minerals usually found in plinthites (Netterberg, 2013).

The citrate-carbonate-dithionite (CBD)-extractable iron content (a measure of the total free iron oxide and hydroxide minerals present) of hardpans plinthite ranges between 43 and 77 % (Fitzpatrick, 1978; Fitzpatrick and Schwertmann, 1982). In the case of plinthic soils and gravels

Table 2: Typical Chemical Composition of Plinthites

Component	**% By Mass**	**Main Form of Occurrence**
SiO_2	5 -70	Quartz, Feldspar, Clay Minerals
Al_2O_3	5 -35	Feldspar, Clay Minerals, Gibbsite
Fe_2O_3 (2)	5 -70	Goethite, Hematite
TiO_2	0 - 5	Anatase, Rutile
MnO	0 - 5	?
P_2O_5	0 - 1	
H_2O +	5 - 20	Clay Minerals, Goethite, Gibbsite
Loss on Ignition	5 - 30	Clay Minerals, Goethite, Gibbsite, Organic Matter
Organic Matter	0.2 - 2	Organic Matter

Note: Bauxite and Total Iron are excluded

Source: Netterberg, 1985

Table 3: Sesquioxide minerals typically found in Lateritic materials

Major Element	**Mineral [1]**	**Composition [2]**	**Colour [3]**
Fe	limonite [3]	$Fe.OH.\ nH_2O$	yellow to brown
	goethite	α- FeO(OH)	yellow tobrown to black
	lepidocrocite	γ- FeO(OH)	Orange
	haematite	$\alpha - Fe_2O_3$	red, reddish brown to black
	maghemite	$\gamma - Fe_2O_3$	reddish brown
	magnetite	Fe_3O_4	iron black
	ferrihydrite	$FesHO_8.H_2O$ [4]	reddish brown
Al	gibbsite	$\gamma - Al(OH_3)$	white, greyish, greenish or reddish white
	boehmite	γ - AlO(OH)	white grey, pale lavender, yellow-green
	diaspore	α --AlO(OH)	white grey, pale lavender, yellow-green
Mn	pyrolusite?	MnO_2	Iron black
	manganite?	MnOOH	grey to black
Ti	anatase	TiO_2	red, reddish brown to black
	rutile	TiO_2	red, reddish brown to black
	ilmenite	$FeTiO_3$	Iron black

Source: Netterberg, 2013

Notes:

[1] Other non-sesquioxide mineral include Kaolinite, halloysite, metahalloysite, illite, smectite, chlorite and allophane; while significant organic matter may also be present

[2] A field term used to refer to natural hydrous iron oxides of uncertain identity

[3] Also given as Fe_5O_7 (OH).$4H_2O$, $Fe_2O_3.2FeOOH.2.6H_2O$, $FesHO_8.4H_2O$. etc.

the content of Fe_2O_3 increases and that of Al_2O_3 decreases with particle size, while SiO_2 is highest in intermediate fractions (LNEC *et al*., 1969). Studies on the mineralogy of plinthite in Angola and Mozambique (LNEC *et al*., 1969), South Africa (Fitzpatrick, 1974, 1978, 1983) all show the iron and aluminum in these materials to be dominantly in the form of goethite FeO(OH) (yellow-brown) with lesser haematite (Fe_2O_3), (red) and gibbsite ($Al(OH)_3$) (white), and rarely maghemite (Fe_2O_3) (reddish-brown). Traces of anatase (TiO_2) and rutile (TiO_2) may also be present.

The mineralogical composition of the lateritic soil has an influence on the geotechnical parameters such as specific gravity, shear strength, swelling potential, Atterberg limits, bearing capacity and petrograpic properties (Amadi *et al*., 2012).

2.6 Parent Material

Soil parent material is the material that soil develops from, and may be rock that has decomposed in place, or material that has been deposited by wind, water, or ice. The character and chemical composition of the parent material plays an important role in determining soil properties, especially during the early stages of development (Ritter, 2006).

Plinthites are characterized by their unique color, poor fertility, and high clay content and lower cation exchange capacity. In addition, lateritic soils possess a great amount of iron and aluminum oxides (Shawn, 2001). Iron oxides, existing mainly in the amorphous and crystalline inorganic forms, are one of major components in many soil orders. Parent material is a key factor affecting the iron and mineral composition and distribution for plinthic soils. Anda *et al*., (2008) reported a series of oxisols derived from serpentinite, basalt, and andesite and found that the content of iron oxides has an obvious different distribution. Approximately 19% of iron oxide was determined for the plinthic soils derived from serpentinite. Different parent materials also bring the different physical and chemical properties.

2.7 Geotechnical Properties of Plinthite

The geotechnical properties of lateritic materials generally depend on three factors as revealed by Netterberg, (2014) namely: the nature of the host or parent material (e.g. whether it was predominantly clay, sand or rock); the stage of development (i.e. the extent to which the host material has been cemented or replaced); and the nature of the cementing and/or replacing sesquioxide minerals.

During development, the finer particles, such as clay, silt and sand, tend to become flocculated, aggregated, and cemented into silt to gravel-sized particles of varying strength and porosity (Netterberg, 1969; 1971; various authors cited in Gidigasu, 1976; and Morin and Todor, 1976). These particles or aggregations may or may not be broken down during laboratory testing and during construction. Moreover, both the clay mineral and the cementing and replacing minerals are different from the minerals in the temperate zone soils consisting of discrete particles from which much of our geotechnical experience and specifications have been derived (Netterberg, 2014). Plinthites can therefore be expected to exhibit certain differences in behaviour from “traditional”, temperate zone, materials as illustrated in Table 4.

The presence of porous particles found in laterite, for example, will tend to increase all moisture content determinations, including Atterberg limits, whereas in traditional soil mechanics it is usually assumed that all the water is outside the particles. Kaolinite, the dominant clay in most plinthic materials, has a non-expansive lattice which, compared to other clay mineral types such as smectite, makes the material less susceptible to volumetric expansion in the presence of moisture (Netterberg, 2014). Moreover, the sesquioxides in plinthites may be hydrated and/or

Table 4: Differences between traditional and pedogenic materials

Property	Traditional	Pedogenic
Composition	Natural or crushed aggregate with fines	Varies from clay to rock
Aggregate	Solid, strong rock	Porous, weakly cemented fines
Fines	Rock particles with or without clay	Cemented, coated and aggregated clay and/or silt particles
Clay minerals	Mostly illite or smectite	Wide variety, e.g Kaolinite, Halloysite Palygorskite etc.
Cement	None (usually)	Iron oxides, calcium carbonate, etc
Hydration	None	Variable
Chemical reactivity	Inert	Reactive
Solubility	Insoluble	May be soluble
Weathering	Weathering or stable	Forming or weathering
Atterberg limits	Stable	Sensitive to drying and mixing
Grading	Stable	Sensitive to drying and working
Salinity	Non-Saline	May be saline
Self-stabilization	Non-self-stabilizing	May be self-stabilizing
Stabilization (cement)	Increase strength	Usually increases strength
Stabilization (lime)	Decreases plasticity	Usually decreases plasticity And/or increases strength
Variability	Homogeneous	Extremely variable
Climate	Temperate to cold	Arid, tropical and temperate
Traffic	High	Low

Note: “Traditional” materials: comprise typically fluvioglacial gravels found in temperate, northern hemisphere countries as well as crushed rock.

Pedogenic materials: comprise materials such as laterite and calcrete and are formed by pedogenic processes.

Source: (Netterberg, 1976)

amorphous, while clays such as hydrated halloysite and allophane may be present. The possible effects of these minerals have been well reviewed by Morin and Todor (1976) and Gidigasu (1976) and, to a large extent, account for the so-called “relaxed” specifications adopted for selecting plinthites, compared with the more traditional specifications such as those of AASHTO (2011).

In essence, the differences between traditional and pedogenic materials (e.g. plinthites) render the geotechnical behaviour of the latter less predictable for the interpretation of the results of fundamental engineering tests such as Atterberg limits and grading (Netterberg, 2014).

The geotechnical properties of plinthites generally considered to be the most relevant to their performance include: particle size distribution, atterberg limits, strength of the coarse particles, compaction and bearing strength. Another aspect of plinthic materials which may be relevant is the concept of self-hardening, or a time-dependent improvement in performance in traditional specifications (Netterberg, 2014).

2.7.1 Particle Size Distribution

Netterberg, (2014) reported that grading analyses are only applicable to the more immature types of laterite such as relatively loose or soft soils like plinthite, nodular laterite and honeycomb laterite in their natural state. Other varieties occur as either boulder or hardpan laterite which are too coarse, or as indurated horizons which require excavation and processing before they can properly be said to have a grading. Moreover, such grading may also be changed by construction processes and by the test method adopted. A clear understanding of the assumptions implicit in the test and calculation methods is therefore fundamental to the assessment of any analysis of particle size.

2.7. 2 Atterberg limits, shrinkage and swelling

According to Netterberg, (2014), atterberg limits (plastic index and liquid limit), together with shrinkage and swell limits, are used in most traditional specifications as selection criteria for road construction materials. However, for laterites, the determination of these limits is fraught with a number of complications and the results are also atypical of those associated with traditional (non-pedogenic) materials as summarized below:

2.7.2.1 Material variability

The plasticity of plinthites varies widely, both from borrow pit to borrow pit and within a borrow pit. This makes it necessary to stockpile the material very carefully on the basis of a visual assessment of its homogeneity to ensure that each stockpile is as similar as possible for testing purposes (Netterberg, 2014).

2.7.2.2 Sensitivity to preparation of soil fines

The results of the Atterberg limit tests are very sensitive to the manner of preparation of the soil fines in terms of mechanical reworking and drying, and these actions may cause irreversible changes in their engineering properties (e.g. Morin and Todor, 1976; Sharp *et al.*, 2001). Some examples of the effect of remoulding are shown in Table 5 which suggest that mechanical processing (e.g. excavating, grading, compacting) of an insitu laterite may degrade its engineering properties.

Table 5: Effect of remoulding on Atterberg Limits of lateritic soils

Soil	**Liquid limit**		**Plasticity Index**		**Source**
	Natural	**Remoulded**	**Natural**	**Remoulded**	
Red clay, Kenya	74	84	36	45	Newill (1961)
Red clay, Kenya	77	91	16	32	Newill (1961)
Lateritic soil, Cuba	46	53	15	22	Winterkorn *et al*., (1951)
Lateritic soil, Cuba	60	70	21	30	Townsend (1969)

Source: (Townsend, 1985)

2.7.2.3 Air drying versus oven drying

Netterberg, (2014), revealed that conventional oven drying at 105°C can irreversibly change many of the properties of plinthites. Drying is necessary for all of the common tests (grading, Atterberg Limits and compaction characteristics) but it is suspected that oven drying removes some of the water of hydration, which does not affect the material properties but is reflected in higher moisture content determinations.

2.7.2.4 Period of mixing

Materials with friable and aggregated particles such as plinthites are sensitive to the degree and period of mixing. A mixing time of 10 minutes is specified in NITRR (1979; TMH1 (1986) whilst Lyon Associates Inc (1971) suggest that a standard mixing time of 5 minutes (half of the South African and BS standards of 10 minutes) should be rigorously adhered to.

2.7.2.5 Swell

The swell of plinthic soils is low even when the Atterberg limits are high (LNEC *et al*., 1969) and the De Castro (1969) swell test offers an alternative or supplementary method of assessing the properties of the fines. The maximum swell of the fraction passing 0.425 mm is approximately equal to 8 times the molecular silica / sesquioxide ratio (apparently of the fraction passing 2 µm), and might thus provide an alternative to this ratio.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Locations

The study areas are located in eight sites situated within Younger Basalts, Older Basalts and Basement Complex within Northern Guinea Savannah ecological zone (Fig. 1). Soils formed on Younger Basaltic parent material were sampled in Southern Kaduna, around Kwoi in Jaba local government area. The Younger Basalt lies on latitude 09^{O}25’57.4” N and longitude 08^{O}00’ 12.5” E and in Gidan-Waya in Kagoro local government area along Gidan Waya – Jos route (latitude 09^{O} 27’51.4” N and longitude 08^{O} 23’47.9” E).

Soils formed on the Older Basaltic parent material were sampled in Hwal around Mista Ali, Bassa Local Government Area of Plateau State, Jos – Zaria road. One of the two sites on the Older Basalt was sampled on latitude 10^{o} 0035.1” N and longitude 08^{o} 51’8.0” E, while the other site was sampled on latitude 10^{o} 00’ 33.6” N and longitude 08^{o} 51’30.2” E.

Four sites were selected on the Basement Complex parent materials, they include schist, older laterite, older granite and younger laterite. The soils formed on schist parent materials were sampled within Zaria region, Marabar Guga to the west of Samaru along Zaria – Sokoto road. The Shist site lies on latitude 11^{O} 12’51.8” N and longitude 07^{o} 31’44.8” E. The soils formed on older laterite parent materials were sampled at Biye (Zaria region) to the west of Samaru. The site was situated of latitude 11^{o} 09’51.0” N and longitude 07^{o} 36’07.6” E. Soil developed on older granite parent material was sampled at Hanwa (Zaria region) along Kano – Kaduna road. The site lies on latitude 11^{o} 07’07.11” N and longitude 07^{o} 41’46.9” E.

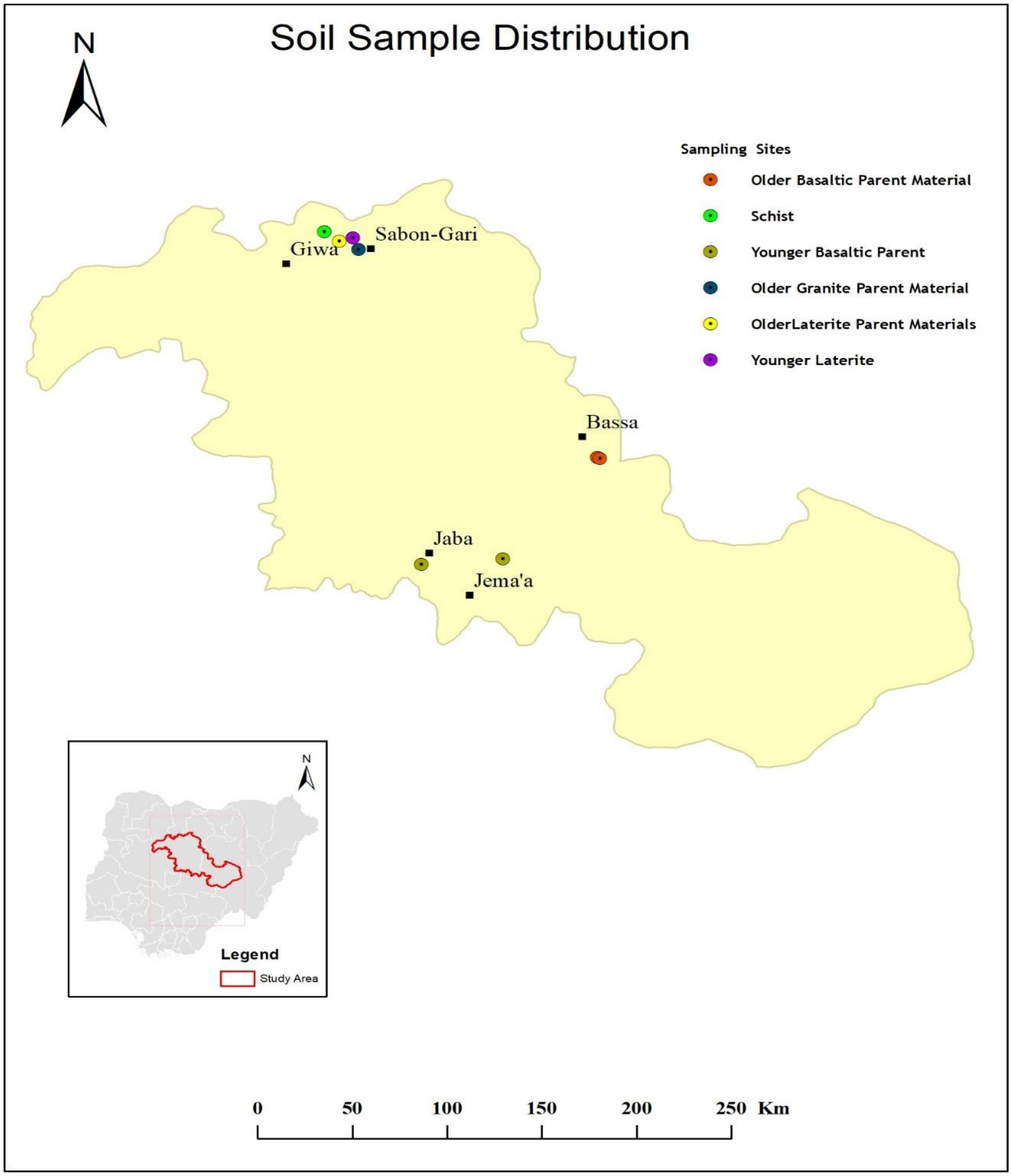

Fig 1: Map of Nigeria showing study sites

The soils formed on younger laterite parent materials were sampled at Bassawa (Zaria region). The site is situated on latitude 11° 10’54.0” N and 07° 40’02.2” E.

3.2 Geology

3.2.1 Basalts

The geology of the Jos Plateau is made up predominantly of Basement Complex rocks of the Precambrian age. They include gneisses, migmatites and granites. Younger granites appear as intrusions into the Basement Complex, forming a series of ring complexes.

Younger granites are thought to be of Jurrasic age, tertiary to recent volcanoes have given rise to Lateritised Older basalts, unlateritised Older basalts, which are generally associated with the former, and Newer Basalts that are typically large flows that can be traced to reasonably well-preserved cones (Kparmwang, 1993)

The Newer Basalts collected from the Jema’a platform is underlain predominantly by igneous and metamorphic rocks belonging to the Precambrian to Lower Palaeozoic Basement Complex (Fig. 2). They include gneisses, schists, migmatites and granites that are very similar to that of the Jos Plateau.

3.2.2 Basement Complex

The project sites in the basement complex geology are within the high plains of Hausa land (Fig. 2); a series of nearly level to gently undulating plains, above which rise some iron-capped surfaces called mesas and hills or granites and gneiss. The underlying geology is basement complex of metamorphic and igneous rocks (Mortimore, 1970).

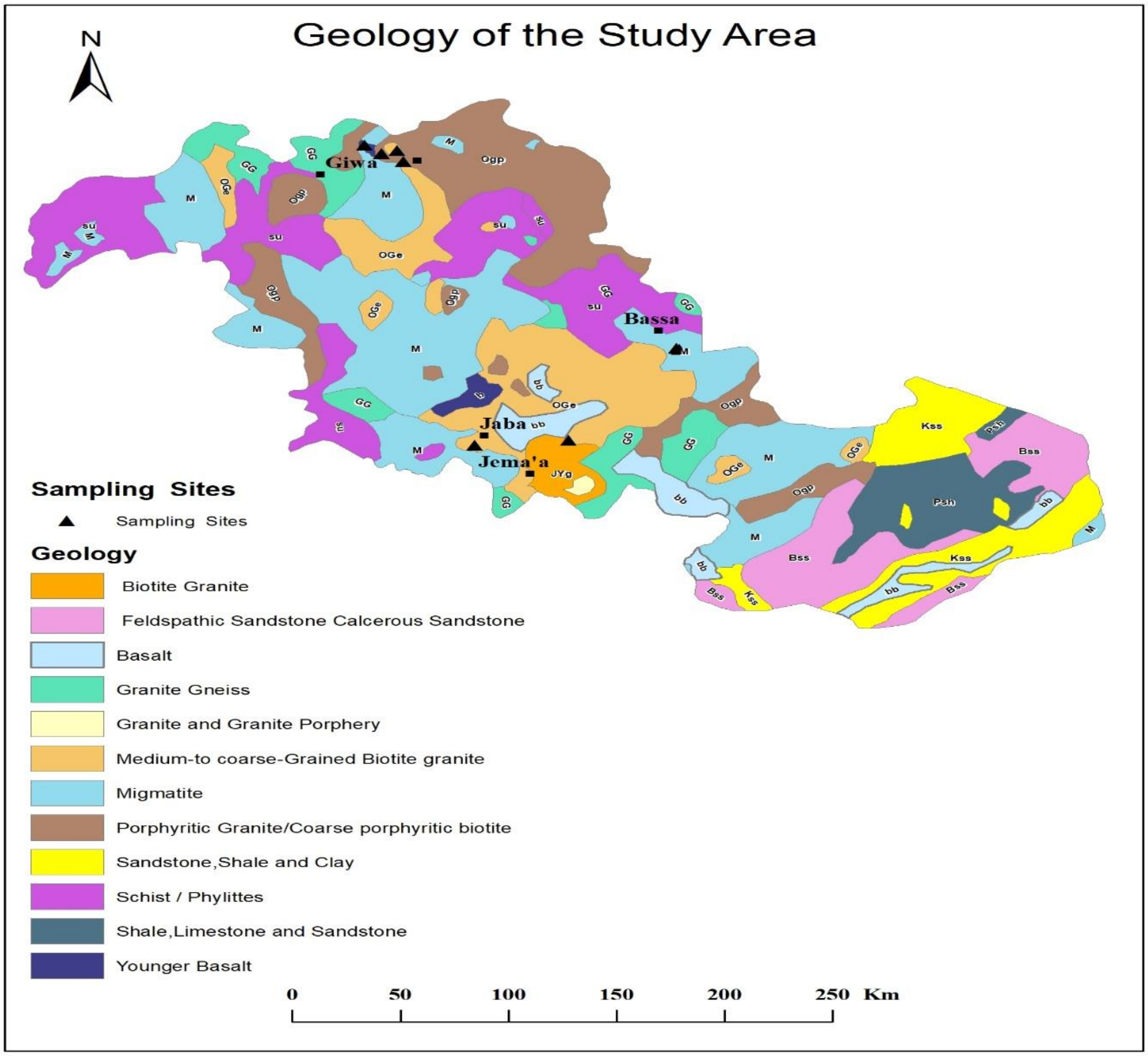

Fig 2: Geological Map showing the study site

Ojanuga (2006) reported the following groups of basement complex rocks in the Zaria region: biotite – Gneisses, Older granites, Metasediments and Superficial Deposits Biotite gneisses probably dominate under most of the eastern part of Zaria region. They are medium to coarse grained and moderately to weak foliated rocks, principally composed of quartz, oligoclase, biotite and occasionally porphyroblastic microcline. Discordant microcline – porphyroblastic lenses are common in the vicinity of older granite masses. Biotite-rich stringers also occur.

3.3 Geomorphology

Ojanuga (2006) stated that the land forms of the Jos Plateau are divided into three main units. The first group is the hills and mountains; these contain a high proportion of bare rock standing more than 1500m above the surrounding terrain, they are steep sided, rugged and occur as isolated hills, groups of hills or mountains ranges (Plates 1 and 2).

The second group is dissected terrain, which is found close to the edges of the plateau. It includes a variety of low rocky hills and rock outcrops, and the intervening valleys which are frequently deeply incised. Slopes are usually steep but small pockets of flatter land occurs.

The third group is the undulating terrain, which ranged from 1100 to 1300m in the north to 1400m in the south. It occupies most of the main surface of the plateau and has been divided into five subunits reflecting various degrees of erosion and different parent materials.

The Jema'a platform has been divided into mountains, dissected areas and plains, similar to those of the Jos Plateau.

Plate 1: Background of the Study Area Showing Extinct Volcanic Cone (Pedon BS1 Kwoi)

Plate 2: Background of the Study Area Showing Volcanic Cone (Pedon BS1 Kwoi)

The older granites manifest themselves, in the shape of the north-south trending lines of smooth domed inselbergs prominent near Zaria (Osazuwa *et al*., 1994; Wadrop and Mai, 1994; Oluyide, 1995).

Zaria region which consists of basement complex parent materials aspect of the study area was described by Ojanuga (2006) as the Gusau – Kaduna – Minna plain extensive, almost level to gently undulating, slightly dissected plain broken in places by groups of rocky hills and in selbergs. These are due to outcrops of granitic gneisses or quartzite hills and granite whalebacks (Ojanuga, 2006); McCurry, 1973).

Much of the area lies between an elevation of west of Birnin Gwari and 800m (south west of Zaria) above sea level. The general height difference between valleys and adjacent crustal areas is about 20 to 40m. Typical cross sections consist of broad crustal area with scattered iron pan capping, long planner middle slopes of less than 3^o and short steepened lower slopes showing signs of accelerated erosion.

3.4 Climate

The climate on the Plateau is the semi-temperate climate with temperatures ranging from 18 °C (64.4 °F) to 25 °C (77.0 °F). It is primarily controlled by the position and latitude of the hills in relation to the general circulation in the West African region. Altitude lowers the temperature and causes precipitation of rain. The seasonal migration north of the warm humid maritime air mass, with the sun, brings south-easterly and westerly rain bearing winds. The winds are forced upwards giving rise to a zone of 1524mm mean annual rainfall on the plain below the plateau to over 1778mm (up to 2060mm in some locations) in the escarpment and hill zone itself. The rainfall then declines in the north-easterly direction across Kafanchan side of the east-west hill mass.

3.4.1 Rainfall

The seasonal distribution of mean monthly rainfall and the annual rainfall (1121.3 mm) for Samaru is presented in Tables 1. The data showed that the peak rainfall in the area occurs in the months of July, August and September. Much of the rainfall, particularly between July and September were associated with storms of high intensity.

3.4.2 Temperature

The mean monthly record of temperature from Samaru shows a range of 14 9^{o}C to 21.14^{o}C in a year. The air temperature usually drops during the harmattan period of November to February and increases until it attains a peak in April just before the rains begin. The temperature then drops to a very low value in January and then rises to its secondary peak in April. The mean annual temperature is about 19.76^{o}C.

3.4.3 Pattern of Radiation

The mean monthly global radiations and actual sunshine hours as recorded by over a 16-year period in Samaru is presented in Table 1. The mean daily number of sunshine hours in Samaru area, per annum is 7.59 hours.

3.4.4 Evaporation

The mean monthly values of evaporation in Samaru range between a minimum average of 176.12 mm in September and a maximum average of 371.90mm in March (Table 1). The total annual evapotranspiration of 3010.92mm is in excess of the total annual rainfall of 1121.3mm.

Table 1: Summary of Climatic data of Samaru (2000-2016)

Months	Relative Humidity (%)	Temperature maximum (^oC)	Temperature minimum (^oC)	Sunshine (Hours)	Open Pan Evaporation (mm/month)	Rainfall (mm)
January	15.01	33.32	14.94	8.50	296.13	0
February	13.22	33.94	17.32	8.22	316.74	0
March	15.44	36.55	20.97	6.75	371.90	5.35
April	35.75	38.17	24.14	8.20	337.07	32.19
May	56.54	34.91	22.70	8.18	256.61	108.86
June	67.71	31.90	21.41	7.83	205.06	141.3
July	73.19	30.59	20.93	6.89	184.7	252.07
August	77.82	29.80	20.73	5.47	179.65	337.25
September	71.97	31.52	22.96	6.47	176.12	191.04
October	54.17	33.42	19.86	6.96	191.54	53.24
November	25.01	33.85	16.14	8.55	235.25	0
December	16.87	32.89	15.03	9.06	260.15	0
TOTAL		-	-	-	3010.92	1121.3

Source: Institute for Agricultural Research (IAR) Meteorological Station Samaru, ABU Zaria

The factors responsible for such high evapotranspiration rates are the high rates of solar radiation and wind action. There are only three months in a year (July, August and September) when rainfall is in excess of evapotranspiration; over most of the remaining nine months, there is moisture deficit in the soil. This may be attributed to global warming.

3.4.5 Relative Humidity

In Samaru, mean monthly relative humidity range between 13.22% in February and 77.82% in August. The peak period of relative humidity is between May to September which is related to the period of rainfall establishment in the area for the crop growing season.

3.5 Vegetation

The study areas are situated within the Northern Guinea Savanna zone. It is characterized by open, subhumid, broad-leaved savanna woodland vegetation at varying stages of regrowth, with short to medium grasses (Keay, 1953). The vegetation on the whole has been greatly disturbed either by grazing, burning, tree falling for firewood and timber, and cultivation. Few of the common woody tree and shrub species in the area include; *Isoberlina doka, Uapaca togoensis, Parkea clappertoniana, Butterospermum* spp*, Termarindus indica, Daniellia oliveri, Terminalia, Acacia* spp, *Combretum glutinosum* and *Detarium microcarpum* (Olorode, 2002; Higgins, 1963). The area is covered with more extensive grasses of *Aristida*, *Pennisetum*, *Andropogon*, *Hyparrhenia and Ctenium* (Olorode, 2002).

3.6 Land Use

The major types of land use in the study areas include arable farming, forestry, logging, mining, livestock farming as well as industrial and urban development. A wide range of crops are grown in this zone consisting of grains, roots and tubers, legumes and vegetables. Farm sizes are usually in the range of 2 – 7ha (Ojanuga, 2006). Arable farming is based mainly on subsistence farming through a system of bush fallowing shifting cultivation in areas where population is sparse. Small parcels of land are cleared and planted to annual crops. The main food crops include; sorghum, millet, soyabeans, cowpeas, and sweet potatoes. Cash crops include; maize, yam, rice, tomatoes, cabbage, carrots, onions, sugar cane, groundnuts, and cowpea (FDALR, 1990; Ojanuga, 2006). Some fruit trees include mango, guava cashew and pawpaw.

3.7 Field Studies

The preliminary preparations involved reconnaissance survey to identify sites, collection of topographical and geological maps, profile sinking, soil sampling and morphological description.

3.7.1 Field exploratory survey

Field exploratory survey was conducted for the purpose of identifying suitable landscape areas for the study. Two parent materials were chosen to give room for broad comparism namely; sites with plinthitic soils were identified on Basement complex and Basaltic parent materials. Sampling was carried out at crest position to avoid the interference of topography in the data analysis.

Marabar Guga, Hanwa, Bassawa and Biye were explored for the Basement Complex parent material sites all in the Zaria region, Kaduna State. Soil samples were collected on two groups of Basalts in the Northern Guinea Savanna ecological zone of Nigeria. The Basaltic parent material sites were explored in Kwoi in Kaduna State and Hwal area, Jos along Jos-Zaria road. The plinthic soils developed on younger Basaltic parent materials were explored in Kwoi and Gidan Waya, while those of older basaltic parent materials were explored from Hwal area.

Topographical maps (1:50,000) were used to further identify crestal positions within each of the basaltic rocks parent material sites identified on the geological map. The actual point on which the soil profile pit was sited was marked by using GPRS.

3.7.2 Soil samples

Soil samples were collected from four profile pits based on genetic horizons at crest position within cultivated fields on each of the two parent materials selected for the study area.

3.7.3 Soil morphological properties

Soil depth, colour, mottling, structure, texture, consistence, horizon boundary, roots, concretions and pores were observed and described in the field following the procedure described of the USDA Soil Survey Manual (Soil Survey Division Staff, 1993).

3.8 Laboratory Analysis

Soil samples collected from the various pedogenic horizons were air dried in the laboratory, crushed with porcelain pestle and mortar and sieved to remove, material greater than 2mm (gravel). Percent gravel to total soil was calculated. The less than 2mm material was used for laboratory analysis.

3.8.1 Particle size distribution

The particle size analysis was determined by the standard hydrometer method (Gee and Bauder 1986).

3.8.2 Bulk density

Bulk density was determined by oven-drying the undisturbed soils samples collected in 10cm^3 metal cylinders to constant weight at 105^{o}C, and dividing the dry weight of the sample by the total volume of the sample (Blake and Hartge 1986).

$$\text{Bulk density (Mgm}^{-3}\text{)} = \frac{\text{Weight of oven dry soil}}{\text{Volume of soil}} \qquad (1)$$

3.8.3 Particle density of the soils

Particle density was determined from the standard pycnometer method described by Blake and Hartge (1986).

3.8.4 Total porosity

Total porosity was calculated mathematically (Danielson and Sutherland, 1986) from the particle density (P_p) and bulk density (P_b) of the soils using the formula:

$$\text{T. P \%} = 100 \frac{(1 - P_b)}{P_p} \qquad (2)$$

3.8.5 Soil reaction (pH)

Soil pH was determined in both water and 0.01M $CaCl_2$ solution at a 1:1 soil/water or solution ratio. Ten grams of 2mm sieved air-dried soil in a 50 ml plastic beaker was mixed with 25 ml distilled water and stirred for 30 minutes. The soil suspension was allowed to stand for 30 minutes undistilled. pH meter was calibrated using pH buffer 4, 7, 9. The electrode was emersed into the soil, and the pH read after 30 seconds. Above procedure was repeated using 0.01M $CaCl_2$ solution.

3.8.6 Exchangeable bases

Exchangeable Ca, Mg, K and Na was carried out following method described by Thomas (1982). Ten grams of 2 mm sieved soil was put into a funnel fitted with a funnel over 100 cm^3 volumetric flask. The soil was leached in the funnel with 1 N pH7 Ammonium acetate solution to a volume of 100 cm^3. Leaching was done with about 10 mls at each washing.

After leaching, the leachate was preserved for determination of Na, Ca, Mg and K. Potassium and sodium was read from undiluted extract on a Galennkamp flame analyser. After reading K and Na, the extracts were diluted 10 times with the addition of 2 ml of 6.5% lanthanum chloride solution to prevent ionic interference, Calcium and magnesium were read on Unicam model Sp 192 atomic absorption spectrophotometer (ASS) at 423 and 285 nM wavelength, respectively.

3.8.7 Exchange acidity

Ten grams of soil used was leached with 1 M KC1 solution, total exchange acidity (H + AI) was determined by titration of extract with standard NaOH solution (Thomas, 1982). The exchangeable aluminium was determined colorimetrically as described by IITA (1979). The difference between total exchange acidity and exchangeable aluminium gave the amount of exchangeable hydrogen.

3.8.8 Cation exchange capacity

Cation exchange capacity was determined by neutral (pH 7.0) NH_4OAc saturation method (Rhoades, 1982). Ten (10) grams of 2mm sieved soil was added into a 100cm^3 plastic beaker and

40ml of 1N pH7 ammonium acetate added. The suspension was stirred with a glass rod and left overnight. The soil was filtered with light suction using a 55mm Buchner funnel (corning size No 40), and leached with 1N pH 7 ammonium acetate to a volume of 250cm^3.

The leachate was preserved and Ca, Mg, K and Na determined on AAS. The leachate was tested to be free of calcium by using few drops of 1N NH_4Cl 10% oxalate and dilute NH_4OH. For test of calcium the solution was heated and the presence of calcium was indicated by a white precipitate. The soil was then leached with 1N NH_4Cl pH 7 four times with 25mls portion at a time and once with 25ml of 0.25N pH 7 NH_4Cl and this solution discarded. Electrolyte was washed out with 150 – 200 mls of isopropyl alcohol or ethanol.

The effective CEC was obtained by summation of exchangeable bases and exchangeable acidity (IITA, 1979) by pipetting 50 ml of the leachate into 250 ml beaker. Five (5) drops of phenolphalein indicator was added and the solution was titrated with 0.1N NaOH to a permanent pink end point. The amount of 0.1N NaOH used was recorded (correspond to meq Al + H). One (1) drop of 0.1N HCl was added to the solution in the above step to bring it back to colourless condition. Ten (10) ml of NaF solution was added, while being stirred constantly, the solution was titrated with 0.1N HCl until colour just disappears. Two (2) drops of indicator was added until colour just disappears and never reappears within 2 minutes. The total amount of 0.1N HCl used was recorded meq 0.1N HCl = Exchangeable Al. Cation Exchange Capacity (CEC) clay fraction was calculated by the Zounelreld (1971) method as followed:

$$\text{CEC (clay)} = \frac{CEC\,(soil) - (3.5\%C)}{\%\,clay}\,x100 \qquad (3)$$

3.8.9 Base saturation (BS) percentage

The base saturation was calculated for both CEC NH_4OA_C and ECEC from the formula:

$$\% \text{ BS} = \frac{\text{Total Exchange Bases}}{\text{CEC or ECEC}} \times 100 \tag{4}$$

3.8.10 Exchangeable sodium percentage (ESP)

The exchangeable sodium percentage was calculated as the proportion of the CEC (NH_4OA_C) occupied by sodium cations as follows:

$$\text{ESP} = \frac{\text{Exchangeable Sodium}}{\text{CEC } (NH_4OA_C)} \times 100 \tag{5}$$

3.8.11 Electrical conductivity

Electrical conductivity was determined at a 1:2.5 soil/water ratio using a Wheatstone bridge at 2.5^oC.

3.8.12 Organic carbon

The organic carbon was determined using Walkley-Black dichromate wet oxidation method as described by Nelson and Summers (1982) Erlenmeyer flask. Five (5) ml of 1N $K_2Cr_2O_7$ was added using a pipette, and then the flask was swirled gently to disperse the soil.

Ten (10) ml of concentrated H_2SO_4 from a measuring cylinder was added and swirled for 1minute again (if colour turns greenish the amount of soil was reduced to half). The flask was allowed to stand on asbestos sheet for 30 minutes, while 100 ml of distilled water was added to the flask and let to cool (If suspension is cloudy a fast filter paper was used to filter the suspension).

Fifteen (15) ml of phosphoric acid was added and then 5 drops of indicator. The solution was titrated with ferrous ammonium sulphate solution with a white ground. Change in colour: blue-green –dark green – red. A blank determination was done in the organic carbon content was calculated using the formular:

$$\text{Organic carbon \%} = \frac{(meq.K_2Cr_2O_7 - meq.FeSO_4)\,x\,0.003\,x\,100\,x\,F}{wt.of\ air\ dry\,soil\,taken} \qquad (6)$$

Where F = correction factor 1.33 or

$$\text{Organic carbon \%} = \frac{(blank\ titrate - actual\ titre)\,x\,0.3\,x\,Mx\,F}{weight\ of\ air\ dry\,soil\,taken} \qquad (7)$$

Where M = concentration of ferrous ammonium sulphate

F = Correction factor

% OC x 1.729 = % organic matter

3.8.13 Available phosphorus (AP)

Available phosphorus was determined following the procedure described by (IITA, 1979). Using the Bray extractor method (Bray and Kurtz, 1945) as follows:

Five (5) grams of soil was weighed into a tube with stopper and 35cm^3 (with pipette) of the extraction solution added. The container was shaken for 1 minute and the suspension filtered (pipette) was transferred into a dry 100 cm^3 beaker and 25 cm^3 Stannoous chloride dilute solution and mixed. After 10 minutes and not later than 15 minutes, the colour development was measured at 890 nm on a spectronic 20. The absorption was read and standards were determined in the same way.

3.8.14 Citrate-bicarbonate-dithionite (CBD) extractable iron, aluminium and manganese oxides (Fe_d Al_d and Mn_d)

Free iron, aluminium and manganese were extracted following the method of Mehra and Jackson (1960) as follows: Twenty (20) grams of fine earth fraction was treated in mortar and all of it passed through 0.2mm sieve. 1g of the soil was weighed into 50cm^3 plastic centrifuge tube and 40cm^3 of sodium citrate solution and 5cm^3 of sodium bicarbonate solution added. The mixture was heated on water bath to 70 – 80^{o}C (but not above 80^{o}C). One (1) gram of sodium dithionite salt was added and stirred continuously for 1 minute and occasionally for 15 minutes.

The suspension was centrifuged and the clear supernatant solution decanted into 200cm^3 volumetric flask. Afterwards the soil was washed twice with 40cm^3 sodium citrate, centrifuged and the clear supernatant solution added to the extract in the 200cm^3 volumetric flask.

Finally, the volumetric flask was filled to mark with H_2O. After mixing the contents of Fe, Al and Mn were determined in the extract using Atomic Absorption Spectroscopy (AAS).

3.8.15 Acid oxalate extractable iron, aluminium and manganese oxides

Amorphous inorganic form of Fe, Al and Mn oxides were extracted using oxalate (pH 3) in the dark (McKeague and Day, 1966) using the modified Tamnis method on described by IITA (1979) as follows: Half gram of soil was weighed into 50cm^3 centrifuge tube and 25 cm^3 of acidified ammonium oxalate solution was added. The tube was closed with a stopper and shaken in darkness for 4 hours. Before measurement of Fe, 10 cm^3 of extract was transferred in a 100 cm^3 volumetric flask and diluted to mark with water. Iron, aluminium and manganese oxides in the extract were determined on ASS at 373.9 and 280nM.

3.8.16 Pyrophosphate extractable iron, aluminium and manganese oxides

Amorphous organic form of Fe, Al and Mn oxides was extracted using pyrophosphate solution as described by Makeague (1967). Iron, Al and Mn in the extract were determined following the method of Mehra and Jackson (1960) as described by IITA (1979). The content of Fe, Al and Mn was determined after ten times dilution on a pye unicam model Sp 192 AAS at 280nM and 373.9nM wavelengths.

3.8.17 Mineralogical Analysis

3.8.18 Total elemental oxides analysis

The total elemental oxides were analyzed at the National Geoscience Laboratory Centre Barnawa, Kaduna. The total elemental oxides were determined using energy dispersing X-ray fluorescence (EDXRF) XRF SPEC (Minipal4).

The < 2mm soil samples were further ground to 150µm and powdered samples were used for the analysis. The conditions for analysis were set as follows:

i. Mo filter at 30 kV for rare earth elements

ii. Kaptor filter at 20 kV for Si, Al, P, etc

iii. Filter (none) at Kkv for alkaline and earth elements

The relative intensity of weathering of total elemental oxides was determined by using titanium as the suitable index element (Muhs *et al*., 2001). The relative loss of element was estimated using relative retained element (Ro) formula (Caspari *et al*., 2006).

$Ro \quad = X_h \text{ x } Ti_p$

$X_p \quad Ti_h$

Where, X_h = element of interest in horizon estimate

X_p = element of interest in parent material (rock)

Ti_h = index element (Titanium in horizon to estimate

Ti_p = index element (Titanium) in parent material (rock)

Ro > 1 = Relative accumulation of element (gain)

1 = No relative accumulation or depletion of element

< 1 = Relative depletion of element (loss)

O = Element absent in soil

3.8.19 Methodology for Geotechnical Tests

3.8.20 Soil samples

After digging and describing the profile pits, horizons that depicted the best developed plinthite diagnostics were dug out and packed in strong bags and labelled. A minimum of 300 kg of soil was taken from each of the eight pedons. The soil samples were then air dried and crushed in a mortar and sieved with a 10 mm sieve. The part that passed through 10 mm sieve was used for moulding of the blocks.

3.8.21 Block moulding (natural soil)

The soils were moulded into blocks in their natural form by adding adequate amount of water to each of the samples and mixing them with a shovel (Plates 3 and 4).


Plate 3: Moulding blocks

Plate 4: Wetting of soil and moulding blocks

To achieve a good mould several additions of water in little quantities was done until the soil was moist enough to be put in the mould. The damped soil was poured into the mould with the aid of a shovel and the mould was removed.

The mould was soaked with water before pouring the damped soil. The mould was also washed each time, after removing the mould to enable easy removal and to produce a good mould. Six good blocks were produced from each sample for compressive test (Plates 5 and 6). The blocks were covered with empty bags to minimize cracking and left to dry in open air for at least 30 days before subjecting them to compressive test.

3.8.22 Geotechnical index properties

Geotechnical index properties of plinthite collected from 8 pedons were determined to provide a base for explanation of the compressive test results of the soil and to determine their engineering classification for construction purpose. They include the following:

a. Unconfined compressive strength test (UCS): The UCS was carried out by subjecting each of the blocks compression on DENISON Compression test machine Mode No. TIB/MC capacity 250 tons and reading their values (KN/m^2). The dimensions of each of the blocks were taken before subjecting them to test.

b. Percent passing: Expresses the percentage of the total sample that is finer than each sieve size, rather than as the percentage retained. Percentage finer is commonly referred to as percentage passing. All percentages are calculated on a weight basis.

c. Liquid limit %: Two hundred (200) grams of the soil sample was weighed and passed through 425 μm sieve and mixed with water to form a thick homogeneous paste. The paste

Plate 5: Blocks ready for compressive strength test

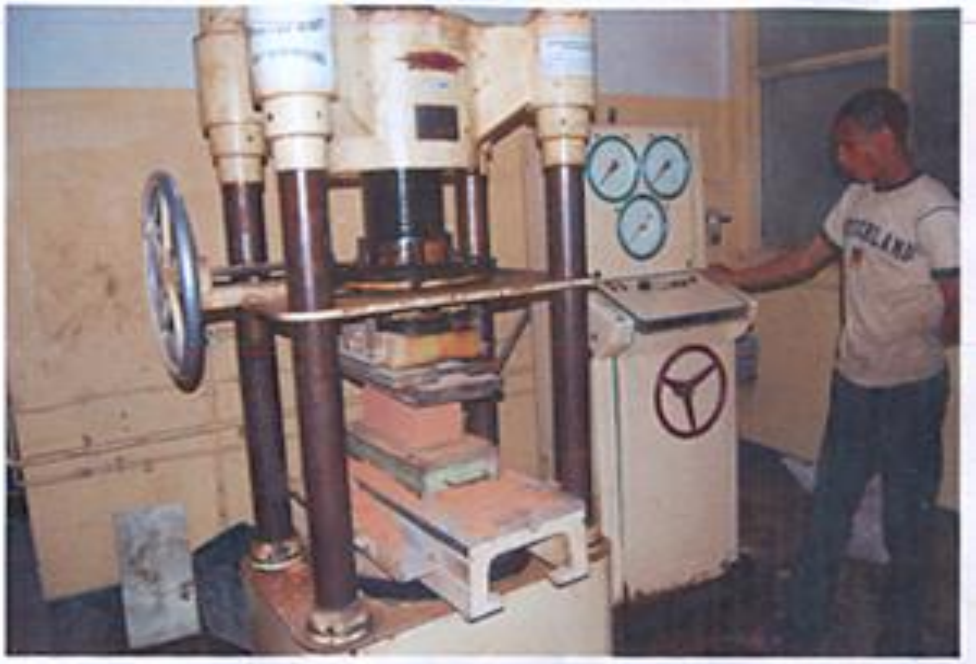

Plate 6: Crushing of blocks for compressive strength test

was collected inside the Casangrade's apparatus cup with a grove created and the number of blows to close it was recorded.

d. Plastic limit %: Two hundred (200) grams of the soil sample was weighed and passed through 425 µm test sieve and then mixed with water till it became homogenous and plastic to be shaped to ball. The ball of soil was rolled on a glass plate until the thread cracks at approximately 3 mm diameter. The 3 mm diameter sample was placed in the oven at 105°C to determine the plastic limit.

e. Plasticity index %: Numerical difference between plastic limit and liquid limit

f. AASHTO classification: The AASHTO system uses both grain-size distribution and Atterberg limits data to assign a group classification and a group index to the soil. The group classification ranges from A-1 (best soils) to A-8 (worst soils). Group index values near 0 indicate good soils, while values of 20 or more indicate very poor soils. However, a soil that may be "good" for use as a highway subgrade might be "very poor" for other purposes, and vice versa

g. Maximum Dry Density (Mg/m^3): The mass and volume of the soil samples were taken

3.8.23 Unconfined compressive strength test (UCS)

Unconfined Compressive Strength (UCS) testing strength of the blocks is the most common and adaptable method for evaluating strength of stabilized soil. It is the main test recommended for the determination of required amount of additive to be used in stabilization of soil (B. S. 1924, Methods of testing for stabilized soil, British Standard Institute, London, 1997). The unit of measurement being KN/m^2.

3.9 Soil Classification

Soil classification was carried out according to USDA – Soil Taxonomy (Soil Survey Staff, 2010) and World Reference Base for Soil Resource (FAO, 2014).

3.10 Statistical Analysis

Descriptive statistics were used to assess soil properties. Data obtained were subjected to analysis of variance using SAS (Statistical Analysis System) software version 9.3 (2011). Means were separated using the Duncan multiple range test. Relationship between Geotechnical index properties and soil pedogenic properties was done by correlation analysis.

CHAPTER FOUR

4.0 RESULTS

4.1 Morphological Properties

Soil morphological properties considered included soil depth, structure, consistence, concretions, roots and pores. Summary of these morphological properties are presented in Table 4.1 and details of profile description are given in Appendix A. Detail morphological properties are shown below:

4.1.1 Soil Depth

The soils formed on two major materials were considered to be deep to very deep (120 – 186 cm). For the soils formed on the basement complex, the depth ranged from 120 to 186 cm. The shallowest pedon OGR (120 cm) was observed on the older granite while the deepest pedon was obtained on the older laterite OL (186 cm). Soils formed on Basaltic parent materials were also considered as deep to very deep with profile depths of 130 and 173 cm (Plate 7). The deepest profile was observed on the Newer Basalt (BS2) with a depth of 173 cm, closely followed by the older Basalt (BS3) with a depth of 170 cm and shallowest obtained in pedon BS1 (130 cm) (Table 4.1).

4.1.2 Soil Colour

Surface horizon of soils on basement complex were dominantly reddish (Table 4.1)

Plate 7. Pedon BS2 Showing Basaltic Plinthite Soil Profile

Table 4.1: Morphological properties and classification of pedons of soils studied

	Depth	Munsell Colour		Mottle	Texture	Structure	Consistence				
	(cm)	Moist	Dry	Colour			Wet	Moist	Dry	Boundary	Other Features
Pedon SC (Plinthusult – Clayey Skeletal, kaolintic isohyperthermic)											
Ap	1-13	7.5YR 4/3	7.5YR 6/4		scl	1csbk	sopo	fr	sh	cs	Many medium pores; common very fine roots; many fine mica flakes, common termite nests and channels.
Btv1	13-30	2.5YR 4/3	7.5YR 6/4		vgcl	0m	sp	vfr	sh	cs	Common medium roots; many medium iron concretions with quartz grains; many fine mica flakes; few termite nests
Btv2	30-56	2.5YR 48	2.5YR 6/8		vgscl	0m	sp	fr	sh	cs	Common fine pores; few medium roots; common fine iron nodules; common fine mica flakes and quartz grains; common termite channels and nests.
Btv3	56-122	2.5YR 48	2.5YR 4/6		egscl	0m	sspo	vfr	sh	cs	Common fine pores; few medium roots; common fine iron nodules; common fine mica flakes and quartz grains.
Btv4	122-170	2.5YR 68	2.5YR 6/8		vgscl	0m	sspo	fr	sh	cs	Common medium pores; many very fine roots; common medium iron nodules.

Table 4.1: Morphological properties and classification of pedons of soils studied (Cont….)

	Depth	Munsell Colour		Mottle	Texture	Structure	Consistence				
	(cm)	Moist	Dry	Colour			Wet	Moist	Dry	Boundary	Other Features
Pedon OL (Plinthusult – Clayey Skeletal, kaolintic isohyperthermic)											
Ap	0-12	7.5YR 4/4	7.5YR 6/6		gcl	1csbk	sspo	fr	sh	cs	Common medium roots; many mica flakes, common termite nests and channels.
AB	12-110	7.5YR 4/4	7.5YR 6/4		gscl	0m	sp	fr	sh	cs	Common medium pores; few very fine roots; few medium mica flakes, common termite nests and channels.
Btv1	110-135	5.0YR 4/6	5YR 6/8		vgscl	0m	sp	fr	sh	cs	Common medium pores; few very fine roots; few medium hard iron nodules; many fine mica flakes; common termite nests and channels.
Btv2	135-186	5YR 4/6	5YR 6/8		egscl	0m	sspo	vfr	sh	cs	Common fine pores; few medium roots; common fine iron nodules; common fine mica flakes and quartz grains.

Table 4.1: Morphological properties and classification of pedons of soils studied (Cont……)

	Depth	Munsell Colour		Mottle	Texture	Structure	Consistence				
	(cm)	Moist	Dry	Colour			Wet	Moist	Dry	Boundary	Other Features
Pedon OGR (Plinthusult – Clayey Skeletal, kaolintic isohyperthermic)											
Ap	0-39	10YR 3/3	10YR 3/3		scl	1csbk	sopo	fr	sh	cs	Many common very fine roots; many fine micas flakes; common termite nests and channels.
Btv1	39-79	5YR 4/6	5YR 6/8		gscl		sp	fr	sh	cs	
Btv2	79-120	5YR 6/8	5YR 4/6		cl		sspo	fv	sh		Common medium pores; many very fine roots; common medium iron nodules; common termite nests.
Pedon YL (Plinthusult – Clayey Skeletal, kaolintic isohyperthermic)											
Ap	0-30	7YR 4/4	7YR 66		scl		sopo	fr	sh	cs	
Btv1	30-70	2.5YR 4/6	2.5YR 58		vgscl		sp	fr	sh	ds	
Btv2	70-160	2.5YR 5/8	2.5YR 4/6		egscl		sspo	fr	S	gs	

Table 4.1: Morphological properties and classification of pedons of soils studied (Cont….)

	Depth (cm)	Munsell Colour		Mottle Colour	Texture	Structure	Consistence			Boundary	Other Features
		Moist	Dry				Wet	Moist	Dry		
Pedon BS1 (Plinthusult – Clayey Skeletal, kaolintic isohyperthermic)											
Ap	0-20	2.5YR 3/4	2.5YR 4/4		scl	2msbk	sp	fr	sh	cs	Many very fine and fine roots; few fine mica flakes; medium animal holes and few coarse nests.
Bt1	20-76	5YR ¾	5YR 3/4		scl	2csbk	sp	fr	sh	ds	Common fine roots; common medium ant holes and nests; common very fine mica flakes.
Bt2	76-106	2.5YR 3/6	2.5YR 4/8		gcl	2csbk	sp	vfr	sh	cs	Few thin clay cutans; common very fine and fine roots.
Bt3	106-130	10YR 4/3	10YR 4/8		gcl	1msbk	sp	vfr	sh		Common thin clay cutans; common medium fine roots; common very fine mica flakes.
Pedon BS2 (Plinthusult – Clayey Skeletal, kaolintic isohyperthermic)											
Ap	0-25	2.5YR 4/4	2.5YR 6/8		scl	3sbk	sp	fr	sh	cs	Many very fine and fine roots; many medium and nests.
Bt1	25-73	5YR ¾	5YR 5/8		gscl	3csbk	sp	fr	sh	ds	Few thin clay cutans; many fine and medium roots; many fine mica flakes; few fine animal holes.
Btv2	73-105	5YR 5/8	5YR 5/8		gscl	2msbk	sp	fr	sh	cs	Common thin clay cutans; common medium and fine roots; common very fine mica flakes.
Btv3	105-120	5YR 4/6	5YR 5/8		gscl	2msbk	sp	fr	sh	cs	Few thin clay cutans; common fine roots; common very fine mica flakes; medium animal holes.
Btv4	120-173	2YR 4/8	2YR 6/8		scl	2msbk	sp	fr	sh	cs	Common thin clay cutans; common very fine and fine roots; common very fine and fine mica flakes.

Table 4.1: Morphological properties and classification of pedons of soils studied (Cont….)

	Depth (cm)	Munsell Colour		Mottle Colour	Texture	Structure	Consistence			Boundary	Other Features
		Moist	Dry				Wet	Moist	Dry		
Pedon BS3 (Plinthusult – Clayey Skeletal, kaolintic isohyperthermic)											
Ap	0-20	5YR 4/4	5YR 5/8		gscl	2msbk	sp	fr	sh	cs	Many fine medium roots; many medium ants nests.
Btv1	20-56	5YR 4/6	5YR 5/8		gscl	2msbk	sp	vfr	sh	cs	Many very fine roots; common medium termites holes and nests.
Btv2	56-90	2.5YR 4/6	2.5YR 4/8		scl	2msbk	sp	fr	sh	ds	Few thin clay cutans; many very fine roots; many fine mica flakes; few medium animal holes.
Btv3	90-170	2.5YR 4/8	2.5YR 6/8		scl	1msbk	sp	fr	sh		Common thin clay cutans; common medium and fine roots; common very fine mica flakes.
Pedon BS4 (Plinthusult – Clayey Skeletal, kaolintic isohyperthermic)											
Ap	0-18	7.5YR 3/2	7.5YR 4/3		scl	2msbk	sp	fr	sh	cs	Many fine and medium roots; termite's holes and nests.
ABt1	18 – 52	10YR 4/6	10YR 4/6		gscl	2msbk	sp	vfr	sh	cs	Few thin clay cutans; many fine and medium roots; few medium ant holes.
Btv2	52 – 68	10YR 4/6	10YR 5/8		gscl	2msbk	sp	fr	sh	ds	Few thin clay cutans; many fine and medium roots; many fine mica flakes; few fine animal holes.
BC1	68 – 145	5YR ¾	5YR 4/6		scl	2msbk	sp	fr	sh		Common thin clay cutans; common medium and fine roots; common very fine mica flakes.

4.1.3 Soil Texture

Soil texture in the surface horizons of soils formed on basement complex varied between sandy loam and sandy clay loam. Sandy loam dominated all the Ap horizon of all the four pedons. The surface horizons were all found to be sandy clay loam except pedon OGR (BCcv) which was sandy loam (Table 4.2)

Soil texture for the surface horizons of soils of basaltic parent material was formed to be sandy clay loam for pedons BS1 and BS2 (newer basalts) and sandy loam for pedons BS3 and BS4 (older basalts). The surface horizon values all recorded sandy clay loam textures for all pedons in the basaltic parent materials (Table 4.1).

4.1.4 Soil Structure

Medium sub-angular blocky with few fine and coarse blocky structure dominated structure of soils developed on basement complex parent material. The structures were moderately developed (Table 4.1).

The subsoils of pedon OGR had coarse and strongly developed blocky structure while that of pedon SC was completely medium platy. The subsoils of pedon OL had coarse and strongly developed blocky structure than OGR. The structure of basalts was dominated by blocky structures (Table 4.1).

4.1.5 Soil consistence

Soils on basement complex were generally slightly sticky and slightly plastic (wet). The subsoils varied between sticky and slightly plastic (wet) and sticky and plastic (wet) consistence. The soils all varied between friable and firm (moist) consistence. Slightly hard to hard consistence was observed for all the soils under dry condition except for pedon OGR on older granite where the surface horizon was soft (dry) (Table 4.1).

Most soils in the basaltic parent material were generally sticky and plastic (wet), very friable to friable (moist) and slightly hard (dry). On the older basalts, they were slightly sticky and slightly plastic (wet); friable to firm (moist) and hard (dry) for the newer basalts (Table 4.1).

4.1.7 Miscellaneous observations

Plinthization was evident in all subsurface horizons of pedons studied (Table 4.1).

4.2 Soil Physical Properties

4.2.1 Particle Size Distribution

Table 4.2 presents results on the particle size distribution. Gravel content in the surface horizon of the soil formed on the basement complex varied from 15 to 40 %. The highest gravel content (40 %) was obtained in SC followed by pedon OL with 30 %. The lowest content of the gravels was observed in pedon OGR (10 %). The profile distribution of gravel was irregular with depth, however the highest gravel contents were obtained in the underlying horizons of pedon YL, horizon Btcv2 (80 %).

Very low gravel contents were observed in soils formed on the Basaltic parent material with values ranging between 1 to 4%; similarly, lower contents of gravel were obtained in the underlying horizons (1 – 6%). The distributions were slightly regular with soil depth.

Total sand in the surface horizons of the basement complex ranged between 60 and 72 (mean 65.50) and (64 and 70) (68) gkg^{-1}. The highest content was in pedon OGR (72%) (Ap) while the lowest value (64%) was observed in pedon SC (Ap). Surface horizon values of total sand in Basalt

Table 4.2: Particle Size Distribution and Textural Classes of Soils in the Study Areas

Pedon	Depth cm	Gravel	Clay %	Silt	Sand	Tex. Class
			Soils on Basement Complex			
Pedon SC						
Ap	0 - 13	40	16	20	64	Sandy loam
ABcv	13 - 30	30	28	16	56	Sandy clay loam
Bcv	30 - 56	20	24	10	66	Sandy clay loam
Btcv	56 - 122	90	32	18	50	Sandy clay loam
BCcv	122 - 170	35	28	12	60	Sandy clay loam
Pedon OL						
Ap	0 - 12	30	12	28	60	Sandy loam
ABtcv	12 - 110	30	30	16	54	Sandy clay loam
Bcv	110 - 135	25	26	18	56	Sandy clay loam
BCcv	135 - 186	50	24	18	58	Sandy clay loam
Pedon OGR						
Ap	0 - 39	10	14	14	72	Sandy loam
Btcv	39 - 79	40	24	10	66	Sandy clay loam
BCcv	79 - 120	50	18	16	66	Sandy loam
Pedon YL						
Ap	0 - 30	15	18	16	66	Sandy loam
Btcv1	30 - 70	45	26	12	62	Sandy clay loam
Btcv2	70 - 160	80	28	16	56	Sandy clay loam
Pedon BS1		**Soils on Basaltic Rocks**				
Ap	0 - 22	4	26	10	64	Sandy clay loam
Btcv	22 - 76	4	32	14	54	Sandy clay loam
Bcv1	76 - 106	4	26	12	62	Sandy clay loam
Bcv2	106 - 130	4	26	14	60	Sandy clay loam
BCcv	130 - 160	4	24	12	64	Sandy clay loam
Pedon BS2						
Ap	0 - 25	1	20	10	70	Sandy clay loam
Bcv1	25 - 75	1	26	12	62	Sandy clay loam
Bcv2	75 - 105	1	28	14	58	Sandy clay loam
Btcv1	105 - 120	2	28	16	50	Sandy clay loam
Bcv	120 - 173	4	24	16	60	Sandy clay loam
Pedon BS3						
Ap	0 - 20	4	16	14	70	Sandy loam
Btcv1	20 - 56	5	28	10	62	Sandy clay loam
Btcv2	56 - 90	5	28	16	56	Sandy clay loam
BCv	90 - 170	6	24	10	66	Sandy clay loam
Pedon BS4						
Ap	0 - 18	4	18	12	70	Sandy loam
ABcv	18 - 52	5	24	12	64	Sandy clay loam
Btcv1	52 - 68	5	26	14	60	Sandy clay loam
Btcv2	68 - 145	5	30	14	56	Sandy clay loam

ranging from 50% to 64%. The highest value (64%) ABcv was found in pedon BS4 while the lowest (50%) was in BS2 Btcv. The distribution was slightly regular with depth.

Silt content in the Basement complex soils ranged from 14% to 28% in the surface horizons. The highest contents were obtained in pedon OL with 28% while the lowest (10%) was in pedon OGR.

Subsurface horizon values ranged from 10% to 18%. The highest value (18%) was obtained in pedons SC (Btcv) and OL (Bcv, BCcv). The distributions were regular with depth except pedon SC.

Silt content in Basalts ranged from 10% to 14% in the surface horizons. The surface values ranged from 10% to 16% with the highest values (16%) in pedons BS2(Btcv) and BS3 (Btcv2). The lowest value (10%) was recorded in pedon BS3(BCv)

Clay content in the surface horizon of basement complex soils ranged between 12% to 16% while the underlying horizon ranged from 18% to 32%. The highest value (32%) was recorded in pedon SC (ABcv).

Subsurface horizon values ranged from 18% to 32% with the highest value obtained in pedon SC(ABcv). Values were observed to decrease regularly with the depth.

The soils on basalt recorded 16% to 26% in the surface horizons than in a surface horizon values ranged from 24% to 32%. Pedon BS1(Btcv) obtained the highest content 32% while pedons BS1 (BCcv), BS2 (Bcv) and BS3 (BCv) had the lowest contents (24%) (Table 4.2).

4.2.2 Particle Density

Surface horizon values for basement complex soils ranged from 2.44 to 2.65 Mg/m^3 with the surface horizon values of range of 2.44 to 2.68 Mg/m^3. The highest value (2.68 Mg/m^3) was recorded in SC (Bcv) and the lowest (2.44 Mg/m^3) was recorded in YL (Btcv1). The surface horizon values ranged between 2.44 and 2.68 Mgm^{-3} . The highest value (2.68 Mg/m^3) was obtained in SC (Bcv) while the lowest (2.44 Mg/m^3$_)$ value was in YL(Btcv1) (Table 4.3)

For the soils formed on Basalt, particle density value ranged from 2.39 to 2.61 Mg/m^3 in the surface horizons. The surface horizon values ranged from 2.02 to 2.76 Mg/m^3. The highest value (2.76 Mg/m^3) was obtained in BS1(BCcv) while the lowest value (2.02 Mg/m^3) (Btcv1) was obtained in pedon BS2 (Table 4.3).

4.2.3 Bulk Density

Bulk density values for the soils formed on Basement complex ranged from 1.48 to 1.60 Mg/m^3 in the surface horizons. The subsurface values were found to be 1.35 to 1.80 Mg/m^3. The highest value (1.80 Mg/m^3) was recorded in SC (Btcv) while the lowest value (1.25 Mg/m^3) was obtained in pedon YL (Btcv2). Values were irregularly distributed with depth (Table 4.3).

For the soils formed on Basaltic parent, bulk density values varied between 1.49 and 1.71 Mg/m^3 in the surface horizons. The subsurface horizon values obtained the range 1.33 to 1.60 Mg/m^3. The highest value (1.71 Mg/m^3) was obtained in pedon BS4 (Btcv) while the lowest value (1.33 Mg/m^3) was obtained in the same pedon BS4 (Bcv) (Table 4.3).

Table 4.3: Bulk density, particle density and total porosity of the soils studied

Pedon	Depth (cm)	Particle Density Mg/m^3	Bulk Density Mg/m^3	Total Porosity %
Pedon SC				
Ap	0-13	2.61	1.49	43
ABcv	13-30	2.54	1.57	38
Bcv	30-56	2.68	1.55	42
Btcv	56-122	2.58	1.80	30
BCcv	122-170	2.68	1.45	46
Pedon OL				
Ap	0-12	2.65	1.48	44
ABtcv	12-110	2.61	1.60	39
Bcv	110-135	2.58	1.70	34
BCcv	135-160	2.58	1.59	39
Pedon OGR				
Ap	0-39	2.44	1.60	34
Btcv	39-79	2.49	1.68	33
BCcv	79-120	2.48	1.70	32
Pedon YL				
Ap	0-30	2.55	1.49	42
Brcv1	30-70	2.44	1.37	44
Btcv2	70-160	2.57	1.35	47
Pedon BS1				
Ap	0-20	2.48	1.49	40
Btcv	20-76	2.54	1.38	46
Bcv1	76-106	2.74	1.57	43
Bcv2	106-130	2.75	1.45	47
BCcv	130-168	2.76	1.46	47
Pedon BS2				
Ap	0-25	2.45	1.56	36
Bcv	25-75	2.51	1.30	48
Btcv1	75-105	2.02	1.24	39
Btcv2	105-120	2.5	1.35	46
Bcv	120-173	2.45	1.31	47
Pedon BS3				
Ap	0-20	2.39	1.71	28
Btcv1	20-56	2.62	1.54	41
Btcv2	56-90	2.65	1.59	40
Bcv	90-170	2.61	1.59	39
Pedon BS4				
Ap	0-18	2.61	1.64	37
ABtcv	18-52	2.55	1.52	40
Bcv	52-68	2.59	1.33	49
Btcv	68-145	2.48	1.60	36

4.2.4 Total Porosity

Total porosity values ranged from 34 to 44% for the surface horizon of the soils on Basalt complex parent. The subsurface horizon values recorded the ranged of 30 to 75%. Values were observed to be higher in the surface horizon of all the pedons except pedon YL (Table 4.3).

Soils formed on Basaltic parent had the range of 28 to 40% in their surface horizons while the highest value (49%) was obtained in pedon BS4 (Btcv). Values generally increased with depth (Table 4.3).

4.2.5 Average Compressive Strength N(mm^2)

Unconfined compressive strength was used to evaluate the strength of stabilized blocks. The value for the comprehensive strength is presented in Table 4. 6. The average compressive strength shows that OL (1.68 N/mm^2) was significantly higher followed by OGR (1.44 N/mm^2), SC (0.93 N/mm^2), BS4 (0.83 N/mm^2), which were significantly different and YL (0.77 N/mm^2), BS1 (0.72 N/mm^2) and BS3 (0.69 N/mm^2) which were significantly the same, followed by BS2 (0.53 N/mm^2) which was the least. (Table 4.4). Correlation matrix between pedogenic properties and compressive strength (CS) is shown in Table 4.5.

4.2.6 Atterberg limit tests

The details of the liquid and plastic tests for all the soils studied are presented in Table 4.6. Liquid limits in all the soils were significantly different with OGR (51%) having the highest value, followed by BS1 (48.8%), BS2 (46.3%), BS3 (44.9%) and BS4 (45.0%) which were statistically similar and statistically different from YL (44.2%), OL (40%) and SC (34.4%) with the lowest value. Also, means values of Plastic limits showed significant differences among all the studied

Table 4:4 Compressive Strength test on Plinthite blocks of all the soils studied

Pedons	**Length (mm)**	**Breadth (mm)**	**Height (m)**	**Area (mm^2)**	**Failure Load (KN)**	**Average Compressive Strength (N/mm^2)**
SC	316.5ab	141.5b	140.8cd	44782.7c	42.0b	0.93c
OL	305.8d	141.2b	140.5cd	43431.7d	73.2a	1.68a
OGR	319.2a	145.2a	138.7d	46332.5ab	67.0a	1.44b
YL	313.0c	142.5b	141.5bcd	44601.2c	34.5cd	0.77d
BS1	315.5bc	145.0a	144.8ab	45747.5b	33.0cd	0.72d
BS2	318.3ab	146.5a	138.5d	46636.7a	24.7e	0.53e
BS3	315.3bc	145.2a	146.0a	45775.8b	31.8d	0.69d
BS4	319.2a	146.3a	143.0abc	46705.8a	39.0bc	0.83cd
SE±	1.18	0.6	1.39	275.4	2.37	0.05

Table 4.5: Correlation matrix between pedogenic properties and compressive strength (CS) of the soils Studied

	Failure Load (KN)	**Compressive Strength (N/mm^2)**	**CS (I/CS)**	**CS (CS2)**	**CS (CS SQRT)**	**CS (Log10)**
As203	-0.25	-0.25	0.42	-0.19	-0.29	-0.33
Bulk Density	0.58	0.58	-0.56	0.57	0.58	0.59
Total Porosity	-0.46	-0.44	0.39	-0.43	-0.44	-0.43
Gravel	0.32	0.33	-0.36	0.31	0.34	0.35
Clay	-0.29	-0.25	0.16	-0.27	-0.23	-0.21
Silt	0.29	0.32	-0.22	0.35	0.29	0.27
Sand	0.55	0.56	-0.59	0.52	0.58	0.59
Fed	0.19	0.17	-0.32	0.09	0.21	0.25
Feox	-0.17	-0.21	0.13	-0.24	-0.19	-0.17
Fep	0.16	0.19	-0.27	0.16	0.21	0.23
Ald	0.27	0.28	-0.31	0.27	0.28	0.29
Alox	-0.47	-0.48	0.58	-0.42	-0.51	-0.54
Alp	0.19	0.22	-0.28	0.18	0.24	0.25
Mnd	-0.16	-0.16	0.31	-0.11	-0.19	-0.23
Mnox	-0.01	-0.01	0.12	0.01	-0.03	0.06
Mnp	-0.01	-0.01	0.13	0.32	-0.03	-0.06
Feox/d	0.19	0.17	-0.32	0.09	0.21	0.25
Alox/d	-0.49	-0.49	0.63	-0.43	-0.53	-0.57
Mnox/d	-0.07	-0.07	-0.02	-0.01	-0.05	-0.02
OC	-0.30	-0.28	0.39	-0.22	-0.31	-0.34

Significant r values at 5% LOS ≥ 0.381, 1% LOS ≥ 0.487

soils with BS1 (28.8%) having the greatest value followed by BS4 (26.8%), BS2 (24.4%), BS3 (22.5%), SC (21.2%), OL (19.6%), YL (18.2%) and OGR (13.4%).

4.2.7 Plastic index (%)

Plasticity index values of the pedons were significantly influenced by the parent materials (Table 4.6). Soils with OGR had the highest value (37.6%) followed by BS1 (28.2%), YL (25.8%), BS3 (22.3%), BS2 (21.6%), OL (20.4%), BS4 (18.3%) and SC (13.3%).

4.2.8 Maximum dry density (MDD)

Maximum dry density varied significantly among the studied pedons (Table 4.6). Higher value (1.93 Mgm^{-3}) was recorded under SC, followed by OGR (1.88 Mgm^{-3}), YL (1.81 Mgm^{-3}), OL (1.74 Mgm^{-3}), BS3 (1.71 Mgm^{-3}), BS2 (1.67 Mgm^{-3}), BS4 (1.66 Mgm^{-3}) and BS1 (1.62 Mgm^{-3}) respectively. The values are between the range of (1.74 to 1.93 Mgm^{-3}) for Basaltic parent materials and (1.71 to 1.62 Mgm^{-3}) for Basement Complex parent materials.

4.2.9 Optimum moisture content (OMC)

Table 4.6 is the summary of optimum moisture tests carried out for all the soils studied. Mean values were statistically different with BS1 having the greatest value (49.6%), followed by BS2 (18.5%), BS3 (18.5%), BS4 (17.5%), OL (16%), YL (14%), SC (13.5%), and OGR (12.6%) which were statistically the same.

Furthermore, a correlation matrix was carried out between pedogenic properties and geotechnical test (Table 4.7). The results showed that Fe(ox) correlated positively with OMC (0.39), PL (0.42) and negatively with ACS (0.70). Also, Al(ox) correlated negatively with ACS (0.42), Mn(ox) correlated positively with MDD (0.66) and negatively with LL (0.64), OMC (0.41), PL (0.52) and PI (0.63). More so, Clay correlated positively with LL (0.69), OMC (0.44) and PI (0.37). $Mn_{x/d}$

Table 4.6: Summary of geotechnical tests for all the soils studied

Pedons	Liquid limit (%)	Plastic limit (%)	Plasticity Index (%)	Maximum Dry Density (Mgm^{-3})	Optimum Moisture Content (%)	Average Compressive Strength N(mm^{2})
SC	34.4g	21.2e	13.3h	1.93a	13.5b	0.93c
OL	40.0f	19.6f	20.4f	1.74d	16.0b	1.68a
OGR	51.0a	13.4h	37.6a	1.88b	12.6b	1.44b
YL	44.2e	18.2g	25.8c	1.81c	14.0b	0.77d
BS1	48.8b	28.8a	28.2b	1.62g	49.6a	0.72d
BS2	46.3c	24.4c	21.6e	1.67ef	18.5b	0.53e
BS3	44.9d	22.5d	22.3d	1.71de	18.5b	0.69d
BS4	45.0d	26.8b	18.3g	1.66f	17.5b	0.83cd
SE±	0.15	0.04	0.06	0.01	11.17	0.15

correlated positively with LL (0.66), MDD (0.89) and negatively with OMC (0.85), PL (0.64) and PI (0.50).

Table 4.8 shows the correlation of Average Compressive Strength (ACS) with LL, PL, PI, MDD and OMC. This reveal that ACS correlated negatively with PL (0.62) and OMC (0.23) and positively with PI (0.25) and MDD (0.41).

4.3 Chemical Properties

4.3.1 Soil pH

The soil pH of surface horizons of profiles on Basement complex parent materials varied from 5.1 to 5.7 while for the underlying horizons, pH values ranged from 4.8 to 6.1 (Table 4.9).

For the pedons on the Basaltic parent materials pH values ranged from 4.5 to 5.5. In the underlying horizons, soil pH values were slightly similar and ranged from 4.5 to 5.6. Generally, pH values were irregularly distributed with soil depths across the parent materials. Changed in pH values of the surface horizons of profiles on Basement complex parent materials varied negatively from 0.80 to 1.9. The surface horizon values obtained 0.20 to 1.9, for pedons on the Basaltic parent material values ranged from 0.6 to 1.3 in the surface horizons while the underlying horizons varied from 0.6 to 1.9.

4.3.2 Exchangeable Bases

Table 4.9 shows the mean values of all exchangeable bases. Exchangeable calcium contents of surface horizons of profiles on basement complex parent materials varied from 1.58 to 3.76 cmol (+) kg^{-1}, while the underlying horizons exchangeable calcium values ranged from 1.7 to 3.89 cmol (+) kg^{-1}.

Table 4.7: Correlation Matrix between Pedogenic Properties and Geotechnical Properties

	LL	MDD	OMC	PL	PI	ACS
Fe$_{(ox)}$	0.089	- 0.257	0.395	0.422	- 0.220	- 0.703
Al$_{(ox)}$	0.167	- 0.197	0.285	- 0.157	0.309	- 0.421
Mn$_{(ox)}$	-0.636	0.655	- 0.412	- 0.523	- 0.632	- 0.385
Fe$_{(p)}$	- 0.108	0.433	- 0.597	0.452	0.246	0.697
Al$_{(p)}$	- 0.265	0.654	- 0.670	- 0.450	- 0.142	0.657
Mn$_{(p)}$	- 0.484	0.254	- 0.130	0.545	0.372	0.394
Fe$_{(d)}$	- 0.449	0.295	- 0.406	- 0.161	- 0.461	- 0.169
Al$_{(d)}$	- 0.188	0.230	- 0.532	- 0.977	0.281	0.465
Mn$_{(d)}$	- 0.077	- 0.178	0.373	- 0.042	- 0.266	- 0.576
Sand	- 0.481	0.238	- 0.256	- 0.413	- 0.277	- 0.532
Silt	- 0.0533	0.043	- 0.125	- 0.151	- 0.050	0.7217
Clay	0.691	- 0.352	0.437	0.203	0.374	0.1896
Al$_{x/d}$	0.325	0.230	0.594	0.711	0.457	0.190
Fe$_{x/d}$	0.476	- 0.494	0.731	- 0.034	0.391	- 0.434
Mn$_{x/d}$	0.655	0.888	- 0.846	- 0.641	- 0.503	0.116

Table 4.8 Correlation between the Geotechnical test properties

	LL	PL	PI	MDD	OMC	ACS
LL	1					
PL	0.012	1				
PI	0.84***	-0.45	1			
MDD	-0.43	-0.76	0.014	1		
OMC	0.24	0.49	0.13	-0.49	1	
ACS	-0.12	-0.62	0.25	0.41	-0.23	1

Table 4.9 Chemical properties of the soils

	$pH(H_2O)$	$pH(CaCl_2)$	OC	TN	AP	Ca	Mg	k	Na	H+Al	CEC	Base Sat CEC	ECEC	Base Sat ECEC
			g/kg	g/kg	mg/kg	← Cmol(+)kg^{-1}								
Pedon SC														
Ap	5.70	4.40	6.80	3.20	10.50	1.58	0.81	0.21	0.15	1.20	6.40	78.59	3.95	80.74
Bcv	5.80	4.80	2.00	2.50	12.30	1.80	0.68	0.09	0.06	2.00	7.40	61.76	4.63	69.56
Btcv	5.80	4.90	1.60	2.80	8.75	2.80	0.47	0.14	0.09	0.80	8.30	65.18	4.30	87.12
BCcv	5.40	4.40	1.50	1.80	14.00	2.98	0.52	0.12	0.08	2.00	10.60	37.64	5.70	66.61
Pedon OL														
Ap	5.20	4.50	2.10	0.80	14.00	3.06	0.89	0.18	0.10	0.80	6.50	69.69	5.03	84.99
ABtcv	5.70	3.80	7.00	0.10	13.10	1.70	0.61	0.47	0.30	0.80	5.80	85.34	3.88	86.09
Bcv	5.80	5.40	4.10	0.70	12.30	3.89	1.74	0.32	0.25	0.80	13.8	57.54	7.00	90.85
BCcv	5.80	5.10	2.90	1.80	13.10	2.95	1.58	0.27	0.19	1.00	8.70	65.17	5.99	85.01
Pedon OGR														
Ap	5.70	5.10	3.50	1.40	14.00	2.75	1.66	0.25	0.21	1.00	6.60	81.21	5.87	84.23
Btcv	5.80	4.60	6.60	2.10	19.30	2.34	0.31	0.14	0.09	1.00	6.10	78.53	3.88	82.73
BCcv	6.10	5.20	0.20	1.40	13.10	3.49	0.80	0.14	0.07	1.00	10.50	62.09	5.50	86.7
Pedon YL														
Ap	5.10	4.00	0.60	1.10	10.50	3.76	0.63	0.18	0.12	0.60	7.40	70.00	5.29	89.62
Btcv1	4.80	4.00	6.40	1.80	14.90	1.80	0.49	0.12	0.10	2.00	7.80	59.87	4.51	70.02
Btcv2	5.90	4.40	1.40	2.10	17.50	2.32	0.91	0.22	0.17	1.00	10.50	52.76	4.62	84.71

Table 4.9: Cont……Chemical properties of soils in the respective study areas

	pH (H_2O)	pH ($CaCl_2$)	OC	TN	AP	Ca	Mg	k	Na	H+Al	CEC	Base Sat CEC	ECEC	Base Sat ECEC	ESP	CEC Clay
			g/kg	g/kg	Mg/kg	←					Cmol kg^{-1}				→	
Pedon BS1																
Ap	4.50	4.3	3.40	1.40	16.63	2.00	0.78	0.19	0.10	3.00	12.8	38.83	6.07	62.36	15.62	88.54
Btcv	5.10	3.8	5.60	1.75	12.30	1.00	0.15	0.09	0.07	2.40	11.7	28.46	3.71	58.12	17.86	53.22
Bcv1	5.40	3.5	3.40	1.40	10.50	1.36	0.20	0.10	0.06	2.60	12.1	28.84	4.32	57.31	15.12	93.57
Bcv2	5.60	3.7	3.20	1.10	11.38	1.43	0.20	0.09	0.05	1.60	12.2	30.41	3.37	69.86	16.31	72.38
BCcv	5.50	3.9	1.80	1.75	12.30	1.43	0.24	0.09	0.06	2.20	12.8	30.07	4.02	63.64	16.32	43.52
Pedon BS2																
Ap	5.50	4.6	4.30	1.05	12.30	1.48	0.23	0.13	0.09	1.20	13.00	30.23	3.13	76.61	16.07	98.04
Bcv	4.80	3.9	6.60	1.75	22.75	1.83	0.30	0.13	0.08	4.40	10.40	39.33	6.74	48.17	17.59	91.08
Btcv1	4.90	3.8	4.30	1.61	21.00	1.20	0.20	0.07	0.05	3.00	7.60	47.89	4.52	54.82	28.55	45.84
Btcv2	4.50	3.6	0.80	1.40	21.00	3.03	0.26	0.14	0.11	2.80	8.50	62.82	6.34	65.61	22.47	11.20
Bcv	4.80	3.8	5.10	1.05	10.50	1.97	0.10	0.04	0.02	3.20	8.60	48.84	5.33	56.76	24.30	72.83
Pedon BS3																
Ap	5.30	3.50	2.90	1.65	13.13	2.60	0.31	0.22	0.17	2.00	8.00	63.00	5.30	71.59	23.87	31.32
Btcv1	5.30	4.30	6.70	2.45	21.00	2.30	0.81	0.28	0.21	0.80	6.30	86.98	4.40	87.26	33.17	30.02
Btcv2	5.10	4.50	3.70	1.05	12.30	3.23	1.05	0.21	0.18	1.00	9.10	64.72	5.67	85.49	15.38	58.02
BCv	5.00	3.90	2.20	1.61	14.88	6.92	1.75	0.21	0.15	1.20	11.90	87.73	10.23	89.69	13.11	51.74
Pedon BS4																
Ap	5.30	4.30	0.25	1.75	10.50	4.71	1.89	0.20	0.14	1.40	10.20	81.96	8.34	85.65	15.29	40.20
ABtcv	5.30	4.70	0.63	1.05	12.30	2.92	0.81	0.30	0.25	1.00	8.40	64.64	5.28	84.45	16.67	55.56
Bcv	5.50	4.50	0.35	1.40	12.30	4.43	0.93	0.33	0.27	2.00	9.50	66.73	7.96	76.02	6.84	50.40
Btcv1	5.60	4.20	0.41	2.00	11.38	1.78	0.34	0.20	0.16	2.00	11.20	23.39	4.48	56.71	2.68	82.08
Btcv2	5.20	4.00	3.30	2.45	14.00	3.12	0.49	0.30	0.23	1.60	16.60	40.96	5.74	80.95	17.41	129.69

For the pedons on the Basaltic parent materials, values varied between 1.48 and 4.71 cmol (+) kg in the surface horizons while the subsurface horizons ranged between 1.00 and 6.92 cmol (+) kg^{-1}. The highest value was observed in pedon BS3 (BCv) while the lowest value was in pedon BS2 (Bcv). Values were regularly distributed with increase in depth.

Magnesium content in the surface horizons of the Basement complex parent ranged from 0.63 to 1.66 cmol (+) kg^{-1}. The subsoil values obtained the range 0.47 to 1.74 cmol (+) kg^{-1}. The highest value was obtained in pedon OL (Bcv) while the lowest was recorded in SC (Btcv). For soils on Basaltic parent material, values of magnesium varied from 0.23 to 1.89 cmol (+) kg^{-1} in the surface horizons. The subsurface horizon values ranged from 0.10 to 1.89 cmol (+) kg^{-1}. The highest value was observed in BS4 (Ap) while the lowest value in BS2(Bcv). Values were observed to be higher in the surface horizons; increased with depth in the subsurface horizons.

The potassium contents in the surface horizons of Basement complex soils ranged between 0.18 and 0.25 cmol (+) kg^{-1} while the underlying horizons ranged from 0.9 to 0.47 cmol (+) kg^{-1}. The highest value was recorded in pedon OL (ABtcv) while and the lowest was observed in SC (Bcv). Values were observed to be higher in the surface horizons than in the underlying horizons. Values of potassium in the Basaltic soil profiles ranged from 0.13 to 0.22 cmol (+) kg^{-1} in the surface from 0.07 to 0.33 cmol (+) kg^{-1}. The highest value was observed in BS4 (Bcv). Values were slightly higher in the underlying horizons.

Exchangeable sodium contents in the surface horizons of the soils on basement complex ranged from 0.10 to 0.21 cmol (+) kg^{-1} for surface horizons and 0.06 to 0.30 cmol (+) kg^{-1} for underlying horizons with the highest value being obtained in pedon OL (ABtcv) and lowest value in SC (Bcv).

For the soils on Basaltic parent materials, exchangeable sodium contents varied from 0.09 to 0.17 cmol (+) kg^{-1} in the surface horizons and 0.02 to 0.27 cmol (+) kg^{-1} in the underlying horizons with the highest value recorded in BS4 (Btcv) while the lowest in BS2 (Bcv). Values were observed to decrease with depth and the increase in the underlying horizons.

Furthermore, organic carbon contents of the soils formed on Basement complex parent materials ranged from 0.6 to 6.8 gkg^{-1} in the surface horizons. The subsurface horizons values ranged from 0.2 to 6.6 gkg^{-1}. The highest value was obtained in SC (Ap) while the lowest was recorded in OGR (Btcv) (Table 4.9).

For the soil profiles on Basaltic parent materials, organic carbon content in the surface horizons ranged from 2.5 to 4.3 gkg^{-1}. The underlying horizon values were found to range from 0.8 to 6.7 gkg^{-1}. The highest value was observed in BS3 (Btcv1) while the lowest value was recorded in BS2 (Btcv2). Values generally decreased with depth in all the profiles but surface horizon values were all lower than the values of the underlying horizons (Table 4.9).

Total nitrogen contents of the soil profiles formed on Basement complex parent material ranged from 0.8 to 3.2 cmol (+) kg^{-1} for the surface horizons, while the underlying horizon value ranged from 0.7 to 2.8 cmol (+) kg^{-1}. Values in the Ap horizons of all the profiles were observed to be lower than the underlying horizons (Table 4.9).

Available phosphorus content of soil profiles formed on Basement complex parent materials ranged from 10.50 to 14.00 mgkg^{-1} in the surface horizons while the values in the underlying horizons varied between 8.75 and 19.25 mgkg^{-1}. The highest value was observed in pedon OGR (Btcv) while the lowest value was found in SC (Btcv). Values were observed to be irregularly distributed with depth.

4.3.3 Exchange Acidity

Exchange acidity values of soil profiles on Basement complex parent materials ranged from 0.60 to 1.2 cmol (+) kg^{-1} while the subsurface horizon values recorded a range of 0.8 to 2.0 cmol (+) kg^{-1}. Values were observed to be regularly distributed with decrease with depth (Table 4.9).

For the soil profiles on Basaltic parent materials, values on the surface horizons varied between 1.20 to 3.00 cmol (+) kg^{-1} while the underlying horizons ranged from 0.80 to 4.4 cmol (+) kg^{-1}. Values were observed to irregularly distributed with depth (Table 4.9).

4.3.4 Cation exchange Capacity

Cation exchange capacity (CEC-NH_4OAc) values for soils formed on Basement Complex soils ranged from 6.4 to 7.4 cmol (+) kg^{-1} for the surface horizons (Table 4.9). The underlying horizons value obtained the range from 5.8 to 13.8 cmol (+) kg^{-1}. The highest value was recorded in OL (Bcv) while the lowest value was also in OL (ABtcv). Values were regularly distributed and increased with depth (Table 4.9).

For the soils on Basaltic parent materials, the values in the surface horizons ranged from 8.00 to 13.00 cmol (+) kg^{-1} (Table 4.9). The surface horizon values ranged from 6.30 to 16.60 cmol (+) kg^{-1}, values increased with depth in BS1 and BS3 while for BS3 and BS4 values were irregularly distributed (Table 4.9).

Effective cation exchange capacity for the surface soils on Basement Complex ranged from 5.33 to 6.36 cmol (+) kg^{-1}(Table 4.9). Values in the underlying horizons obtained range 5.79 to 8.74 cmol (+) kg^{-1}. The highest value was observed in OL(Bcv) while the lowest was recorded in OL(ABtcv). Values were irregularly distributed with depth in all the pedons (Table 4.9).

For soils on Basaltic parent materials, surface horizons values ranged from 5.13 to 9.76 cmol (+) kg^{-1} while the underlying horizons ranged from 4.62 to 9.76 cmol (+) kg^{-1} (Table 4.9). The highest value was recorded in BS4 (Ap) while the lowest value was in BS4 (Btcv1). Values decreased with depth except for pedon BS2 increased irregularly with depth (Table 4.9).

4.3.5 Base Saturation

Values of base saturation (NH_4OAc) in soils on Basement complex ranged from 69.69 to 81.21% in the surface horizon, the subsurface horizon values obtained the range 37.64 to 85.34% (Table 4.9). The highest value was in OL(ABtcv) while the lowest was recorded in SC (BCcv). Values decreased regularly with depth in OGR and YL while it decreased irregularly with depth in SC and OL (Table 4.9).

For soils on Basaltic parent materials, base saturation (NH_4OAc) values ranged from 62.36 to 85.65% in the surface horizons while the underlying horizons ranged from 48.17 to 89.69%. The highest value was obtained in BS3 (Bcv) while the lowest value was in BS2 (Bcv) (Table 4.9).

4.3.6 Exchangeable Sodium percentage (ESP)

Exchangeable sodium percentage values in the surface horizons of profiles on Basement complex parent materials range from 8.24 to 37.96%. The underlying horizons ranged from 3.49 to 37.41%. The highest value was recorded in SC (Ap) while the lowest value was in SC (BCcv). Values were irregularly distributed with depth (Table 4.9).

For soils on Basaltic parent materials, values ranged from 15.29 to 23.87% in the surface horizons. The underlying horizons values ranged between 2.68 and 33.17%. The highest value was recorded in BS3 (Btcv1). Values irregularly increased with depth in all the pedons (Table 4.9).

4.4 Pedogenic Forms of Iron, Aluminum and Manganese Oxides.

4.4.1 Pedogenic Forms of Iron

The citrate-bicarbonate (Fed) extractable (total free iron oxides) contents in the surface horizons of profiles on Basement complex parent materials ranged from 1.87 to 5.28% (Table 4.10). The underlying horizon values obtained range 2.39 to 5.36%. The highest value was recorded in pedon YL (Btcv1) while the lowest value was recorded in SC (Btcv). Values were observed to be higher in the plinthic horizons of all the pedons except pedon OL(Ap) which was slightly higher than the overlying horizons (Table 4.10).

For the soils on Basaltic parent materials, content of extractable citrate-bicarbonate dithionite iron oxide (CBD) in the surface horizons ranged from 1.91 to 3.83% (Table 4.10). The values in the underlying horizons obtained range 0.002 to 5.64%. The highest value was observed in pedon BS4 (|Btcv2) while the lowest value was recorded in BS2 (Btcv1) (Table 4.10).

Table 4.10 Pedogenic forms of Iron, Aluminium and Manganese oxides and their active

	Fe_d	Fe_{ox}	Fe_p	Al_d	Al_{ox}	Al_p	Mn_d	Mn_{ox}	Mn_p	$Al_{ox/d}$	$Mn_{ox/d}$	Clay/Fe_d	Clay/Al_d	Clay/Mn_d	Fe_p/Fe_d	Mn_p/Mn_d	$Fe_{x/d}$
											%						
Pedon SC																	
Ap	1.87	0.72	0.09	1.64	0.59	5.72	0.07	0.007	0.028	0.036	0.109	27.70	33.89	294.12	0.05	0.42	0.39
Bcv	3.17	0.58	0.26	1.83	1.59	29.52	0.03	0.016	0.007	0.087	0.583	44.91	16.34	962.96	0.08	0.26	0.18
Btcv	2.39	1.47	0.15	0.49	1.59	4.86	0.02	0.006	0.006	0.321	0.332	19.07	17.59	1696.97	0.06	0.35	0.61
Ccv	3.22	0.35	0.36	4.12	0.66	9.00	0.02	0.016	0.008	0.016	1.052	79.88	42.20	1866.67	0.11	0.56	0.11
Pedon OL																	
Ap	4.15	1.47	1.12	5.61	2.65	14.98	0.10	0.012	0.076	0.047	0.117	16.24	9.04	234.15	0.27	0.77	0.37
ABtcv	3.15	0.91	0.57	4.87	2.85	6.19	0.09	0.005	0.013	0.058	0.055	17.64	5.61	177.78	0.18	0.14	0.29
Bcv	2.64	0.55	0.72	4.45	1.61	16.56	0.07	0.006	0.023	0.036	0.088	50.63	17.38	388.89	0.27	0.32	0.21
BCcv	3.04	1.11	0.43	2.91	2.68	3.38	0.03	0.003	0.027	0.092	0.109	25.33	10.42	888.89	0.14	0.84	0.36
Pedon OGR																	
Ap	1.26	0.49	0.31	8.44	1.52	8.24	0.03	0.005	0.025	0.018	0.164	48.53	15.84	774.19	0.24	0.81	0.39
Btcv	4.73	1.06	0.53	7.78	7.85	6.30	0.04	0.002	0.017	0.101	0.048	16.98	2.29	473.68	0.11	0.44	0.22
BCcv	4.09	0.83	0.31	9.91	4.19	6.10	0.06	0.018	0.031	0.042	0.310	28.85	5.72	417.39	0.08	0.54	0.20
Pedon YL																	
Ap	5.28	1.16	0.55	4.66	7.89	7.50	0.06	0.012	0.069	0.169	0.198	22.52	3.29	422.76	0.10	1.13	0.22
Btcv1	5.36	0.33	0.58	9.87	7.55	3.58	0.04	0.005	0.004	0.076	0.126	89.82	3.97	833.33	0.11	0.12	0.06
Btcv2	2.62	0.84	0.95	9.26	4.94	5.74	0.04	0.008	0.001	0.053	0.226	19.08	3.24	432.43	0.36	0.04	0.32

Table 4.10 Cont….. Pedogenic forms of Iron, Aluminium and Manganese oxides and their active

	Fe_d	Fe_{ox}	Fe_p	Al_d	Al_{ox}	Al_p	Mn_d	Mn_{ox}	Mn_p	$Al_{ox/d}$	$Mn_{ox/d}$	$Clay/Fe_d$	$Clay/Al_d$	$Clay/Mn_d$	Fe_p/Fe_d	Mn_p/Mn_d	$Fe_{x/d}$
											%						
Pedon BS1																	
Ap	3.11	0.52	0.92	8.15	7.55	30.97	0.01	0.004	0.034	0.093	0.390	53.74	3.71	2800.00	0.29	3.37	0.17
Btcv	3.83	0.56	0.46	8.14	6.31	5.90	0.01	0.005	0.028	0.077	1.019	42.89	3.81	4800.00	0.12	5.52	0.15
Bcv1	5.33	1.20	0.35	4.26	3.95	4.10	0.01	0.006	0.031	0.093	1.727	26.64	8.10	9142.85	0.07	8.74	0.23
Bcv2	2.08	1.05	0.23	7.88	3.63	0.28	0.01	0.003	0.001	0.046	0.475	26.81	7.72	5090.91	0.11	0.22	0.50
BCcv	2.47	0.83	0.62	6.95	3.41	3.88	0.04	0.002	0.031	0.049	0.043	16.87	4.10	325.58	0.25	0.71	0.34
Pedon BS2																	
Ap	3.21	0.98	0.41	11.04	4.32	5.15	0.07	0.001	0.031	0.039	0.013	24.33	5.55	342.86	0.13	0.44	0.31
Bcv	1.88	1.24	0.56	1.01	6.10	3.64	0.10	0.021	0.038	0.602	0.201	14.52	2.95	173.91	0.29	0.37	0.66
Btcv1	0.01	1.15	0.19	1.96	8.78	5.88	0.04	0.006	0.003	0.446	0.143	15.68	2.05	433.74	1255.33	0.08	7653.33
Btcv2	3.56	0.71	0.16	1.39	7.52	4.18	0.06	0.015	0.026	0.543	0.233	36.67	3.46	412.69	0.05	0.42	0.19
Bcv	2.22	0.97	0.32	0.61	7.22	3.79	0.11	0.020	0.099	1.195	0.179	28.93	3.87	248.89	0.14	0.88	0.44
Pedon BS3																	
Ap	1.91	0.73	0.1	1.58	6.63	4.19	0.13	0.017	0.023	0.421	0.145	35.88	3.92	202.35	0.05	0.18	0.38
Btcv1	1.28	1.02	0.25	1.03	1.31	9.09	0.22	0.011	0.045	0.127	0.052	31.45	24.53	144.79	0.19	0.20	0.79
Btcv2	2.27	0.72	0.31	1.02	9.91	3.69	0.04	0.006	0.016	0.967	0.147	35.91	2.62	650.00	0.14	0.39	0.32
BCv	1.43	1.35	0.29	1.39	7.23	3.61	0.03	0.006	0.047	0.519	0.226	19.23	3.59	945.46	0.21	1.72	0.95
Pedon BS4																	
Ap	3.25	1.45	0.38	1.59	11.81	5.31	0.13	0.006	0.061	0.74	0.049	16.60	2.03	188.97	0.12	0.48	0.45
ABtcv	3.79	1.61	0.44	2.28	9.24	5.46	0.07	0.004	0.025	0.405	0.056	7.50	1.29	166.67	0.12	0.34	0.43
Bcv	4.13	1.103	0.29	3.09	0.88	11.29	0.04	0.001	0.006	0.028	0.013	27.21	34.15	779.22	0.07	0.16	0.27
Btcv1	4.58	1.362	0.14	3.65	3.11	4.72	0.05	0.005	0.007	0.085	0.112	19.09	8.35	577.78	0.03	0.16	0.29
Btcv2	5.64	1.289	0.35	2.91	3.00	2.43	0.05	0.007	0.007	0.103	0.142	18.62	7.99	466.02	0.06	0.13	0.23

4.4.2 Active Iron and Clay/Dithionite Iron Ratio

Active iron ratio ($Fe_{ox/d}$) in the surface horizons of soils on Basement complex parent materials ranged from 0.17 to 0.398, values in the underlying horizons obtained range 0.06 to 0.61 and the highest value was observed in SC (Btcv) while the lowest value was recorded in YL (Btcv1). Generally, active iron ratio decreased with depth in all the profiles (Table 4.10).

For the soils on Basaltic parent materials, values varied between 0.17 and 0.45 in the surface horizons and between 0.15 and 0.95 in the subsurface horizon (Table 4.10). The highest value was recorded in BS3 (BCv) while the lowest value was found in BS1 (Btcv). Generally, values increased with depth in all the profiles (Table 4.10).

Clay/dithionite iron ratio in the Basement complex soil profiles ranged from 16.24 to 48.58 in the surface horizons while the underlying horizon values recorded range 16.98 to 89.82 (Table 4.10). The highest value was recorded in OGR (Ap) while the lowest value was found in OL (Ap). The plinthic horizons were observed to obtain the highest values in all the profiles (Table 4.10).

The contents of Oxalate extractable iron oxide (Fe_{ox}) in the surface horizons of the soils on Basement complex parent materials ranged from 0.49 to 1.47% (Table 4.10). The underlying values obtained range from 0.33 to 1.47%. Values were observed to be highest in pedon OL (Ap) while the lowest value occurred in OGR (Ap) (Table 4.10).

For soils on Basaltic parent materials, surface horizon values ranged from 0.73 to 1.45%. The underlying horizons obtained range 0.56 to 1.61% (Table 4.10). The highest value was recorded in BS4 (ABtcv) while the lowest value was obtained in BS4 (ABtcv) while the lowest value was obtained in BS (Btcv). Values were regularly distributed with depth in all the pedons (Table 4.10).

Pyrophosphate extractable iron oxide (Fe_p) values in the soil profiles on Basement complex parent material values in the surface horizons ranged from 0.09 to 1.12% (Table 4.10). The underlying horizon values ranged from 0.15 to 0.95%. The highest value was recorded in OL(Ap) while values were irregularly distributed with depth (Table 4.10).

For the profile on Basaltic parent materials, values Fe_p varied between 0.10 to 0.60% in the surface horizons (Table 4.10). The subsurface horizons value ranged between 0.14 to 0.62%. The highest value was recorded in BS1 (Ap) while the lowest value was observed in BS4(Btcv1) (Table 4.10).

4.4.3 Pedogenic Forms of Aluminium Oxide

Citrate Bicarbonate Dithionite extractable aluminium oxide (Ald) values in the surface horizons of the profiles on Basement complex ranged from 4.66 to 8.44% (Table 4.10). The underlying horizons values recorded 0.49 to 9.91%. The highest value was recorded in OGR (BCcv). Values were generally higher in the plinthic horizons of all the pedons (Table 4.10).

Citrate Bicarbonate Dithionite extractable iron oxide (Fe_d) content in the soils on Basaltic parent materials ranged between 1.58 and 11.04% in the surface horizons (Table 4.10). The subsurface horizon values ranged from 0.61 to 8.14%. The highest value was recorded in BS2 (Bcv). The plinthic horizons of all the profiles were observed to obtained highest contents of Al_d (Table 4.10).

Oxalate extractable aluminium (Alox) values in the surface horizons of profiles on |Basement complex ranged from 0.59 to 7.89% (Table 4.10). The underlying horizon values ranged from 0.66 to 7.89% (Table 4.10).

For the profiles on Basaltic percent materials, Al_{ox} values ranged from 4.32 to 11.81% for the surface horizons (Table 4.10).

4.4.4 Active Al ratio (Al_{ox}/Al_d)

Active Aluminium ratio Al_{ox}/Al_d values for soils on Basement Complex parent materials ranged from 0.02 to 0.05% while values in the underlying horizons varied between 0.02 to 0.09% (Table 4.10). The highest value was obtained in OL (BCcv) while the lowest was in OGR (Ap). Generally, values were higher in the plinthic horizons (Table 4.10).

For soils on Basaltic parent materials, values of Al_{ox}/Al_d varied from 0.04 to 0.17% in the surface horizons. The subsurface horizon values ranged from 0.02 to 0.32% (Table 4.10). Values increased irregularly with depth in all the profiles except pedon YL which decreased regularly with depth.

The underlying horizons values ranged from 0.88 to 9.91%. The highest value occurred in BS3 (Btcv1), while the lowest value was observed in BS4 (Bcv) Values were generally observed to increase with depth in all profiles except pedon BS4 which had higher values in the surface horizons (Table 4.10).

Pyrophosphate extractable aluminium oxide (Al_p) content in the surface horizons of soils on Basement Complex varied from 5.72 to 14.98%. The underlying horizon values obtained ranged 3.38 to 29.52% (Table 4.10).

For soils on Basaltic parent materials, the Al_p content in the surface horizon ranged from 0.28 to 30.97% (Table 4.10). The highest value was recorded in BS1 (Ap) while the lowest value was observed in BS1 (Bcv2). Values were generally found to be higher in the surface horizons of all profile (Table 4.10).

4.4.5 Pedogenic forms of Manganese

Extractable Citrate Bicarbonate Dithionite Manganese Oxide in the surface horizons of soils on Basement Complex varied from 0.03 to 0.10% (Table 4.10). The underlying horizon values ranged from 0.02 to 0.09%.

For soils formed on Basaltic parent materials, values were ranged from 0.01 to 0.13% in the surface horizons (Table 4.10). The underlying horizon values ranged from 0.01 to 0.22%. The highest value was obtained in BS3 (Btcv1). Values were observed to be higher in the plinthic horizons of all the profiles (Table 4.10).

Oxalate extractable manganese oxide values in the profiles on Basement Complex soils ranged from 0.005 to 0.018% (Table 4.10). The underlying horizons values were found to range between 0.002 to 0.018% (Table 4.10).

For the profile on Basaltic parent materials, values of Mn_{ox} varied from 0.001 to 0.021%. The underlying horizons ranged between 0.001 and 0.021%. The highest value was recorded in BS2 (Bcv) while the lowest was observed in BS4 (Bcv) (Table 4.10).

Pyrophosphate extractable Manganese (Mn_p) values in the profile on Basement Complex soils had values ranged from 0.025 to 0.076% in the surface horizons (Table 4.10). The underlying horizons values ranged from 0.001 to 0.031%.

For soils on Basaltic parent materials, values ranged from 0.023 to 0.061% in the surface horizons (Table 4.10). The values in the underlying horizons recorded 0.001 to 0.099% (Table 4.10). The highest value was recorded in BS2 (Bcv) while the lowest value was recorded in BS1 (BCcv). Values were observed to be irregular distributed with depth (Table 4.10).

4.5. 1 Major Elemental Oxides

Silicon oxide content in the profile on Basement Complex varies from 51.00 to 88.90% in the surface horizons (Table 4.11). Values in the underlying horizons ranged from 51.00 to 69.00%. The highest value was observed in YL (Btcv2) while the lowest value was in OGR and YL (Btcv, Ap respectively). The values were observed to decrease in the surface horizons and increase in the sub-surface horizons with depth in all the profiles (Table 4.11).

For soils on Basaltic parent materials, values ranged from 53 to 67.30% in the surface horizons (Table 4.11). The values in the underlying horizons ranged from 42.00 to 88.60%. The highest value was recorded in pedon BS2 (Bcv) while the lowest was in BS4 (Btcv2) (Table 4.11). Values were irregularly distributed with depth in all the horizons except pedon BS4 which decreased with depth regularly throughout the profile (Table 4.11).

Iron oxide content in the surface horizons of the profiles on Basement complex varied from 2.63 to 17.00% (Table 4.11). The underlying horizons values ranged from 6.35 to 19.61% and the highest values was recorded in YL (Btcv1) while the lowest was in SC (Ap). Values were observed to be higher in the plinthic horizons of all the profiles (Table 4.11).

For profiles on Basaltic parent materials, values ranged from 7.38 to 15.70%, underlying horizons values ranged from 1.27 to 24.38% and the highest value was recorded in BS4 (BT_{CV2})

Table 4.11 Total Elemental Oxides

	Al_2O_3	SiO_2	K_2O	CaO	Tio_2	V_2O_5	Cr_2O_3	MnO	Fe_2O_3	NiO	CuO	ZnO	ZrO_2	SrO	Rb_2O	Ga_2O_3	As_2O_3	Yb_2O_3	PbO	Nd_2O_3	Eu_2O_3	Re_2O_7	Iro_2
												%											
Pedon SC																							
Ap	1.3	88.9	2.92	2.96	1.75	0.056	0.022	0.038	2.63	0.001	0.014	0.001	0.78	0.001	0.028	0.001	0.007	0.001	0.032	0.001	0.030	0.041	0.001
ABcv	22.0	63.0	1.74	3.33	1.56	0.058	0.009	0.038	9.41	0.008	0.014	0.001	0.44	0.001	0.040	0.005	0.001	0.007	0.001	0.001	0.048	0.036	0.035
Btcv	17.0	65.6	1.72	2.99	1.82	0.072	0.010	0.036	10.89	0.009	0.021	0.003	0.55	0.001	0.039	0.015	0.001	0.001	0.074	0.001	0.062	0.036	0.001
BCcv	20.0	61.0	1.26	2.62	1.83	0.078	0.012	0.040	13.10	0.005	0.020	0.003	0.48	0.001	0.033	0.001	0.001	0.020	0.001	0.001	0.059	0.038	0.001
Pedon OL																							
Ap	18.0	63.1	0.42	2.19	2.62	0.088	0.016	0.100	12.86	0.015	0.020	0.002	0.47	0.001	0.001	0.013	0.001	0.009	0.069	0.001	0.084	0.040	0.001
ABtcv	21.0	58.1	2.20	0.28	2.30	0.079	0.020	0.039	13.75	0.016	0.021	0.009	0.48	0.001	0.047	0.007	0.001	0.007	0.001	0.001	0.001	0.040	0.042
Bcv	13.0	68.5	1.74	0.31	2.40	0.077	0.010	0.033	10.50	0.009	0.020	0.004	0.81	0.001	0.030	0.014	0.001	0.001	0.062	0.001	0.048	0.030	0.001
BCcv	21.0	56.3	3.25	0.39	1.70	0.080	0.014	0.039	14.37	0.011	0.019	0.010	0.43	0.001	0.074	0.017	0.001	0.008	0.001	0.001	0.074	0.030	0.001
Pedon OGR																							
Ap	1.37	85.5	4.63	0.56	2.00	0.066	0.001	0.029	3.692	0.012	0.017	0.001	0.93	0.001	0.069	0.003	0.001	0.001	0.001	0.001	0.050	0.049	0.053
Btcv	27.0	51.0	0.43	0.19	2.67	0.100	0.019	0.090	16.57	0.019	0.024	0.015	0.48	0.001	0.027	0.001	0.001	0.001	0.001	0.001	0.085	0.030	0.001
BCcv	26.0	50.0	0.41	0.18	2.74	0.110	0.022	0.096	17.71	0.017	0.023	0.007	0.48	0.001	0.029	0.006	0.001	0.009	0.001	0.001	0.084	0.030	0.042
Pedon YL																							
Ap	27.0	51.0	0.43	0.21	2.46	0.100	0.017	0.087	17.02	0.014	0.024	0.006	0.52	0.001	0.025	0.001	0.001	0.010	0.001	0.001	0.079	0.030	0.001
Btcv1	26.0	49.0	0.38	0.19	2.68	0.110	0.025	0.069	19.61	0.020	0.026	0.008	0.15	0.001	0.020	0.016	0.001	0.001	0.001	0.001	0.090	0.031	0.001
Btcv2	16.0	69.0	3.49	0.37	2.07	0.065	0.009	0.038	6.346	0.008	0.015	0.002	0.54	0.001	0.032	0.001	0.001	0.001	0.046	0.001	0.040	0.032	0.001

Table 4.11 Cont…Total Elemental Oxide

	Al_2O_3 %	SiO_2 %	K_2O %	CaO %	Tio_2 %	V_2O_5 %	Cr_2O_3 %	MnO %	Fe_2O_3 %	NiO %	CuO %	ZnO %	ZrO_2 %	SrO %	Rb_2O %	Ga_2O_3 %	As_2O_3 %	Yb_2O_3 %	PbO %	Nd_2O_3 %	Eu_2O_3 %	Re_2O_7 %	Iro_2 %
Pedon BS1																							
Ap	24.00	56.0	1.99	0.36	2.24	0.086	0.021	0.031	13.32	0.28	0.02	0.012	0.44	0.001	0.042	0.015	0.001	0.001	0.001	0.001	0.067	0.030	0.001
Btcv	20.00	56.0	2.22	0.34	2.51	0.091	0.022	0.038	15.01	0.015	0.024	0.01	0.49	0.001	0.052	0.021	0.001	0.01	0.001	0.001	0.066	0.040	0.001
Bcv1	22.00	52.0	1.98	0.33	2.28	0.093	0.025	0.04	17.75	0.016	0.019	0.009	0.47	0.001	0.045	0.007	0.001	0.001	0.001	0.001	0.074	0.030	0.046
Bcv2	15.00	69.3	3.40	0.37	2.51	0.076	0.013	0.034	6.403	0.0077	0.016	0.003	0.44	0.04	0.035	0.011	0.001	0.005	0.052	0.001	0.040	0.034	0.001
BCcv	22.00	60.5	2.29	0.55	2.03	0.076	0.018	0.031	10.86	0.011	0.017	0.006	0.54	0.001	0.045	0.014	0.001	0.02	0.001	0.001	0.040	0.030	0.001
Pedon BS2																							
Ap	25.00	53	1.98	0.24	2.01	0.082	0.022	0.040	15.70	0.034	0.021	0.008	0.39	0.001	0.042	0.009	0.001	0.001	0.001	0.001	0.001	0.033	0.038
Bcv	3.10	87.3	2.22	0.33	2.2	0.059	0.005	0.048	3.25	0.002	0.02	0.001	0.77	0.001	0.001	0.001	0.001	0.02	0.001	0.001	0.042	0.001	0.001
Btcv1	16.00	70.9	1.59	0.32	1.84	0.063	0.01	0.037	7.25	0.008	0.019	0.001	0.78	0.001	0.026	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Btcv2	18.00	64.1	1.47	0.33	1.82	0.080	0.019	0.036	12.28	0.004	0.022	0.001	0.66	0.001	0.03	0.016	0.001	0.018	0.001	0.001	0.071	0.001	0.001
Bcv	1.58	88.6	4.42	0.59	2.27	0.061	0.001	0.053	1.27	0.005	0.016	0.003	0.93	0.001	0.043	0.001	0.010	0.001	0.02	0.001	0.030	0.046	0.001
Pedon BS3																							
Ap	18.00	65.9	3.67	0.53	1.71	0.062	0.012	0.035	7.382	0.009	0.014	0.001	0.62	0.001	0.062	0.001	0.001	0.001	0.055	0.001	0.053	0.045	0.001
Btcv1	12.00	72.7	5.01	0.21	1.79	0.062	0.0074	0.037	5.609	0.0052	0.013	0.001	0.56	0.043	0.059	0.004	0.001	0.001	0.001	0.001	0.053	0.046	0.032
Btcv2	21.00	58.3	4.70	0.22	1.71	0.082	0.013	0.052	11.23	0.011	0.020	0.010	0.47	0.055	0.089	0.016	0.001	0.001	0.001	0.033	0.040	0.043	0.001
BCv	22.00	58.0	7.31	0.21	1.45	0.067	0.0094	0.043	9.125	0.011	0.017	0.009	0.29	0.054	0.001	0.016	0.001	0.001	0.052	0.001	0.064	0.035	0.001
Pedon BS4																							
Ap	17.00	67.3	1.13	0.23	2.40	0.078	0.016	0.067	9.808	0.0096	0.016	0.001	0.46	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.059	0.001	0.044
ABtcv	25.00	54.2	1.27	0.22	2.59	0.098	0.021	0.048	14.52	0.018	0.024	0.007	0.52	0.001	0.038	0.009	0.001	0.001	0.001	0.001	0.069	0.030	0.039
Bcv	28.00	46.0	1.26	0.2	2.35	0.110	0.023	0.046	19.36	0.019	0.025	0.023	0.40	0.001	0.034	0.017	0.001	0.006	0.001	0.001	0.065	0.030	0.001
Btcv1	32.00	44.0	1.21	0.81	2.12	0.094	0.022	0.041	17.98	0.018	0.020	0.006	0.38	0.001	0.033	0.014	0.001	0.001	0.001	0.001	0.068	0.030	0.001
Btcv2	27.00	42.0	1.69	0.19	2.05	0.100	0.030	0.040	24.38	0.009	0.024	0.001	0.35	0.001	0.039	0.017	0.001	0.030	0.001	0.001	0.120	0.001	0.001

while the lowest values were in BS2 (B_{CV}). Values were observed to be higher in the plinthic horizons of all the profiles (Table 4.11).

Total aluminum oxide contents in the surface horizons of profile on Basement complex parent materials ranged from 1.30 to 27.00%. Values in the underlying horizons ranged from 13.00 to 27.00%. The highest values occurred in YL (A_P) and OGR (B_{tcv}) values were observed to be higher in the plinthic horizons of all the profile (Table 4.11).

For profiles on Basaltic parent materials, values varied from 17.00 to 25.00% in the surface horizons. The subsurface horizons values varied from 1.58 to 32.00%. The highest value was recorded in BS4 (Btcv) while the lowest value was recorded in BS2 (Bcv (Table 4.11). Values were irregularly distributed and however, plinthic horizons had the highest values in all the profiles (Table 4.11).

Calcium oxide total elemental oxide contents in surface horizons of profiles on Basement complex parent materials ranged from 0.21 to 2.96% (Table 4.11). The underlying horizons values obtained range 0.18 to 3.33%. The highest value was recorded in SC (ABcv) while the lowest value was obtained in OGR (BCcv). Values were observed to decreased with depth in OGR while values were irregularly distributed with depth in SC, OL and YL (Table 4.11).

Potassium oxide total elemental oxides in profile on Basement complex parent materials varied from 0.42 to 4.63% in the surface horizons (Table 4.11). The underlying horizons values ranged from 0.38 to 3.25%. The highest value was recorded in OGR (Ap) while the lowest value was in YL (Btcv1). Generally, values decreased regularly with depth throughout all the profiles (Table 4.11).

For profiles on Basaltic parent materials, potassium oxide contents of surface horizons varied from 1.13 to 3.67%, values in the underlying horizons varied between 1.21 to 7.31 (Table 4.11).

The highest value was recorded in BS3 (Bcv) while the lowest value was observed in BS4 (Btcv1). Values were observed to be irregularly distributed with depth in all the profiles (Table 4.11).

Total elemental oxide contents manganese in the surface horizons of profiles on Basement complex parent materials ranged from 0.03 to 0.10 while the underlying horizons ranged from 0.003 to 0.1. The highest values occurred in OGR (BCcv) while the lowest value was recorded in OL (Bcv) (Table 4.11).

For profiles on Basaltic parent materials, values ranged from 0.03 to 0.67% in the surface horizons and underlying horizons values ranged from 0.03 to 0.05% (Table 4.11). The highest value was recorded in pedon BS4 (Ap) while the lowest was recorded in BS2 (Bcv). Values were observed to be irregularly distributed with depth (Table 4.11).

Total elemental oxides of titanium oxide contents in the surface horizons of its profiles on Basement complex varied between 2.00 and 2.62% and the underlying horizons values ranged from 1.56 to 2.74% (Table 4.11). The highest value was recorded in OGR (BCcv) while the lowest value was recorded in OGR (Ap). Generally, values were higher in the plinthic horizons of all the profiles (Table 4.11).

4.5.2 Trace Elements

Values of total elemental Copper oxide (CuO) in the profiles on Basement complex parent materials ranged from 0.014 to 0.026% in the surface horizons and the underlying horizons values ranged from 0.015 to 0.026% (Table 4.11). The highest value was recorded in OGR (Btcv1) while the lowest values were found in YL (Btcv2).

Profile on Basaltic parent materials obtained ranged 0.014 to 0.021% in the surface horizons, the surface horizons values ranged was obtained in BS4 (Bcv), while the lowest value was observed in BS3 (Btcv1). Generally, values were irregularly distributed in all the profiles (Table 4.11).

Zinc oxide total elemental oxides values ranged from 0.001 to 0.006% in the surface horizons of profiles on Basement complex parent materials, value in the undying horizons ranged from 0.001 to 0.015%. The highest value was recorded in OGR (BCcv) while the lowest value was recorded in SC (ABcv) (Table 4.11).

For profiles on basaltic parent materials, values recorded range 0.001 to 0.008% and the underlying horizons recorded 0.001 to 0.023%. The highest value recorded in BS4 (Bcv) while the lowest value was in BS2 (Bcv, Btcv1, Btcv2) BS3 (Btcv) and BS4 (Btcv2). Generally, values were higher in the subsurface horizons of all the profiles (Table 4.11).

Total elemental oxide values for ZrO_2 in surface horizons of profiles on Basement complex parent materials ranged from 0.47 to 0.93% and the underlying horizon values ranged from 0.15 to 0.81% (Table 4.11). The highest value was obtained in pedon OGR (Ap) while the lowest value was recorded in YL (Btcv1). Generally, values were irregularly distributed with depth (Table 4.11).

For profiles on Basaltic parent materials, values varied from 0.39 to 0.62% while the underlying horizons values varied from 0.29 to 0.93%. The highest value was obtained in BS2 (Bcv) while the lowest value was recorded in BS3 (BCv). Generally, values were irregularly distributed in all the profiles ZrO_2 (Table 4.11).

Values of ZrO_2 in the surface horizons of profiles on Basement complex parent materials ranged from 0.47 to 0.93% and the underlying horizons values ranged from 0.15 to 0.81% (Table 4.11). The greatest value was recorded in OL (Bcv) while the lowest value was found in YL (Btcv1). Generally, values were higher in the surface horizons except for pedon OL (Table 4.11).

For soils on Basaltic parent materials, values ranged from 0.39 to 0.62% in the surface horizons while the subsurface horizons values ranged from 0.29 to 0.93% (Table 4.11). The highest value was recorded in BS2 (Bcv) while the lowest value was obtained in BS3 (Bcv). Values in BS3 were regularly distributed with decrease in depth while BS1, BS2 and BS4 were irregularly distributed with depth.

Total elemental oxides for Gr_2O_3 in the surface horizons of profiles on Basement complex parent materials ranged from 0.001 to 0.013% and the underlying horizons values ranged from 0.001 to 0.016% (Table 4.11). The highest value was recorded in YL (Btcv1) while the lowest value was found in OGR (Btcv) and YL (Btcv2) (Table 4.11).

For soils on Basaltic parent materials, values in the surface horizons varied between 0.001 to 0.015% and underlying horizons, values varied from 0.001 to 0.027%. The highest value was obtained in BS1 (Btcv) while the lowest value was found in BS2 (Bcv, Btcv1) respectively. Values increased irregularly with depth in BS3 and Bs4 while BS1 and Bs2 were irregularly distributed with depth (Table 4.11).

The contents of total elemental oxides of Eu_2O_3 in the surface horizons of profiles on Basement complex parent materials ranged from 0.030 to 0.084% and underlying horizons, values ranged from 0.001 to 0.090%. The highest value was recorded in pedon YL (Btcv1) while the lowest value was obtained in OL (ABtcv) (Table 4.11).

For profiles on Basaltic parent material, values ranged from 0.001 to 0.067% in the surface horizons and underlying horizon values ranged from 0.001 to 0.074%. The highest value was observed in BS1(Bcv1) while the lowest value was observed in BSW2 (Btcv1) while the lowest value was observed in BS2 (Btcv1). Values were irregularly distributed with depth in all the profiles (Table 4.11).

CHAPTER FIVE

DISCUSSIONS

5.1 Morphological Properties

Soil morphological properties discussed are soil depth, structure, consistence, concretion, roots, pores and horizonation.

5.1.1 Soil Depth

Soils formed on the two parent materials were very deep, to deep according to Soil Survey Manual, (1993). Deeper soils were obtained on soils on older laterites. The depth restrictions were as a result of partially decomposed rocks encountered at the depths. Similar restrictions were also reported by carlan *et al.*, (1985) Raji, (1995) and Idoga *et al.*, (2007).

5.1.2 Soil Color

Variation in soil colors on the two parent materials were generally more pronounced between horizons than between soils. Surface horizons color were dominantly dark brown while the subsurface horizon colors were yellowish red to red. The great variation in color noted in the profiles were reported by other workers in different part of Nigeria (Raji, 1995; Ogunkunle, 2009; Yakubu and Ojanuga 2009; Ande, 2010).

Dark brown coloration of surface horizon (Ap) was attributed to humification resulting in melanization indicating braunification as a major pedogenic process occurring in these soils (Buol *et al.*, 1980) while the yellowish red to red color dominating the surface horizons were attributed to laterization process (Raji, 1995).

5.1.3 Soil Texture

Soils formed on the two parent materials all belong to two textural classes; sandy loam and sandy clay loam. The surface horizons of all the profiles on Basement complex parent materials belongs to sandy loam while the surface soils were dominantly sandy clay loam except pedon OGR which had sandy loam in the subsurface horizon (BCcv).

Similarly, pedons BS3 and BS4 (older basalts) in the surface horizons of soils on Basaltic parent materials had sandy loam texture. However, sandy clay loam was obtained in the surface horizon of BS1 and BS2 i.e. Younger Basalts.

The coarse a textured surface characteristic was a common feature associated with soils formed from Basement complex rocks (Esu 1987; Esu *et al*., 1987, Ezenwa and Esu, 1999) which may be attributed to erosion of fine particles by surface run off down the slope from crestal position and their illuviation into subsoil (Esu *et al*., 1987, Maniyunda, 1999, Fasina *et al*., 2007, Ande, 2010). Soil texture change with increase in depth of soil profiles in the order sandy loam in the surface to sandy clay loam in the subsurface was attributed to eluviation and illuviation of clay from zone of maximum clay accumulation (Yaro, 2005 and Maniyunda *et al*., 2013).

5.1.4 Soil Structure

The soil structure of the two parent materials was dominated by medium sub angular blocky and coarse blocky structure in all the profiles. The surface horizons profiles on Basement complex parent materials were found to be completely sub angular block while those of the Basaltic parent materials were generally sub angular blocky and medium sub angular blocky. Medium sub angular block structure dominated the soil structure of the surface horizons. The dominance of medium sub angular blocky structure in the sub surface horizons was explained to be duely partly to bridging of blocky structures by lateritic materials most likely iron concretions (Kparmwang, 1994).

5.1.4 Soil Consistence

Soil consistence of profiles on the two parent materials all varied between friable and firm (moist) while slightly hard to hard consistence was observed for all the profiles under dry conditions except for pedon OGR on older granite where the surface horizons was soft (Dry). Soil Basement complex parent materials were generally slightly sticky and slightly plastic (Wet). The sub surface soils varied between sticky and slightly sticky and slightly plastic (Wet) and sticky and plastic (Wet) while the profiles on Basaltic parent materials were generally sticky and plastic (Wet), very friable to friable (Moist) and slightly hard (Dry).

The increase in adhesion of these soils down the profiles was related to increase in illuviation as well observed with sticky and plastic (Wet) consistence in argillic horizons having clay loam structure. Very hard consistence of the subsurface soils in all the profiles was attributed to presence of plinthite on drying (Soils Survey Staff, 1975).

5.16 Horizonation

Horizonation in profiles on the two parent materials was more pronounced between surface and subsurface horizons. The subsurface soils were less pronounced in their horizonation. Surface horizons of profiles on Basement complex parent materials were generally clearly wavy to gradually smooth. While gradually wavy and diffusely irregular horizonation dominated the subsoil’s. Evidence of plinthization was utilized in horizon differentiation. This included presence of cutans, mottles and clay. Horizonation differentiation were abrupt in the lower subsoil horizons of all the soils were attributed to the formation of plinthite. The surface horizons were quite distinct from the subsurface horizons and marked by clear boundaries due to melanization from humification of organic matter in the AP horizons. There were also distinct horizons of nodules giving rise to several distinct horizons in all the profiles.

5.1.7 Miscellaneous Observation

Soils formed on the two parent materials all had evidence of plinthization in the subsurface horizons. Mottles, concretion were also evident in the plinthic horizons. Ant activates were more pronounced in the surface horizons of all the profiles. Generally, root content decrease with depth. Many roots were found in the AP horizons, which were the zones of root activities. Plinthic horizons had iron and manganese nodes in all the profiles. Mica flakes and fine quartz grains were commonly found minerals in all the profiles. Plinthization was observed in all the profiles of the two parent materials and this was attributed to conditions favorable for the development of plinthic soils i.e. accumulation of Fe, Al and Mn oxides either by solution flowing down from higher parts which result in topography concentration or valley position or lower parts of undulating areas where sesquioxides accumulate by fluctuating of ground water or colluvial/alluvial laterite at the bottom of slopes, flood plains of a valley. In this study, soil samples were taken from crest position implying accumulation of sesquioxides was by fluctuation of ground water in the study area.

The presence of termite nests and chemical in all the profiles indicates that termites also contributed significantly to fauna pedoturbation in the soils and termite mounds were found common in all the sites.

5.2 Soils Physical Properties

5.2.1 Particles Size Distribution

The contents of gravel in the two parent materials was observed to vary between surface horizons with higher values in (90%) in soils on Basement complex parent materials in Btcv horizons and dominated particles size fractions (<2mm) in all the profiles of the surface horizons. The higher values of gravel in Basement complex parent materials was attributed to accumulation of quartz grains and greater accumulation of iron oxides to form nodules due to advance pedogenic age as compared with Basalts Yaro, (2005) attributed formation of nodules by iron oxide to advance in pedogenic age. Similar findings on particles size distribution in Basement complex parent materials were reported by Esu *et al*., 1987, Maniyunda, 1999, Odunze, 2006, Mustapha and Fagun, 2007, Obi and Akinbola, 2009, Ande, 2010 and fasina *et al.,* 2007.

The dominance of sand fraction in the surface horizons of soils on Basement complex parent materials was also reported by Maniyunda *et al*., (2013) in Northern Guinea Savannah and the pattern was attributed to the degree of weathering of parent rocks and the decrease in percent content of Bt horizons attributed to illuviation of clay in the Bt horizons. Clay contents in the subsurface horizons of soils on Basement complex parent materials was about two times higher than values for Basement complex soils but only increase regularly with depth in Basalts. The increase in clay with soil depth may be attributed to erosion of clay in the surface horizons and illuviation into subsurface horizons. The clay content increases with depth reaching the highest in Bt horizons and decrease next with depth. This was attributed to possible clay migration by eluviation –

illuviation process resulting in argilluviation. Clay cutans in the soil pores, animal channels and ped surfaces observed were indicators of this process. Similar reports were given by Ojanuga (1979), Esu (1982) and Akinbola (2009). Clay contents in Basalts were highest followed by soils of Basement complex. The lower clay contents of soils Basement complex was largely attributed to occlusion in plinthites, as the pliinthites dries and hardens.

The hardening process involves segregation and crystallization of iron into continuous assemblage what acts as a skeleton, thus ensuring induration while Basalts complex due to age and milder environmental conditions (Kparmwang, 1993).

5.22. Particle Density

Values in all the profiles of the two-parent material were within 2.60 to 2.75 Mgn^{-3} reported for mineral soils by Brady and Weil (2005). The means for Basement complex fell slightly below values reported for some Samaru soils (Yaro, 2005) but were within values reported by Maniyunda *et al*., (2013). The higher particles density values in pedon BS2 (Bcv) in Basalts may be associated with geological formation of the present material and probably that the soil did not develop insitu.

5.2.3 Bulk Density

The regular distribution pattern of bulk density values in OGR and BS3 was attributed to the fact that these soils developed insitu. Similar observation was made by Yaro (2005) in plinthic soils, Samaru in Zaria region. The highest values being in Btv horizons where clay accumulation was observed to be maximum, corroborates with the findings of Anderson *et al*, 1988, Raji (1995) and Maniyunda *et al*., (2013). Bulk density values correlated negatively with total porosity meaning increase in bulk density will reduce porosity of the soils.

5.2.4 Total Porosity

Variation in total porosity values in all the profiles on Basaltic parent materials might be attributed to geological formation of parent materials as pedons BS1 and BS2 were developed on younger basaltic parent materials while pedon BS3 and BS4 were developed on older basaltic parent materials. Crust formation in the cultivation soils were attributed to the low values noted in horizons directly underlying Ap in cultivated soils of Savannah environment as reported by Brady and Weil (2005) in the Savannah soils of Nigeria.

5.2.5 Average Compressive Strength

The average compressive strength according to NBRRI minimum specification (1.65 N/mm^2) favored only older laterites (OL**).** This may be attributed to indurated, massive and tough layer compared to other parent materials.

5.3 Chemical Properties

5.3.1 Soil pH

The variation in pH is expected because of difference in rainfall regime which is much higher in Basalts than in Basement complex (Kparmwang, 1993). The reaction was strongly acidic to moderately acid for surface horizons, very strongly acid to slightly acid to underlying horizons on Basement complex, while the Basalts ranged from very strongly acid to strongly acid for surface horizons, very strongly acid to moderately acid for underlying horizons (Soil Survey Division Staff, 1993). Similar report was made by Maniyunda *et al*., (2013) and Yaro (2005) on the basement complex soils studied in Northern Guinea Savannah.

Soil pH values reported in this study were within range reported by Ezenwa and Esu (1999), Raji and Mohammed (2000), Fasina *et al.* (2007a), Law- Ogboma and Nwachokor (2010) and Maniyunda *et al*. (2013) for the basement complex soils in Northern Guinea Savannah and Kparmwang (1993) in the basalts in the same Savannah vegetation zone. Also, values were observed to only slightly vary in all the horizons of the two-parent material and therefore soils on basalts and basement complex parent materials may be considered to be similar in their surface network charges. These values were observed to be negative in both the surface and subsurface charges. Similar findings were reported by Kparmwang (1993), Raji, 1995, Maniyunda (1999), Yaro (2005) and Law-Ogoma and Nwachokor, (2010).

5.3.2 Exchangeable Bases

Variation in contents of Ca in the soils may be attributed to the difference in parent materials, BS1 and BS2 being developed on younger basalts and BS3 and BS4 developed on older basalt parent material.

The range of exchangeable calcium obtained in surface and subsurface horizons were rated medium to high for the soils developed on Basement complex parent materials (Ezenwa and Esu, 1999), while basement complex soils are also developed on different parent materials.

The exchangeable magnesium in surface soils on basement complex were rated low to medium, medium to high while subsurface horizons were rated medium to high, low to medium. Basalts were rated low to medium in BS3 and BS4 (older basalts) and medium to high in BS1 and BS2 (newer basalts) (Ezenwa and Esu, 1999). Generally exchangeable magnesium contents decreased regularly with depth in all the profiles except pedon BS1 which increased with depth and increased in BC horizon.

All values for exchangeable sodium were rated high in both surface and subsurface horizons of all the profile as they were greater than 0.30 cmol (+) kg^{-1} critical values for Na in Nigeria soils (Esu, 1991 and Maniyunda *et al*., 2013). Exchangeable sodium was irregularly distributed in all the profile of the two parent materials except pedons OGR and BS2. The exchangeable sodium in all the horizons of all the profiles varied only slightly indicating that basement complex and basaltic parent materials similarly contributed exchangeable Na in their soils Maniyunda *et al*. (2013).

A similar trend of the pattern of distribution of exchangeable Na in these soils was reported by Kparmwang (1993) in Basaltic soils in Guinea Savanna, Nigeria; values in surface soils were all generally lower than subsurface soils except in lateralized Basalts and that Na is, therefore likely to be retained largely on clay.

The surface and subsurface soils in the basement complex were rated low to high (Esu, 1991). There was no consistent distribution of values in all the profiles except in OGR which increased steadily with depth. Value of Basalts for all the profile were rated low to medium in the olden basalts and medium in the newer Basalts (Esu, 1991). The ratings are similar to those in Ca and also seen to reflect the degree of leaching in Basalts.

5.3.3 Exchange Acidity

No regular distribution pattern was observed within all the profiles developed on the two parent materials. However, values were observed to be generally high in soils of profiles developed on Basalts.

5.3.4 Cation Exchange Capacity

Soils formed on the two parent materials were all rated low to medium in their surface horizons and low to high and medium in their sub surface horizons. The soils on Basement complex materials were rated low to medium and medium to high in the surface horizon while the sub surface horizons were rated low to medium and medium, low to high and medium in the sub surface horizons (Esu, 1991). Effective CEC values in the two soils formed on the two parent material were rated low to medium for the surface and subsurface horizons of all the profiles

There was no regular pattern in the distribution of the contents of ECEC in all the pedons studied. However, ECEC values were lower than CEC NH_4OAC. This trend was attributed to the fact that CEC of tropical soils are highly pH dependent (Uehera and Gillman, 1981; Balasubramanian *et al.,* 1984; Osher and Buol, 1998). This might also be attributed to pH of soils (<7), since ECEC measures charges of the soil pH, whereas the CEC-NH_4AC measures on the soil colloids at pH (Osher and Buol, 1998).

Base saturation NH_4OAC values in the soils on the two parent's materials were rated high generally in all the profiles. Values in soils on Basement complex parent materials were similar to those of older Basalts i.e pedon BS3 and BS4 while those on the Newer basalts were lower.

5.3.5 Exchangeable Sodium Percentage (Esp)

Results indicated that all soils were considered to be non-sodic as the values were less than 15% critical limit (Brady and Weil, 2005).

5.4 Pedogenic Forms of Iron, Aluminum and Manganese Oxides

5.4.1 Pedogenic Forms of Iron

The higher contents of Fe_d in soils of Basement complex parent materials may be attributed to higher amount of ferromagnesian minerals in their soils Maniyunda *et al*., (2013). Udo (1980) reported that parent's materials influenced relative distribution of free iron oxides. More so, the higher values of total free iron oxides obtained in the subsoil's might be associated with co-translocation of Fe with clay from surface to sub surface horizons through eluviation-illuvian process. Values of total free iron oxides recorded in this study were higher than those reported by Maniyunda *et al*., (2013) for Basement complex but lower than those reported for Basalts by Kparmwang (1993). Variation in total free oxides for different study areas compared to the present one indicated that moisture regime and drainage conditions of soils influence contents of total free iron (Udo, 1980). Also, the amount of total free iron oxide present in the soil is influence by the type of parent rock from which the soil developed. Solis derived from which ferromagnesian rocks, such as basalts and amphibolite generally contain higher amount of dithionite form (Buol *et al*., 1980; Douglas *et al*., 1988).

Furthermore, the trend in the content of oxalate extractable iron (Fe_{ox}) indicate a decrease in Fe_{ox} with pedogenic age as higher value was found in soils of Basaltic parent materials which are pedogenically younger. Similar report was made by Yaro (2005) and Maniyunda *et al*., (2013). The Fe_{ox} values were generally within range of values on older granites and Basalts reported in Northern Guineas Savannah by Mosugu (1989); Kparmwang 1983 and Maniyunda *et al*., (2013), but higher than values reported on Aeolian materials (Maniyunda, 1995 and Raji 1995). Amorphous Fe oxide content was observed to regularly with depth in all the other profiles.

The variation in the Pyrophosphate extractable iron (Fe_p) content of the two parent materials was attributed to difference in the amount of organic matter generated by variation in the different ecological zones of the study area. The soils generally had irregular distribution of Fep in their profiles. This irregular pattern was also reported by Abdourahamane and Yaro (2007) and Maniyunda *et al*., (2013). The values of Fep were higher than the range reported by Raji *et al*., (2000) but lower than range reported in wetland soils in Nigeria (Olaleye *et al*., 2000). However, the values were within range reported in established forest in southern Guinea Savanna by Samndi *et al*., (2006).

5.4.2 Active Iron and Clay/Dithionite Iron ratio

Generally, active Fe ratio decreased with depth in all the profiles studied which indicated that there was higher proportion of iron in crystallize forms in the lower horizons. This result agrees with the report of Anjos *et al*., (1995) that plinthite needs a higher proportion of crystalline iron in order to harden (Daughter and Arnold, 1982).

The higher values of clay dithionite observed in the subsurface horizons way be attributed to the fact that iron oxide movement is partially dependent on clay.

5.4.3 Pedogenic form of Aluminum Oxide

Higher values of pedogenic forms of CBD extractable aluminum oxide in the soils on Basement Complex parent materials than those of Basaltic parent materials may be attributed to the pedogenic age of the soils. Soils on Basement complex are more nature in age than those of the Basaltic parent material. Further, Oxalate extractable aluminum oxide values in the soils formed on the two-parent material had their highest contents in the sub surface horizons which may ascribe to illuviation of aluminum down the profile, as it in noted by increase in Alox with depth (Perkins and Lawrence, 1982).

This report conforms with that of Yaro (2005) in the study of plinthic soils in Northern Guinea Savannah, Nigeria.

5.4.4 Active Al ratio (Alox/Ald)

One reason for the lower content of Active aluminum ratio in the soils on Basement Complex parent material is expected as the soils are pedogenically older. Crystallization process has had enough time to maturity. The differences in geological composition of parent materials of the different soils were attributed to the difference in values observed for both soils. Generally, this report is in conformity with that of Yaro (2005) in study of laterites in Northern Guinea Savannah, Nigeria.

5.4.5 Pedogenic forms of Manganese

Values of manganese were generally high in soils on Basaltic Parent material than in Basement Complex and decreased regularly with depth except OGR which increased regularly with depth in all profiles. This pattern observed was attributed to leaching out and translocation away of manganese in the basement complex while the basalts are relatively less leached and retain higher proportion of manganese.

The values reported in this study both the surface and subsurface horizons are lower than those reported in Basement Complex soils in humid regions Maniyunda (1999) and Maniyunda *et al*., (2013), but higher than those reported in plinthic landscape by Yaro (2005) and on inland valley soils by Essoko and Esu (2003).

Oxalate extractable manganese oxides (Mnox) in the soils on the two parent material were slightly higher in Basalts than in Basement complex and values in Basement complex increase regularly with depth. Also, Pyrophosphate extractable manganese value in the soils on the two parent’s materials obtained their highest values in BS2

A(Bcv) while the lowest value in OGR (Btcv2) and BS1(Bcv2). The same explanation was attributed to the distribution of oxalate extractable manganese, that is proportion of total sand in basement complex is higher and therefore greater leaching of pyrophosphate extractable manganese. The distribution pattern of manganese was similar to that of amorphous form, but differed with crystalline form. This report conforms with that of Yaro (2005) and Maniyunda *et al*., (2013) in studies of soils in Northern Guinea Savannah.

5.4.6 Active Manganese Ratio

Active manganese ratio decreased irregularly with depth of the soil which indicate increase in crystallization process with increase in soil depth as influence by longer moisture regime in the sub surface horizons compared with surface horizons Maniyunda *et al*., (2013).

5.5 Total Elemental Oxides and Relative Weathering intensity

5.5.1 Major Elemental Oxides

The contents of major elemental oxides (total oxide form) from x-ray fluorescence indicated that silicon dominated the soils. Aluminum oxide contents in the profiles of the two parent materials was next to that of iron oxide. Calcium oxide (CaO) content in Basement Complex soils was observed to be higher than those of Basaltic Parent materials which may be attributed to the difference in geological formation of the different parent materials. The lower content of CaO in the plinthic horizons confirms the fact that plinthites are depleted of bases. The values of CaO were within values reported for Northern Guinea Savanna of Nigeria (Yaro, 2005).

Distribution of SiO_2, CaO and K_2O decrease with soil depth which may be attributed to desilication of SiO_2 in the surface horizons and biocycling and leaching of these oxides CaO, MnO and K_2O in these soils Maniyunda *et al*., (2013). The pattern of relative weathering intensity indicated that the different parent materials influenced relative retention of all major elemental oxides.

5.5.2 Trace Elements

The contents of Rb_2O varied from 0.001% in BS2 (Bcv) and BS4 (Ap) to 0.89% in BS3 (Btcv2). values were generally higher in the subsurface horizons than in the surface for all the profiles in the soils on two parent materials. Values generally increased with depth in all the pedons except BS3 which obtained 0.069% in the surface horizon (Ap). Values were generally higher in the soils formed in Basaltic parent material with the highest value 0.089% obtained in BS3 Btcv2.

Values of SrO in the soils formed on the two parent materials were found to obtain the same value of 0.0001% throughout of the horizons of pedons Sc, OL, OGR, YL, BS2 and BS4. However, BS1 obtained a range of 0.001% in all the horizons except Bcv2 which recorded 0.040% and BS3 which had the range 0.001% in Ap to horizon to 0.055% in Btcv2. Values were generally higher in soils on Basaltic parent materials than in Basement complex soils. The complex of Pb0 in the soils formed on the two parent materials obtained their highest values in SC (Btcv) with 0.074% and the lowest being 0.001% in most of the horizons. Values were generally higher in the Basement complex soils than in the soils on Basaltic soil parent materials.

Zinc oxide content varied from 0.001 in most of the horizons in this pedon to 0.12% in 0.012%. Values were generally higher in profiles formed on Basement complex than those of Basaltic parent materials.

Nd_20_3 values were constantly distributed in all the profiles of the two parent materials recording 0.001% in all the horizons except BS3 (Btcv2) which obtained 0.033%. Generally, trace elemental oxides contents was less than 1% in all the soils studied.

5.6 Soil Classification

5.6.1 Criteria for classification (USDA Soil Taxonomy System)

a. Soil Moisture Regime: Annual rainfall in the northern guinea savannah zone of Nigeria average about 1088.26mm. This amount of rainfall is concentrated within 5 – 6 months. The moisture regime within the study area is therefore, Ustic. This implies a limited moisture situation, but the moisture is present when conditions are suitable for plant growth (Soil Survey Staff, 1999). All the pedons were well drained. All the pedons there had predominantly Ustic moisture regime.

b. Soil Temperature Regime: The mean annual temperature in the study area is 22^oC or higher. The mean summer and winter soil temperatures do not differ by up to 5^oC at a depth of 30 and 100cm. This indicates that the difference will be less than 56^oC at the control section, i.e. 50cm depth. The soil temperature regime prevalent here is therefore, the isohyperthermic type (Soil Survey Staff, 1999).

c. Diagnostic Surface Horizons

   1. The Ap epipedons had low colour values (3 – 5) and low Chroma (2 – 4) but were too thin to be recognised as a mollic or umbric epipedon.
   2. The epipedons were Ap horizons that were too thin, too light, poor in bivalent cations, to be an phosphorus to be either anthropic, follistic, histic, melanic or plaggen epipedons.

3. All the Ap horizons overly illuvial horizons (argillic and kandic horizons). Therefore, all the soils possess an ochric epipedon.

4. Diagnostic Subsurface Horizons

   All the pedons developed on the different parent materials had significant accumulation of illuviated layer of lattice silicate clays formed below the eluvial horizons. There were also thin clay cutans in pores in all of the pedons. The subsurface horizons were argillic B horizons.

5.6.2 Classification (USDA Soil Taxonomy)

At the order level, all pedons in soils of the basement complex and the basalts which in addition to an argillic horizon, had a base saturation of at least 35% (by NH_4OA_c) throughout or in the major part of the argillic horizons and are therefore classified as Alfisols except for BS1 of the basalts with less than 35% (by NH_4OA_c), was classified as Ultisols at the order level. At the suborder level, pedons SC, OL, OGR and YL were classified as Ustalfs, because they have Ustic moisture regime. At the great group level, since all the pedons had plinthite that formed a continuous phase or constitute one half or more of the value of some subhorizons within 150 cm of the soil surface, they are therefore classified as Plinthustalfs and Typic Plinthustalfs at the subgroup level.

The classification is carried finally to the family level. Thus, pedons SC, OL, OGR, YL, BS1, BS2, BS3 and BS4 are classified as Typic Plinthustalfs clayey-skeletal kaolinic isohyperthermic.

5.6.3 World reference base for soil resources 2014 classification system

Using the World Reference base for soil resources 2014 (FAO, 2014), all pedons on basement complex and basalts were placed in the Group of Luvisols. These were soils with argic B horizons which had CEC of the clay fractions more than 24 cmol (+) kg^{-1} clay and base saturation (by NH_4OA_C) of at least 35 %, part of the B horizons within 125cm of the surface. At the second level all the pedons studied (pedons SC, OL, OGR, YL, BS1, BS2, BS3 and BS4) were classified as Plinthic Luvisols because they had plinthite within 125cm of surface.

CHAPTER SIX

6.0 SUMMARY, CONCLUSION AND RECOMMENDATION

6.1 SUMMARY AND CONCLUSION

The study was carried out on Plinthic soils developed on Basement Complex and Basaltic Parent materials on crest position of Northern Guinea Savanna, to determine the influence of parent materials on composition and quality of Plinthite as a raw material for the building and construction industry.

Morphological, physical, chemical and mineralogical properties were determined and classified using the USDA soil taxonomy classification system (Soil Survey Staff, 2010) and correlate with world Reference Base for soil resources (WBR) (FAO, 2014). Morphologically, soil of the two-parent material was generally very deep too deep (120-186 cm) except BS4 on Basaltic parent material and YL and OGR on Basement Complex that were restricted due to contact with partially decomposed rock. Dark brown coloration resulting in melanization dominated the surface horizons of soils on the two parent materials while the subsurface soils were reddish yellow and yellowish red in all the profiles studied and attributed to plinthization process. The soils were dominantly sub angular block in structure.

Soil texture varied with increase in depth within the sub soil (Bt) sandy loam to sandy clay loam in the deeper horizons and were attributed to illuviation of clay. Contents of gravels influenced textural classification of the soils and were attributed to plinthization process in all the soils. Sand dominated particle size distribution of the fine earth (<2mm) portion in all the soils formed on the two parent materials.

Chemical properties indicated pH to be extremely acid to moderately acid (3.80 to 5.80). Values of Ca, CEC and base saturation recorded higher values in soils on Basement Complex parent materials than in those on Basaltic parent materials.

The best blocks i.e those that obtained the highest strength occurred in the soils formed on Basement Complex parent material with the highest value 1.67 (Nmm^2) in pedon OL. This was attributed to the higher contents of contents of CBD extractable iron aluminum and manganese oxides which obtained 3.15% 4.87% and 0.09% for iron oxide, aluminum oxide and manganese oxide respectively. Organic carbon content was also observed to affect the compressive strength as values were lower (0.02 to 0.68 cmol (+) kg^{-1}) in soils Basement Complex that produced the best blocks.

The compressive strength of plinthic soils from the two parent materials recorded a wide gap in their values with as observed that pedon OL recorded 1.68 (Nmm^2) while pedon BS2 obtained 0.53 (Nmm^2). The AASHTO and USCS classification depicted that the soils vary in their classification for suitability as construction materials relative to parent materials. All the pedons were classified as Alfisols except for BS1 as Ultisols according to the USDA classification and all pedons as Luvisols according to the World Reference Base for soil resource.

6.2 RECOMMENDATIONS

With adequate soil tests and interpretation by soil scientists the contents of the binding elements in plinthite can be determined and exact requirements of additives for the stabilization of the soils can be obtained and therefore enabling the utilization of the exact quantity of additives for a particular kind of plinthic soil to obtain the established standard of strength and quality for building and construction purpose.

This finding will reduce the quantity of additives which would otherwise have been added in excess of the need for the soil. This practice is recommended for adoption by potential users of plinthite for building and construction in Nigeria. Soil scientists, builders, civil engineers and regional planners should complement themselves in sourcing plinthite as a raw material for building and construction in line with findings in this study that the compressive strength of plinthite vary relative to the parent material in which they develop.

For the purpose of sustainable land use, the collaborative effort of soil scientists, builders and civil engineers is recommended for the purpose of maximizing the exploitation of the best plinthites for building and construction in Nigeria.

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APPENDIX A

SOIL PROFILE DESCRIPTIONS

Profile No.	SC
General Site Information	
Location	Marabar Guga, 5Km to Samaru along Samaru – Sokoto Road (11° 12’ 51.8” N and 07° 31’ 44.8” E)
Elevation	687m
Taxonomic Classification	Alfisols
Soil Parent Material	Shist
Geology	Basement complex
Geomorphology	Gently undulating plain with rock outcrop
Topography	Crest (0 – 2%)
Vegetation	Savanna Parkland
Land Use	Farming
Drainage	Well drained
Depth to Water Table	Not encountered within 170cm
Depth to Impenetrable Layer	Not encountered within 160cm
Surface Characteristics	Cultivated ridges
Described by	Prof. B. A. Raji and G. S. Zarafi
Date Sampled	2012

Horizon Description

Horizon	Depth	Description
Ap	0 – 13	Strong brown (7.5YR 4/3 moist); reddish yellow (7.5YR 6/4 dry); Gravelly silt clay loam; medium strong to medium sub-angular blocky; sticky and plastic, friable (moist), hard (dry); gradual smooth boundary; many medium pores; common very fine roots; many fine mica flakes; common termite nests and channels.
ABcv	13 – 30	Red (2.5YR 4/3 moist); brown (7.5YR 6/6 dry); gravelly clay loam; weak coarse sub-angular blocky structure; sticky and plastic (wet), form (moist), hard (dry); few moderate humus cutans on ped faces; common fine pores; few very fine roots; gradual smooth boundary.
Bcv	30 – 56	Red (2.5YR 4/8 moist); light red (2.5YR 6/8 dry); gravelly sandy clay loam; moderate medium sub-angular blocky structure; sticky and

		plastic (wet), friable (moist), hard (dry); common fine pores; few medium roots; common fine iron nodules; common fine mica flakes and quartz grains; common termite channels and nests; gradual smooth boundary.
Btcv	56 – 122	Red (2.5YR 4/6 moist); light red (2.5YR 6/8 dry); gravelly sandy clay loam, moderate medium sub-angular blocky structure; sticky and plastic (wet), friable moist, hard (dry); common fine pores; very fine roots; very few termite channels abrupt wavy boundary.
BCcv	122 – 170	Red (2.5YR 4/8 moist); red (2.5YR 5/8 dry); very gravelly sandy clay loam; weak sub-angular blocky structure; sticky and plastic (wet), friable (moist), hard (dry); few fine pores; many iron concretions; common medium pores; many fine roots.

Profile No.	OL
General Site Information	
Location	Biye, 2Km to Samaru along Samaru – Sokoto Road (09’ 51.0” N and 07^{o} 36’ 07.6” E)
Elevation	712m
Taxonomic Classification	Alfisols
Soil Parent Material	Older laterite
Geology	Basement complex
Geomorphology	Gently undulating plain with exposed petroplinthite
Topography	Crest (0 – 2%)
Vegetation	Savanna Parkland
Land Use	Maize
Drainage	Well drained
Depth to Water Table	Not encountered within 160cm
Depth to Impenetrable Layer	Not encountered within 160cm
Surface Characteristics	Cultivated ridges
Described by	G. S. Zarafi, 2012

Horizon Description

Horizon	Depth	Description
Ap	0 – 12	Brown (7.5YR 4/4 moist); reddish yellow (7.5YR 6/6 dry); Gravelly clay loam strong medium sub-angular blocky; sticky and plastic (moist), friable (moist), hard (dry); gradual boundary; common medium roots; many mica flakes; common termite nests and channels.
ABtcv	12 – 110	Brown (7.5YR 4/4 moist); brown (7.5YR 5/4 dry); clay; moderate medium sub-angular structure; sticky and plastic (wet), friable (moist), hard (dry); common fine pores; few fine roots; very few termite channels; abrupt wavy boundary.
Bcv	110 – 135	Yellowish red (5YR 4/6 moist); reddish yellow (5YR 6/8 dry); gravelly clay loam; moderate medium sub-angular blocky structure; sticky and plastic (wet), friable (moist), hard (dry); common medium roots; many mica flakes; common termite nests and channels; abrupt wavy boundary.

BCcv	135 – 186	Yellowish red (5YR 4/6 moist); clay; moderate fine to medium sub-angular blocky structure; sticky and plastic (wet), friable (moist), slightly hard (dry); common medium pores; few fine roots; few termite channels.

Profile No.	OGR
General Site Information	
Location	Hanwa, 3Km to Samaru along Kano – Kaduna Road (11° 07’ 07.11” N and 07° 40’ 02.2” E)
Elevation	646m
Taxonomic Classification	Alfisols
Soil Parent Material	Older granite
Geology	Basement complex
Geomorphology	Gently undulating plain with rock outcrops
Topography	Crest (0 – 2%)
Vegetation	Savanna Parkland
Land Use	Maize
Drainage	Well drained
Depth to Water Table	Not encountered within 120cm
Depth to Impenetrable Layer	Not encountered within 120cm
Surface Characteristics	Cultivated ridges
Described by	G. S. Zarafi, 2012

Horizon Description

Horizon	Depth	Description
Ap	0 – 39	Very dark greyish Brown (10YR 3/3 moist); brown (10YR 4/3 dry); strong medium sub-angular blocky; sticky and plastic (moist), friable (moist), hard (dry); smooth boundary; many common very fine roots; many fine mica flakes; common termite nests and channels.
Btcv	39 – 79	Yellowish red (5YR 4/6 moist); reddish yellow (5YR 6/8 dry); sandy clay loam; moderate medium sub-angular block structure; sticky and plastic (wet), friable (moist), hard (dry); few moderate cutans on root and animal channels; many fine pores; common medium roots; gradual boundary.
BCcv	79 – 120	Red (2.5YR 4/8 moist); red (2.5 YR 5/8 dry); gravelly sandy clay loam; weak fine sub-angular blocky structure; slightly sticky and non-plastic (wet), firm (moist), hard (dry); few fine pores many iron-manganese concretions; encountered petroplinthite.

Profile No.	YL

General Site Information

Location	Bassawa, 1.5Km to Samaru along Zaria – Katsina Road (11^{o} 10’ 50.0” N and 07^{o} 40’ 02.2” E)
Elevation	676m
Taxonomic Classification	Alfisols
Soil Parent Material	Younger laterite
Geology	Basement complex
Geomorphology	Gently undulating plain with rock outcrops
Topography	Crest (0 – 2%)
Vegetation	Parkland
Land Use	Maize
Drainage	Well drained
Depth to Water Table	Not encountered within 160cm
Depth to Impenetrable Layer	Not encountered within 160cm
Surface Characteristics	Cultivated ridges, mining of plinthite for commercial production of laterite blocks
Described by	Maniyunda L. and G. S. Zarafi
Date Sampled	2012

Horizon Description

Horizon	Depth	Description
Ap	0 – 30	Brown (7.5YR 4/4 moist); brown (7.5YR 5/4 dry); gravelly sandy clay loam; strong medium sub-angular blocky; sticky plastic (moist), friable (moist), hard (dry); common fine roots; common medium ant holes and nests; common very fine mica flakes.
Btcv1	30 – 70	Red (2.5YR 4/6 moist); red (2.5YR 5/8 dry); gravelly sandy clay loam; few fine faint mottles; moderate medium sub-angular blocky structure; sticky and plastic (wet), friable (moist), hard (dry); few fine pores; common iron-manganese concretion; abrupt smooth boundary.
Btcv2		79 – 160 Red (2.5YR 4/8 moist); red (2.5 YR 5/8 dry); gravelly sandy clay loam; weak fine sub-angular blocky structure; slightly sticky and non-plastic (wet),

firm (moist), hard (dry); few fine pores many iron-manganese concretions.

Profile No.	BS1
General Site Information	
Location	Kwoi, 1Km to Kwoi along Keffi –Kaduna Road (09° 25’ 57.4” N and 08° 00’ 12.5” E)
Elevation	783m
Taxonomic Classification	Ultisols
Soil Parent Material	Basaltic rocks
Geology	Basaltic rocks
Geomorphology	Gently undulating plain
Topography	Crest (0 – 1%)
Vegetation	Parkland
Land Use	Soya beans, Maize
Drainage	Well drained
Depth to Water Table	Not encountered within 168cm
Depth to Impenetrable Layer	Not encountered within 168cm
Surface Characteristics	Cultivated ridges
Described by	G. S. Zarafi
Date Sampled	2012

Horizon Description

Horizon	Depth	Description
Ap	0 – 20	Dark red (2.5YR 3/6 moist); red (2.5YR 4/4 dry); medium moderate sub-angular blocky; very sticky plastic (moist), friable (moist), hard (dry); many very fine and fine roots; few mica flakes; medium animal holes and few coarse nests; many moderate thick clay and Fe cutans on ped faces; common medium pores; many medium Fe-Mn concretions; many fine mica flakes.
Btcv	20 – 76	Dark reddish brown (5YR 3/4 moist); red (2.5YR 4/4 dry); sandy clay loam; medium moderate sub-angular blocky structure; very sticky and very plastic (wet), friable (moist), hard (dry); common fine roots; common medium ant holes and nests; common very fine mica flakes; many medium Fe-Mn concretion.
Btcv1		76 – 106 Dark reddish brown (2.5YR 3/6 moist); red (2.5 YR 4/8 dry); gravelly sandy clay

	loam; moderate medium sub-angular blocky structure; very sticky and plastic (wet), very friable (moist), hard (dry); common thin clay cutans; common medium roots; common very fine mica flakes; clear wavy boundary.
BCcv	Brownish yellow (10YR 5/4 moist); yellowish brown (10YR 5/4 dry); gravelly sandy clay loam; strong fine and medium sub-angular blocky structure; slightly sticky and plastic (wet); very firm (moist); hard (dry); common fine medium pores; common fine many medium soft Fe concretion; gradual smooth boundary.

Profile No.	BS2
General Site Information	
Location	Gidan-Waya, 10Km to Kagoro along Keffi – Kagoro Road (09^{o} 27’ 51.4” N and 08^{o} 23’ 47.9” E)
Elevation	543m
Taxonomic Classification	Alfisols
Soil Parent Material	Newer Basaltic rocks
Geology	Newer Basaltic rocks
Geomorphology	Gently undulating plain
Topography	Crest (0 – 2%)
Vegetation	Parkland
Land Use	Guinea corn
Drainage	Well drained
Depth to Water Table	Not encountered with 173cm
Depth to Impenetrable Layer	Not encountered with 173
Surface Characteristics	Cultivated ridges
Described by	G. S. Zarafi
Date Sampled	2012

Horizon Description

Horizon	Depth	Description
Ap	0 – 25	Red (2.5YR 4/6 moist); red (2.5YR 6/8 dry); gravelly sandy clay loam; moderate medium sub-angular blocky; sticky and plastic (moist), friable (moist), hard (dry); many very fine and fine roots; many ant nests.
Bcv	25 – 73	Yellowish red (5YR 3/4 moist); yellowish red (5YR 5/8 dry); sandy clay loam; moderate medium sub-angular blocky structure; sticky and plastic (wet), friable (moist), hard (dry); common thin clay and Fe cutans; common medium pores; common fine roots; many medium Fe-Mn concretions; many very fine mica flakes; gradual smooth boundary.
Btcv1		73 – 105 Yellowish red (5YR 5/8 moist); reddish yellow (5 YR 5/8 dry); gravelly

	sandy clay loam; moderate medium sub-angular blocky structure; sticky and plastic (wet), friable (moist), hard (dry); many thin clay cutans on ped faces; many medium pores; many medium Fe-Mn concretions; many very fine mica flakes; gradual smooth boundary.
Btcv2	105 - 120 Yellowish red (5YR 4/6 moist); yellowish red (5YR 5/8 dry); moderate fine to medium sub-angular blocky structure; very slightly sticky and plastic (wet); friable (moist); hard (dry); gradual smooth boundary.
Bcv	120 – 173 Red (2.5YR 4/8 moist); red (2.5YR 6/8 dry); moderate medium to coarse sub-angular blocky structure; very sticky and very plastic (wet); friable (moist); common thin clay and Fe cutans on ped faces; common medium pores; common many very fine mica flakes.

Profile No.	BS3
General Site Information	
Location	Hwal Jos Plateau, 8Km to Jos on Jos – Zaria Road (10° 00’ 35.1” N and 08° 51’ 2.8” E)
Elevation	1149m
Taxonomic Classification	Alfisols
Soil Parent Material	Older Basaltic rocks
Geology	Basaltic rocks
Geomorphology	Gently undulating plain
Topography	Crest (0 – 2%)
Vegetation	Parkland
Land Use	Maize
Drainage	Well drained
Depth to Water Table	Not encountered with 170cm
Depth to Impenetrable Layer	Not encountered with 170cm
Surface Characteristics	Cultivated ridges
Described by	G. S. Zarafi
Date Sampled	2012

Horizon Description

Horizon	Depth	Description
Ap	0 – 20	Red (5YR 4/4 moist); Yellowish red (5YR 5/8 dry); gravelly sandy clay loam; moderate medium sub-angular blocky; sticky plastic (moist), friable (moist), hard (dry); many fine medium roots; many medium ants nests.
Btcv1		20 – 56 Yellowish red (5YR 4/6 moist); reddish yellow (5YR 6/8 dry); sandy clay loam; moderate sub-angular blocky structure; sticky

		and plastic (wet), firm (moist), hard (dry); few fine pores; few fine roots diffuse wavy boundary.
Btcv2	56 – 90	Red (2.5YR 4/6 moist); red (2.5 YR 4/8 dry); moderate medium sub-angular blocky structure; sticky and plastic (wet), friable (moist), hard (dry); very few thin clay cutans on pores and decay roots; few fine pores; few very fine roots; few iron nodules abrupt smooth boundary.
Bcv	90 – 170	Red (2.5YR 4/8 moist); red (2.5YR 6/8 dry); sandy clay loam; moderate medium sub-angular blocky; sticky and plastic (wet); friable (moist); hard (dry).

Profile No.	BS4
General Site Information	
Location	Hwal Jos Plateau, 8Km to Jos on Jos – Zaria Road (10° 00’ 33.6” N and 08° 55’ 30.2” E)
Elevation	1145m
Taxonomic Classification	Ultisols
Soil Parent Material	Older Basaltic rocks
Geology	Basaltic rocks
Geomorphology	Gently undulating plain
Topography	Crest (0 – 2%)
Vegetation	Parkland
Land Use	Maize
Drainage	Well drained
Depth to Water Table	Not encountered with 145cm
Depth to Impenetrable Layer	Not encountered with 145cm
Surface Characteristics	Cultivated ridges
Described by	G. S. Zarafi
Date Sampled	2012

Horizon Description

Horizon	Depth	Description
Ap	0 – 18	Dark brown (7.5YR 3/2 moist); brown (7.5YR 5/4 dry); gravelly sandy clay loam; strong medium sub-angular blocky; sticky plastic (moist), friable (moist), hard (dry); many fine and medium roots; termite’s holes and nests.
ABtcv	18 – 52	Yellowish brown (10YR 4/6 moist); yellowish brown (10YR 5/4 dry); very gravelly sandy; clay loam; strong medium sub-angular blocky structure; slightly sticky and slightly plastic (wet), friable (moist), hard (dry); common

		fine medium pores; common fine roots; many fine flakes; clear smooth boundary.
Bcv	52 – 68	Brownish yellow (10YR 4/6 moist); brownish yellow (10YR 5/4 dry); very gravelly sandy clay loam with very red mottles; strong fine and medium sub-angular blocky structure; slightly sticky and plastic (wet), very firm moist; common fine and medium pores; common very fine roots; many medium soft Fe nodules; gradual smooth boundary.
Btcv	68 – 145	Yellowish red (5YR 4/6 moist); yellowish red (5YR 5/8 dry); very gravelly sandy clay loam; moderate to strong fine to medium sub-angular blocky structure; sticky and plastic (wet); friable (moist); slightly hard (dry); many moderate thick clay and Fe cutans on ped faces and in pore channels; common medium pores; many very fine mica flakes.

APPENDIX B

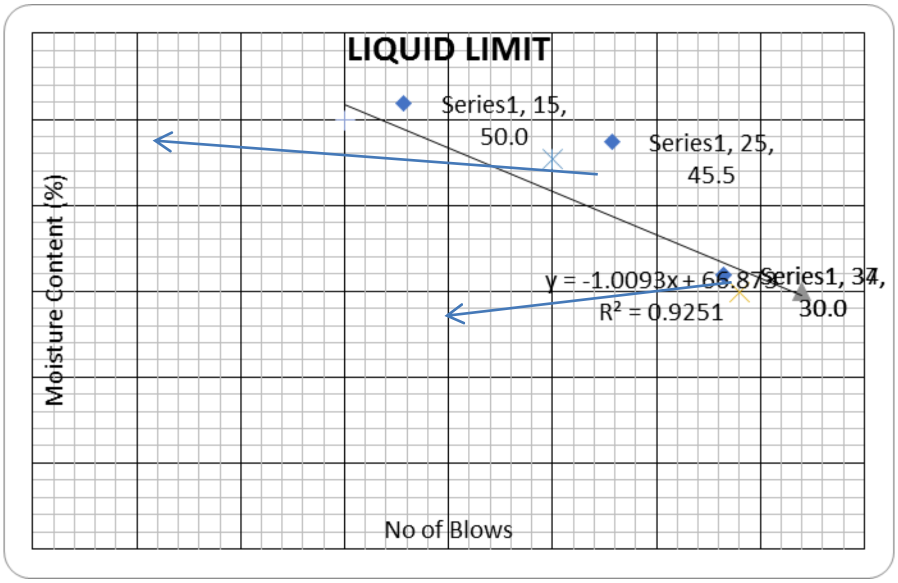
LIQUID AND PLASTIC LIMIT TEST

SITE	**BS2 GIDAN WAYA**	**DATE**	
SAMPLE NO	**A**		
DEPTH			

DESCRIPTION OF SOIL

LIQUID LIMIT (%)	**42.0**
PLASTIC LIMIT (%)	**25.0**
PLASTICITY INDEX (%)	**17.0**

Type of Test				**LIQUID LIMIT**
No of Blows	37	34	25	15
Container No	N	O	U	X
Wet Soil + Cont. g	33.0	36.0	38.0	32.0
Dry Soil + Cont. g	30.0	33.0	33.0	28.0
Container only g	20.0	23.0	22.0	20.0
Dry Soil g	10.0	10.0	11.0	8.0
Moisture g	3.0	3.0	5.0	4.0
Moisture Content %	30.0	30.0	45.5	50.0



Type of Test	**PLASTIC LIMIT**	
Container No	A1	A2
Wet Soil + Cont. g	33.0	29.0
Dry Soil + Cont. g	31.0	27.0
Container only g	23.0	19.0
Dry Soil g	8.0	8.0
Moisture g	2.0	2.0
Moisture Content %	25.0	25.0

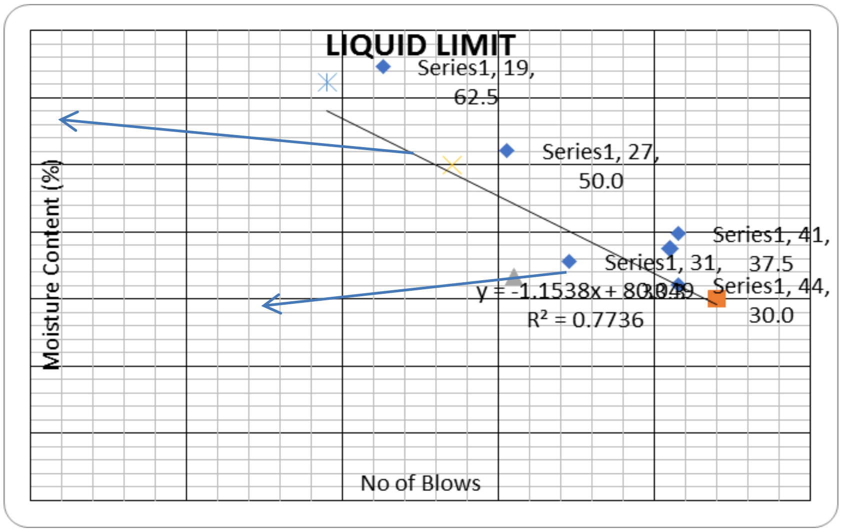
LIQUID AND PLASTIC LIMIT TEST

SITE **OGR HANWA** **DATE**
SAMPLE NO **B**
DEPTH

DESCRIPTION OF SOIL

LIQUID LIMIT (%) **51.0**
PLASTIC LIMIT (%) **13.4**
PLASTICITY INDEX (%) **37.6**

Type of Test		**LIQUID LIMIT**			
No of Blows	41	44	31	27	19
Container No	A3	A4	A5	A6	A7
Wet Soil + Cont. g	33.0	32.0	30.0	35.0	33.0
Dry Soil + Cont. g	30.0	29.0	28.0	31.0	28.0
Container only g	22.0	19.0	22.0	23.0	20.0
Dry Soil g	8.0	10.0	6.0	8.0	8.0
Moisture g	3.0	3.0	2.0	4.0	5.0
Moisture Content %	37.5	30.0	33.3	50.0	62.5



Type of Test	**PLASTIC LIMIT**	
Container No	B1	B2
Wet Soil + Cont. g	31.0	29.0
Dry Soil + Cont. g	30.0	28.0
Container only g	23.0	20.0
Dry Soil g	7.0	8.0
Moisture g	1.0	1.0
Moisture Content %	14.3	12.5

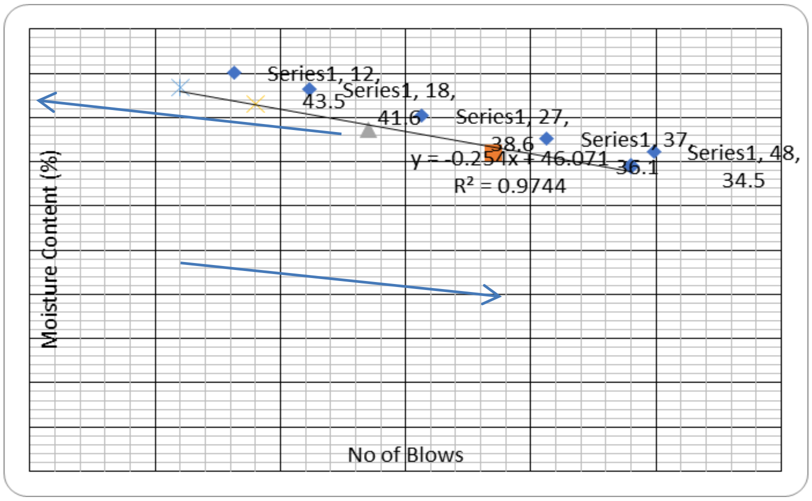
LIQUID AND PLASTIC LIMIT TEST

SITE	**OL1 M. GUGA**	**DATE**
SAMPLE NO		
DEPTH		

DESCRIPTION OF SOIL

LIQUID LIMIT (%)	**40.0**
PLASTIC LIMIT (%)	**19.6**
PLASTICITY INDEX (%)	**20.4**

Type of Test	**LIQUID LIMIT**				
No of Blows	48	37	27	18	12
Container No	135	Q94	X16	Q16	14B
Wet Soil + Cont. g	26.9	30.3	37.6	42.7	52.3
Dry Soil + Cont. g	23.1	25.0	31.0	33.0	40.0
Container only g	12.1	10.3	13.9	9.7	11.7
Dry Soil g	11.0	14.7	17.1	23.3	28.3
Moisture g	3.8	5.3	6.6	9.7	12.3
Moisture Content %	34.5	36.1	38.6	41.6	43.5



Type of Test		**PLASTIC LIMIT**	
Container No	10	Q70	M17
Wet Soil + Cont. g	12.6	16.8	13.3
Dry Soil + Cont. g	12.3	16.5	13.0
Container only g	10.9	14.9	11.4
Dry Soil g	1.4	1.6	1.6
Moisture g	0.3	0.3	0.3
Moisture Content %	21.4	18.8	18.8

LIQUID AND PLASTIC LIMIT TEST

SITE **SC M. GUGA** **DATE**

SAMPLE NO

DEPTH

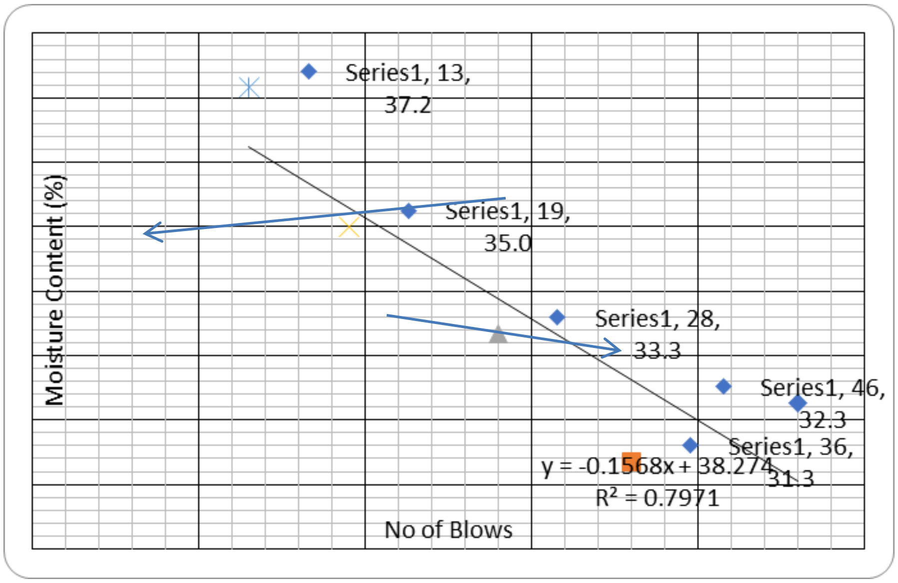
DESCRIPTION OF SOIL

LIQUID LIMIT (%) **34.4**

PLASTIC LIMIT (%) **21.1**

PLASTICITY INDEX (%) **13.3**

Type of Test				**LIQUID LIMIT**	
No of Blows	46	36	28	19	13
Container No	A3	AS0	4	U21	61
Wet Soil + Cont. g	26.3	28.4	38.6	42.0	46.6
Dry Soil + Cont. g	23.3	24.2	32.7	35.0	36.9
Container only g	14.0	10.8	15.0	15.0	10.8
Dry Soil g	9.3	13.4	17.7	20.0	26.1
Moisture g	3.0	4.2	5.9	7.0	9.7
Moisture Content %	32.3	31.3	33.3	35.0	37.2

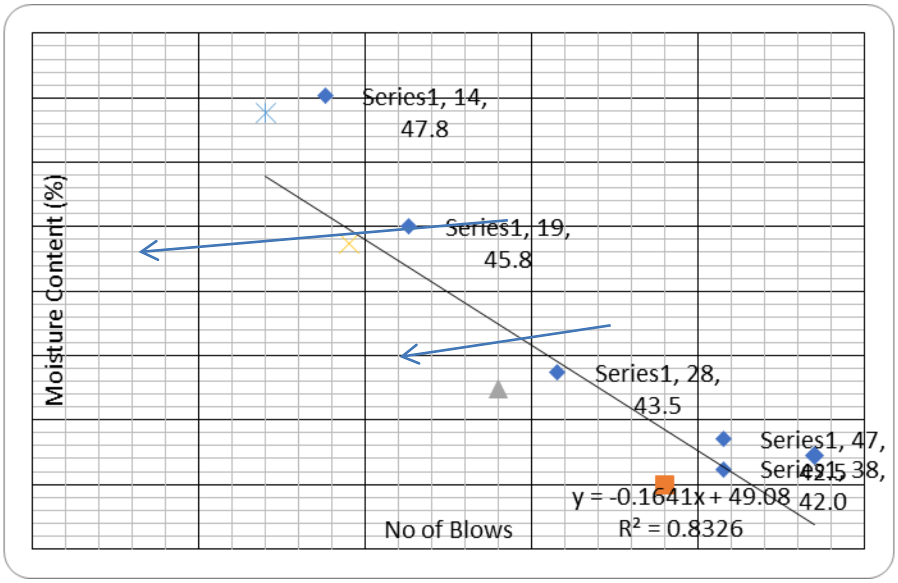


Type of Test			**PLASTIC LIMIT**
Container No	X28	M36	F7
Wet Soil + Cont. g	16.2	13.0	13.2
Dry Soil + Cont. g	15.8	12.7	12.8
Container only g	13.9	11.2	11.0
Dry Soil g	1.9	1.5	1.8
Moisture g	0.4	0.3	0.4
Moisture Content %	21.1	20.0	22.2

LIQUID AND PLASTIC LIMIT TEST

SITE	**BS3 JOS**	**DATE**
SAMPLE NO		
DEPTH		
DESCRIPTION OF SOIL		
LIQUID LIMIT (%)	**45.0**	
PLASTIC LIMIT (%)	**22.5**	
PLASTICITY INDEX (%)	**22.5**	

Type of Test				**LIQUID LIMIT**	
No of Blows	47	38	28	19	14
Container No	X46	7Q	Q27	X48	SM2
Wet Soil + Cont. g	25.2	31.3	38.1	41.1	49.1
Dry Soil + Cont. g	20.7	25.8	30.1	31.4	37.3
Container only g	10.1	12.7	11.7	10.2	12.6
Dry Soil g	10.6	13.1	18.4	21.2	24.7
Moisture g	4.5	5.5	8.0	9.7	11.8
Moisture Content %	42.5	42.0	43.5	45.8	47.8

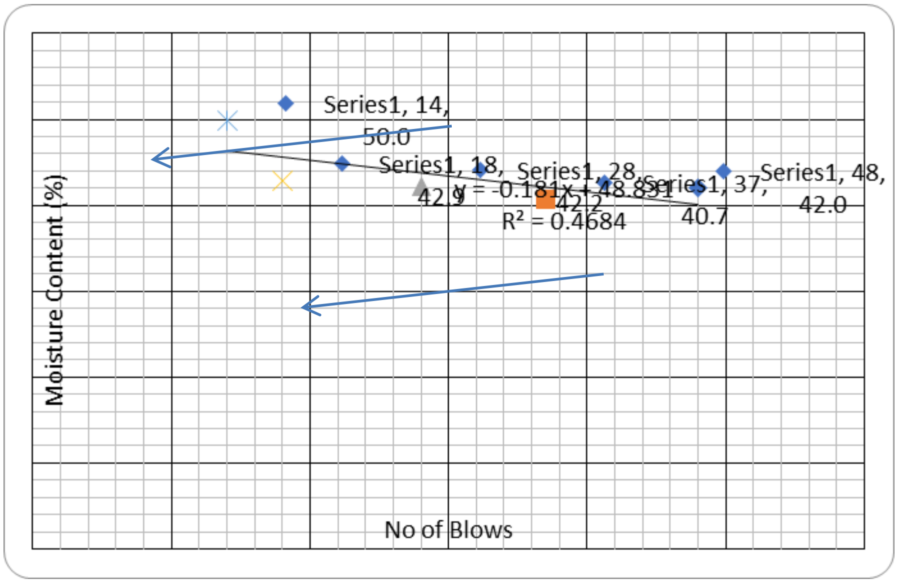


Type of Test		**PLASTIC LIMIT**	
Container No	1Q	Q31	A10
Wet Soil + Cont. g	12.7	13.6	12.4
Dry Soil + Cont. g	12.5	13.0	12.1
Container only g	11.5	11.5	10.9
Dry Soil g	1.0	1.5	1.2
Moisture g	0.2	0.6	0.3
Moisture Content %	20.0	40.0	25.0

LIQUID AND PLASTIC LIMIT TEST

SITE	**YL BASSAWA**	**DATE**
SAMPLE NO		
DEPTH		
DESCRIPTION OF SOIL		
LIQUID LIMIT (%)	**44.0**	
PLASTIC LIMIT (%)	**18.2**	
PLASTICITY INDEX (%)	**25.8**	

Type of Test			**LIQUID LIMIT**		
No of Blows	48	37	28	18	14
Container No	200	X65	N28	63	B
Wet Soil + Cont. g	23.9	29.6	32.5	37.4	45.2
Dry Soil + Cont. g	20.2	25.2	27.1	29.8	34.0
Container only g	11.4	14.4	14.3	12.1	11.6
Dry Soil g	8.8	10.8	12.8	17.7	22.4
Moisture g	3.7	4.4	5.4	7.6	11.2
Moisture Content %	42.0	40.7	42.2	42.9	50.0



Type of Test	**PLASTIC LIMIT**			
Container No	67		X39	X6
Wet Soil + Cont. g	14.8		16.3	13.6
Dry Soil + Cont. g	14.5		16.0	13.1
Container only g	12.9		14.3	11.1
Dry Soil g	1.6		1.7	2.0
Moisture g	0.3		0.3	0.5
Moisture Content %	18.8	17.6	25.0	

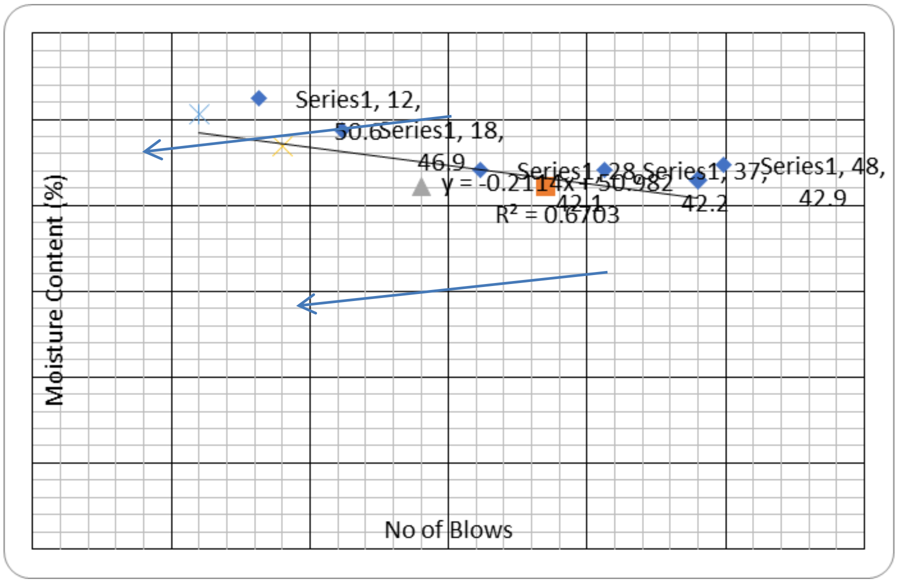
LIQUID AND PLASTIC LIMIT TEST

DEPTH

DESCRIPTION OF SOIL

LIQUID LIMIT (%)	**45.0**
PLASTIC LIMIT (%)	**26.8**
PLASTICITY INDEX (%)	**18.2**

Type of Test	**LIQUID LIMIT**				
No of Blows	48	37	28	18	12
Container No	20	65	20T	X68	X13
Wet Soil + Cont. g	27.6	29.6	39.8	41.1	48.1
Dry Soil + Cont. g	23.7	24.2	32.3	31.3	35.6
Container only g	14.6	11.4	14.5	10.4	10.9
Dry Soil g	9.1	12.8	17.8	20.9	24.7
Moisture g	3.9	5.4	7.5	9.8	12.5
Moisture Content %	42.9	42.2	42.1	46.9	50.6



Type of Test	**PLASTIC LIMIT**		
Container No	8Q	Q33	Q00
Wet Soil + Cont. g	12.5	16.4	15.9
Dry Soil + Cont. g	12.2	16.0	15.5
Container only g	10.9	14.7	14.0
Dry Soil g	1.3	1.3	1.5
Moisture g	0.3	0.4	0.4
Moisture Content %	23.1	30.8	26.7

LIGHT COMPACTION TEST

SITE	**OL1 M.GUGA**	**DATE**	
SAMPLE NO		**MAXIMUM DRY DENSITY Mg/m^3**	1.74
DEPTH		**OPTIMUM MOISTURE CONTENT%**	16.0

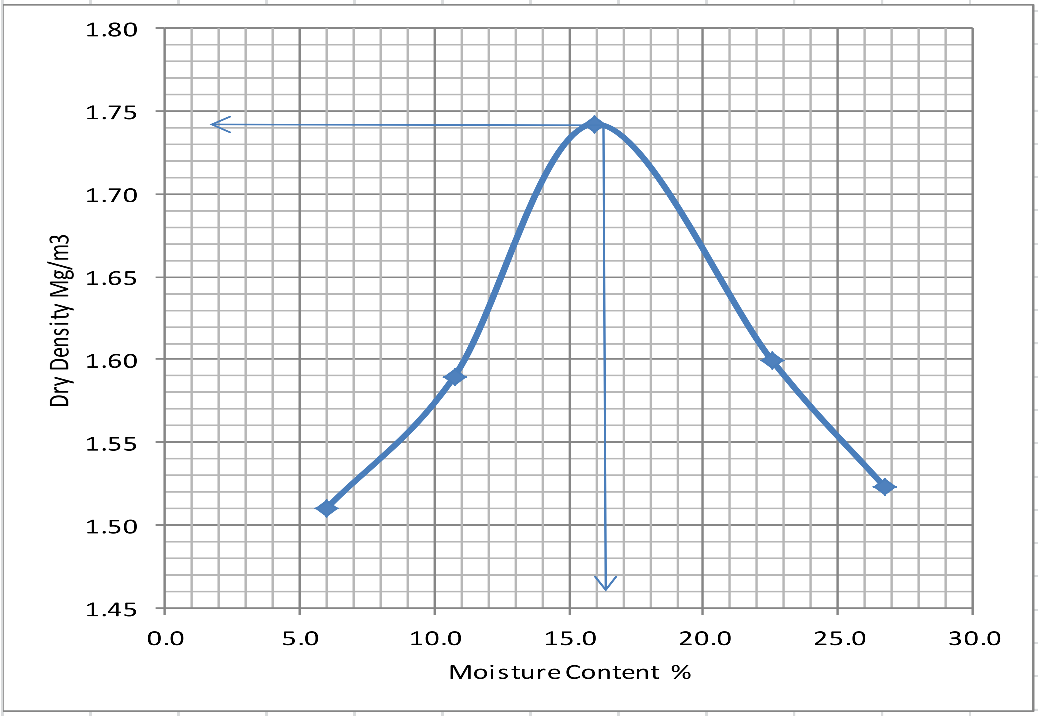
DESCRIPTION OF S

TOTAL WEIGHT OF SAMP	**3000**
VOLUME OF MOUl	**1000**

Mould + We	6160	6320	6580	6520	6490
Mould g	4560	4560	4560	4560	4560
Wet Soil g	1600	1760	2020	1960	1930
Bulk Density	1.6	1.76	2.02	1.96	1.93

Moisture Content Determination

Container N	611	X54	X68	X39	X6	N28	20	1Q	63	A50
Wet Soil + C	42.4	46.8	42.7	58.7	61.4	65.0	72.0	82.9	78.0	98.3
Dry Soil + Co	40.6	44.9	48.8	54.4	54.6	57.9	61.9	69.2	63.6	80.5
Container g	10.5	13.0	10.4	14.3	11.1	14.2	14.6	11.5	12.1	10.8
Dry Soil g	30.1	31.9	38.4	40.1	43.5	43.7	47.3	57.7	51.5	69.7
Moisture g	1.8	1.9	-6.1	4.3	6.8	7.1	10.1	13.7	14.4	17.8
Moisture Co	6.0	6.0	-15.9	10.7	15.6	16.2	21.4	23.7	28.0	25.5
Av. Moistur	6.0		10.7		15.9		22.5		26.7	
Dry Density	1.51		1.59		1.74		1.60		1.52	



LIGHT COMPACTION TEST

SITE **BS2 GIDAN WAYA** **DATE**
SAMPLE NO **MAXIMUM DRY DENSITY Mg/m^3** 1.67
DEPTH **OPTIMUM MOISTURE CONTENT%** 18.5

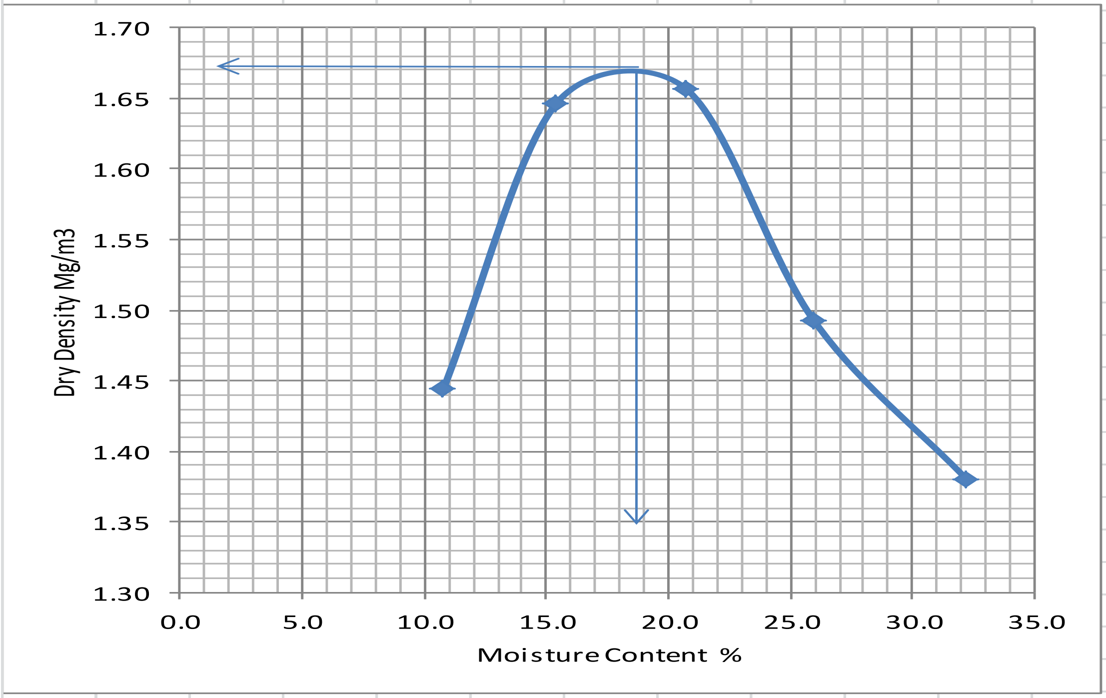
DESCRIPTION OF S

TOTAL WEIGHT OF SAMI **3000**
VOLUME OF MOU **1000**

Mould + We	6160	6460	6560	6440	6385
Mould g	4560	4560	4560	4560	4560
Wet Soil g	1600	1900	2000	1880	1825
Bulk Densit	1.60	1.90	2.00	1.88	1.83

Moisture Content Determination

Container N	167	64	Q94	X65	655	Q10	8Q	X53	X64	A9
Wet Soil + C	49.8	56.0	56.3	58.6	66.9	67.4	73.1	77.8	86.9	92.0
Dry Soil + Cc	46.1	51.7	49.9	52.7	57.6	58.2	60.4	64.3	69.6	72.6
Container g	11.6	12.0	10.2	14.4	11.8	14.7	11.0	12.8	14.9	13.4
Dry Soil g	34.5	39.7	39.7	38.3	45.8	43.5	49.4	51.5	54.7	59.2
Moisture g	3.7	4.3	6.4	5.9	9.3	9.2	12.7	13.5	17.3	19.4
Moisture Cc	10.7	10.8	16.1	15.4	20.3	21.1	25.7	26.2	31.6	32.8
Av. Moistur	10.8		15.4		20.7		26.0		32.2	
Dry Density	1.44		1.65		1.66		1.49		1.38	



LIGHT COMPACTION TEST

SITE SCM GUGA BT **DATE**

SAMPLE NO **MAXIMUM DRY DENSITY Mg/m^3** 1.93

DEPTH **OPTIMUM MOISTURE CONTENT%** 13.5

DESCRIPTION OF SOIL

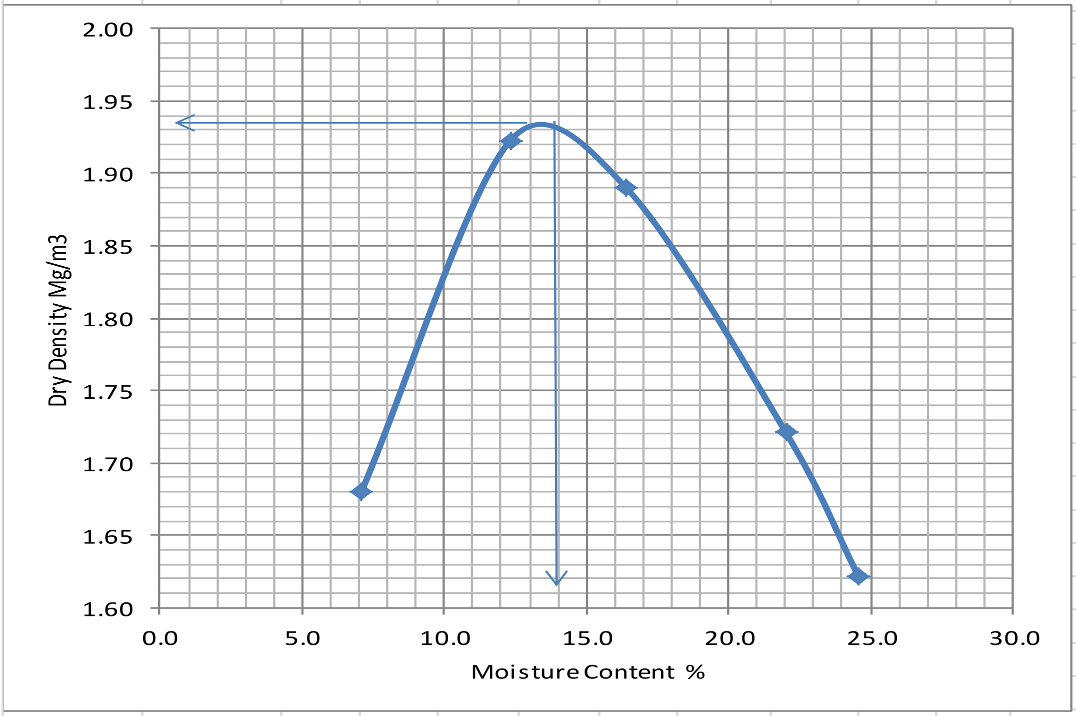
TOTAL WEIGHT OF SAMPLE g 3000

VOLUME OF MOULD cm^3 1000

Mould + Wet Soil g	6360	6720	6760	6660	6580
Mould g	4560	4560	4560	4560	4560
Wet Soil g	1800	2160	2200	2100	2020
Bulk Density Mg/m^3	1.80	2.16	2.20	2.10	2.02

Moisture Content Determination

Container No	X13	Q31	65	SM2	67	20	B	200	64	167
Wet Soil + Cont. g	41.4	46.2	57.0	63.6	73.5	81.6	90.3	92.9	97.4	99.2
Dry Soil + Cont. g	39.2	44.1	52.0	58.0	64.9	72.2	75.9	78.4	80.3	82.2
Container g	10.9	11.4	11.3	12.6	12.9	14.4	11.6	11.4	12.0	11.7
Dry Soil g	28.3	32.7	40.7	45.4	52.0	57.8	64.3	67.0	68.3	70.5
Moisture g	2.2	2.1	5.0	5.6	8.6	9.4	14.4	14.5	17.1	17.0
Moisture Content %	7.8	6.4	12.3	12.3	16.5	16.3	22.4	21.6	25.0	24.1
Av. Moisture Cont%	7.1		12.3		16.4		22.0		24.6	
Dry Density Mg/m^3	1.68		1.92		1.89		1.72		1.62	



LIGHT COMPACTION TEST

SITE **BS3 JOS** **DATE**

SAMPLE NO **MAXIMUM DRY DENSITY Mg/m^3** 1.70

DEPTH **OPTIMUM MOISTURE CONTENT%** 18.5

DESCRIPTION OF SOIL

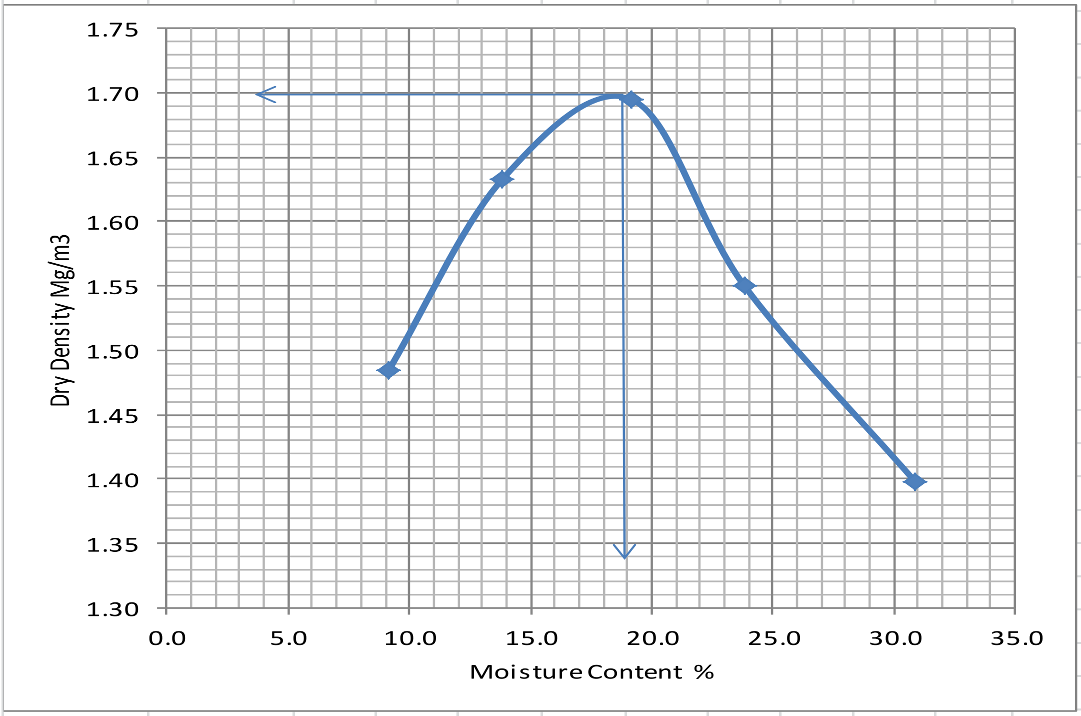
TOTAL WEIGHT OF SAMPLE g **3000**

VOLUME OF MOULD cm^3 **1000**

Mould + Wet Soil g	6180	6420	6580	6480	6390
Mould g	4560	4560	4560	4560	4560
Wet Soil g	1620	1860	2020	1920	1830
Bulk Density Mg/m^3	1.62	1.86	2.02	1.92	1.83

Moisture Content Determination

Container No	1Q	M63	611	X54	A9	X64	X53	655	64	Q94
Wet Soil + Cont. g	49.9	54.6	54.6	55.7	61.8	68.2	65.9	75.3	89.5	97.9
Dry Soil + Cont. g	46.8	51.0	49.4	50.5	54.0	59.6	55.5	63.3	71.8	76.6
Container g	11.5	13.1	10.4	13.0	13.4	14.8	12.8	11.7	12.0	10.3
Dry Soil g	35.3	37.9	39.0	37.5	40.6	44.8	42.7	51.6	59.8	66.3
Moisture g	3.1	3.6	5.2	5.2	7.8	8.6	10.4	12.0	17.7	21.3
Moisture Content %	8.8	9.5	13.3	13.9	19.2	19.2	24.4	23.3	29.6	32.1
Av. Moisture Cont%	9.1		13.9		19.2		23.8		30.9	
Dry Density Mg/m^3	1.48		1.63		1.69		1.55		1.40	



LIGHT COMPACTION TEST

SITE **OG HANWA** **DATE**

SAMPLE NO **MAXIMUM DRY DENSITY Mg/m^3** 1.90

DEPTH **OPTIMUM MOISTURE CONTENT%** 12.6

DESCRIPTION OF SOIL

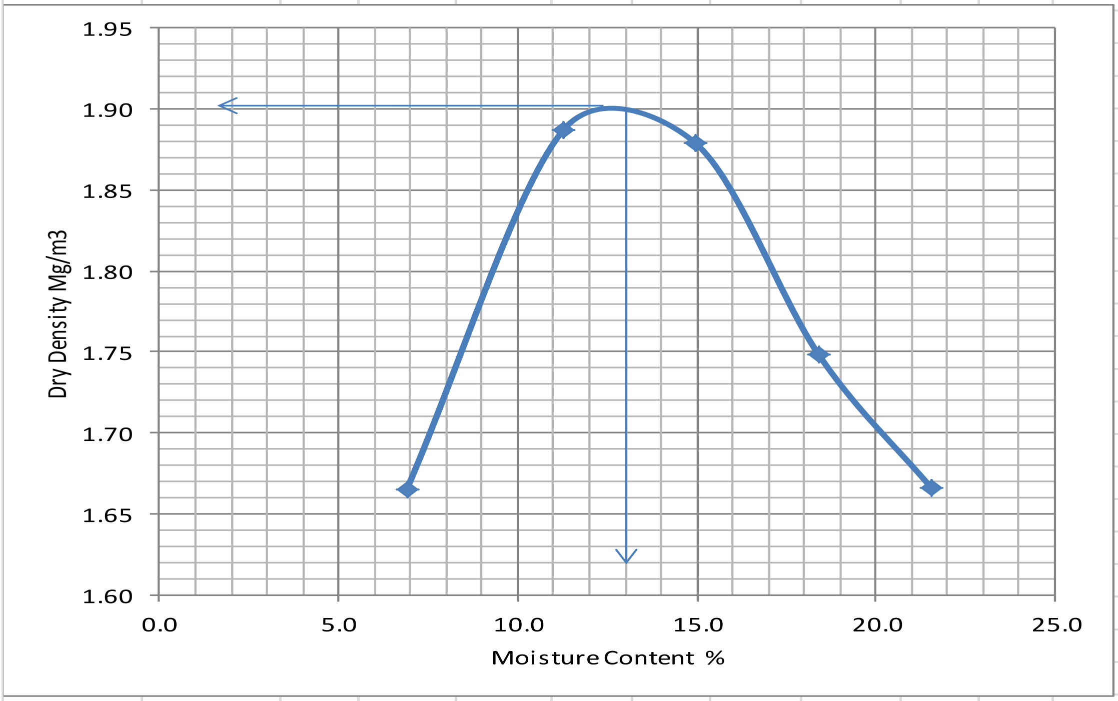
TOTAL WEIGHT OF SAMPLE g **3000**

VOLUME OF MOULD cm^3 **1000**

Mould + Wet Soil g	6340	6660	6720	6630	6585
Mould g	4560	4560	4560	4560	4560
Wet Soil g	1780	2100	2160	2070	2025
Bulk Density Mg/m^3	1.78	2.10	2.16	2.07	2.03

Moisture Content Determination

Container No	Q94	Q16	65	Z20	655	G10	X53	8Q	A9	X64
Wet Soil + Cont. g	43.8	43.9	67.6	70.2	67.1	78.0	87.6	96.8	95.9	98.9
Dry Soil + Cont. g	44.0	41.7	62.1	64.4	60.1	69.0	76.4	83.1	81.7	83.8
Container g	10.3	9.8	14.4	14.0	11.8	9.9	12.8	11.0	13.5	14.8
Dry Soil g	33.7	31.9	47.7	52.6	50.2	56.2	65.4	69.6	66.9	69.0
Moisture g	-0.2	2.2	5.5	5.8	7.0	9.0	11.2	13.7	14.2	15.1
Moisture Content %	-0.6	6.9	11.5	11.0	13.9	16.0	17.1	19.7	21.2	21.9
Av. Moisture Cont%	6.9		11.3		15.0		18.4		21.6	
Dry Density Mg/m^3	1.67		1.89		1.88		1.75		1.67	



LIGHT COMPACTION TEST

SITE	**BS JOS**	**DATE**	
SAMPLE NO		**MAXIMUM DRY DENSITY Mg/m^3**	1.68
DEPTH		**OPTIMUM MOISTURE CONTENT%**	17.5

DESCRIPTION OF SOIL

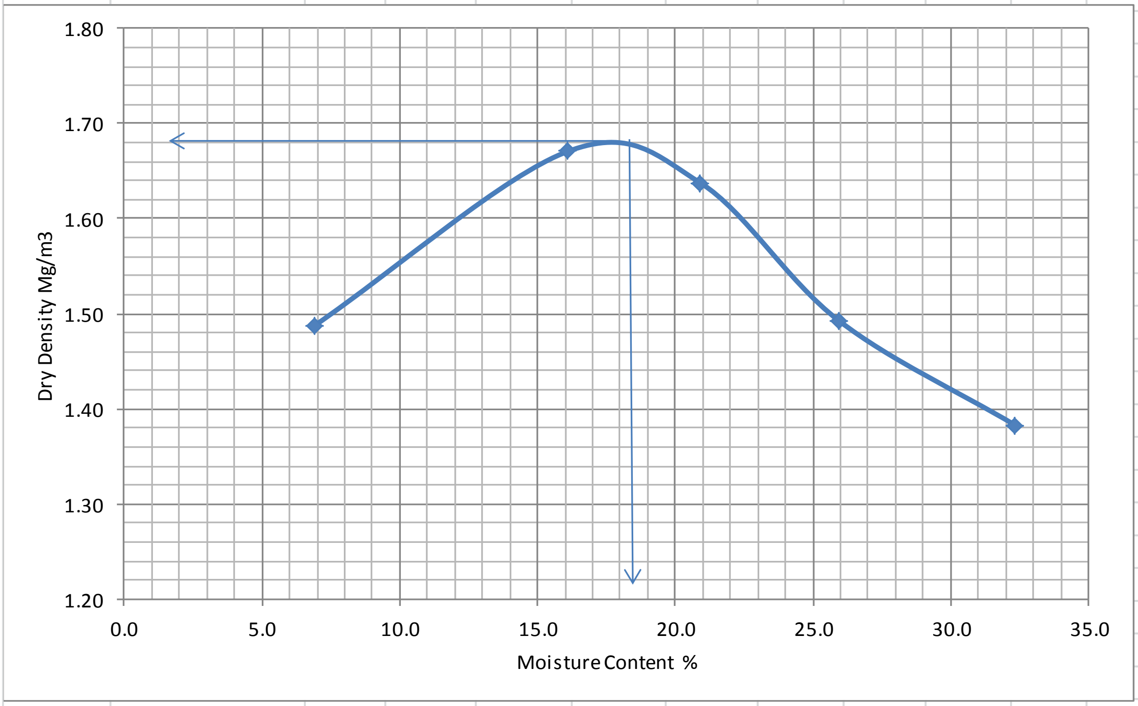
TOTAL WEIGHT OF SAMPLE g **3000**

VOLUME OF MOULD cm^3 **1000**

Mould + Wet Soil g	6150	6500	6540	6440	6390
Mould g	4560	4560	4560	4560	4560
Wet Soil g	1590	1940	1980	1880	1830
Bulk Density Mg/m^3	1.59	1.94	1.98	1.88	1.83

Moisture Content Determination

Container No	M63	A10	Q31	X13	65	SM2	67	20	200	B
Wet Soil + Cont. g	48.0	46.8	46.9	48.5	63.3	67.7	74.7	79.8	79.7	83.0
Dry Soil + Cont. g	44.5	43.1	41.9	43.4	54.2	58.6	61.9	66.2	63.2	65.3
Container g	13.2	10.9	11.3	10.9	11.3	12.6	13.0	14.5	11.5	11.4
Dry Soil g	31.3	32.2	30.6	32.1	41.6	45.6	47.4	54.7	51.8	53.9
Moisture g	3.5	3.7	5.0	5.1	9.1	9.1	12.8	13.6	16.5	17.7
Moisture Content %	11.2	11.5	16.3	15.9	21.9	20.0	27.0	24.9	31.9	32.8
Av. Moisture Cont%	6.9		16.1		20.9		25.9		32.3	
Dry Density Mg/m^3	1.49		1.67		1.64		1.49		1.38	



LIGHT COMPACTION TEST

SITE **YL BASSAWA** **DATE**

SAMPLE NO **MAXIMUM DRY DENSITY Mg/m^3** 1.81

DEPTH **OPTIMUM MOISTURE CONTENT%** 14.0

DESCRIPTION OF SOIL

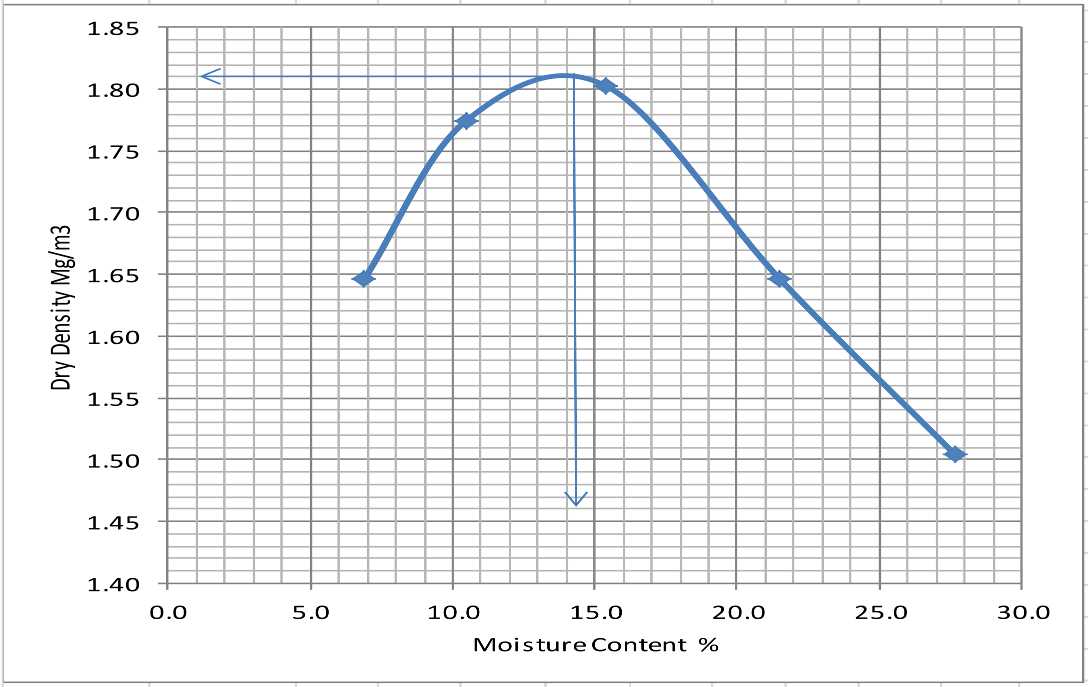
TOTAL WEIGHT OF SAMPLE g **3000**

VOLUME OF MOULD cm^3 **1000**

Mould + Wet Soil g	6320	6520	6640	6560	6480
Mould g	4560	4560	4560	4560	4560
Wet Soil g	1760	1960	2080	2000	1920
Bulk Density Mg/m^3	1.76	1.96	2.08	2.00	1.92

Moisture Content Determination

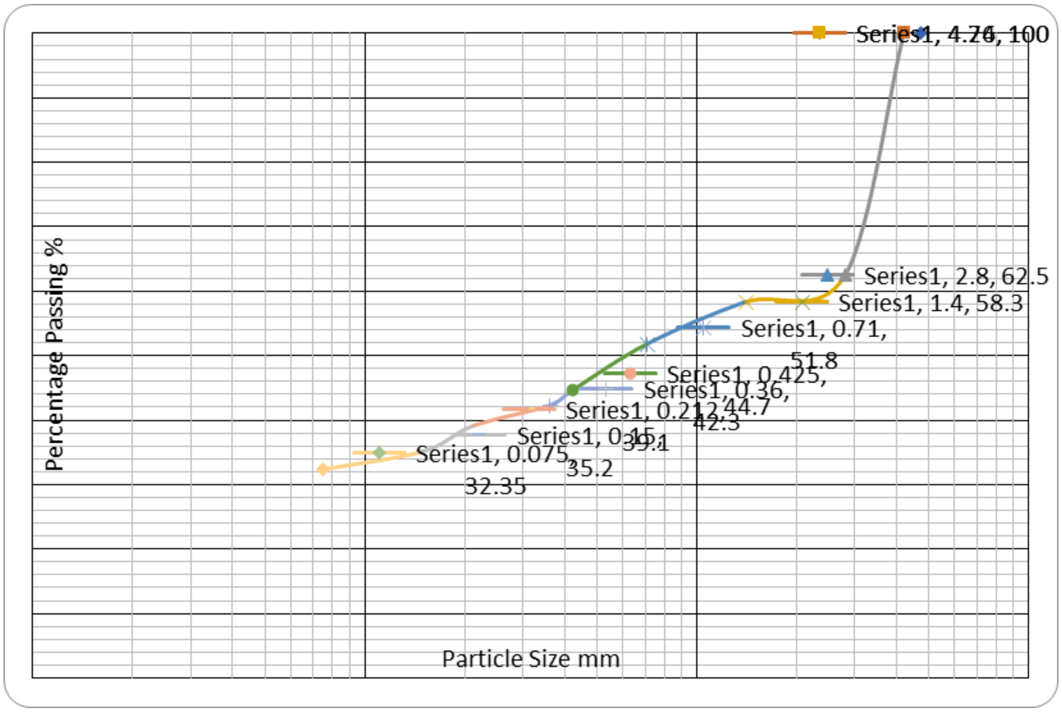
Container No	63	N28	X6	X39	67	X68	X13	SM2	A10	Q31
Wet Soil + Cont. g	47.2	59.0	51.3	57.5	66.8	72.0	79.5	85.0	88.9	93.2
Dry Soil + Cont. g	45.1	55.8	47.2	53.6	59.9	63.2	67.1	72.5	71.7	75.9
Container g	12.1	14.2	11.1	14.3	12.9	10.4	10.9	12.6	10.9	11.4
Dry Soil g	33.0	41.6	36.1	40.7	49.5	52.3	54.5	61.6	60.3	64.5
Moisture g	2.1	3.2	4.1	3.9	6.9	8.8	12.4	12.5	17.2	17.3
Moisture Content %	6.4	7.7	11.4	9.6	13.9	16.8	22.8	20.3	28.5	26.8
Av. Moisture Cont%	6.9		10.5		15.4		21.5		27.7	
Dry Density Mg/m^3	1.65		1.77		1.80		1.65		1.50	



PARTICLE SIZE DISTRIBUTION

SITE	**BS2 GIDAN WAYA**	**DATE**
SAMPLE NO		
DEPTH		
DESCRIPTION OF SOIL		
Total Mass of Sample g	**200**	

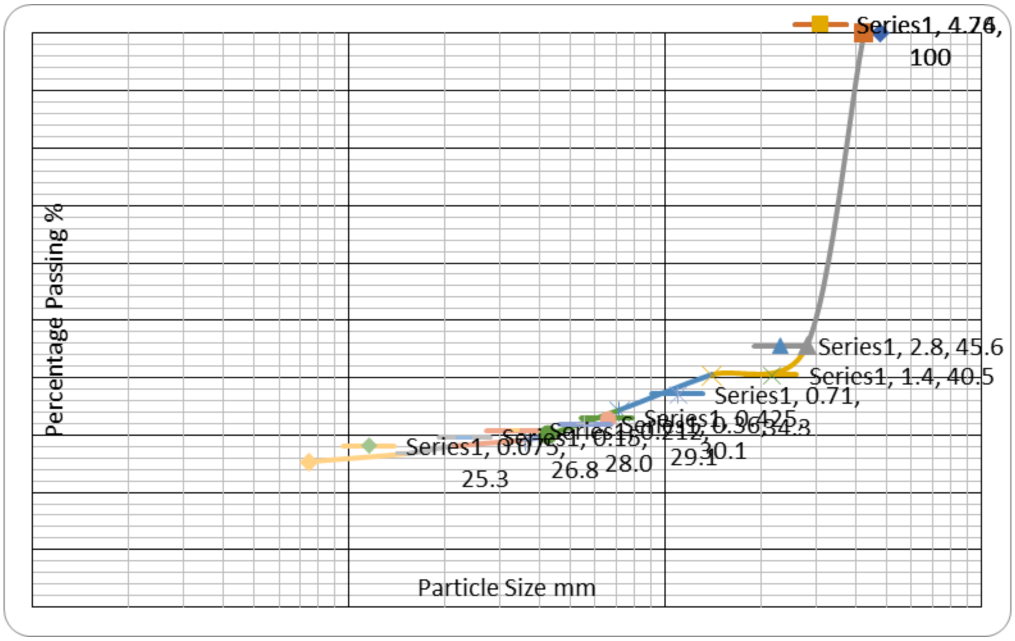
B.S Sieve Size(mm)	Mass Retained (g)	Cumulative Retained (g)	Percent Retained (%)	Percent Passing (%)
4.76	0	0	0	100
4.24	0	0	0	100
2.8	75	75	37.5	62.5
1.4	8.4	83.4	41.7	58.3
0.71	13	96.4	48.2	51.8
0.425	14.2	110.6	55.3	44.7
0.36	4.8	115.4	57.7	42.3
0.212	6.4	121.8	60.9	39.1
0.15	7.8	129.6	64.8	35.2
0.075	5.7	135.3	67.65	32.35
Pan	0.4	135.7	67.85	32.15



PARTICLE SIZE DISTRIBUTION

SITE	**YL BASSAWA**	**DATE**
SAMPLE NO		
DEPTH		
DESCRIPTION OF SOIL		
Total Mass of Sample g	**200**	

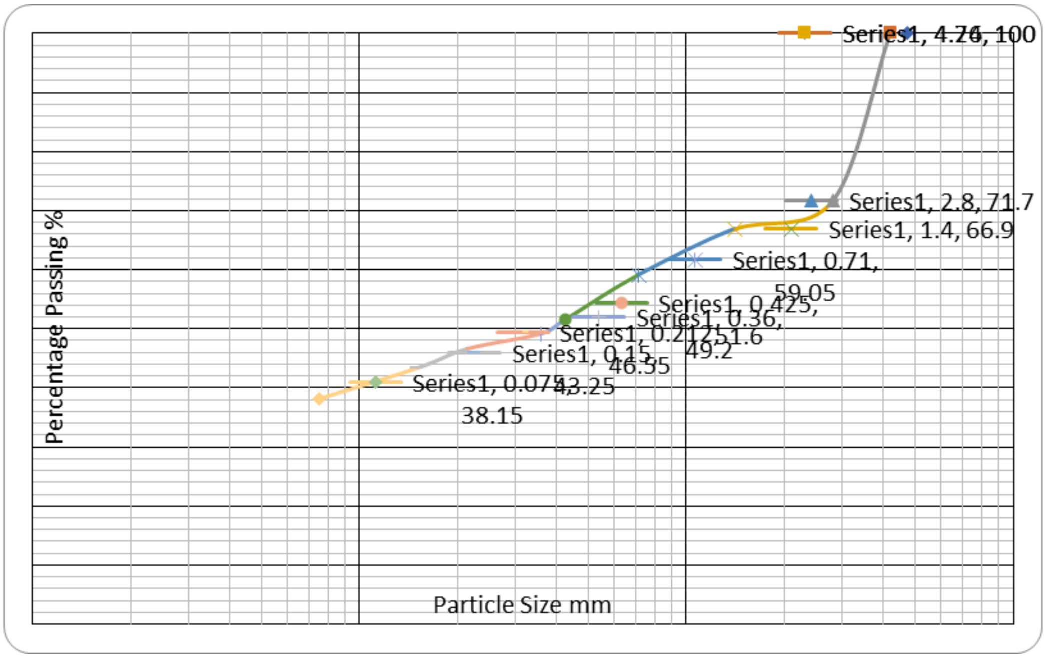
B.S Sieve Size(mm)	**Mass Retained (g)**	**Cumulative Retained (g)**	**Percent Retained (%)**	**Percent Passing (%)**
4.76	0	0	0	100
4.24	0	0	0	100
2.8	108.9	108.9	54.5	45.6
1.4	10.1	119.0	59.5	40.5
0.71	12.4	131.4	65.7	34.3
0.425	8.4	139.8	69.9	30.1
0.36	2.0	141.8	70.9	29.1
0.212	2.3	144.1	72.1	28.0
0.15	2.4	146.5	73.3	26.8
0.075	2.9	149.4	74.7	25.3
Pan	0.3	149.7	74.9	25.2



PARTICLE SIZE DISTRIBUTION

SITE	**OGR HANWA**		**DATE**
SAMPLE NO			
DEPTH			
DESCRIPTION OF SOIL			
Total Mass of Sample g		**200**	

B.S Sieve Size(mm)	Mass Retained (g)	Cumulative Retained (g)	Percent Retained (%)	Percent Passing (%)
4.76	0	0	0	100
4.24	0	0	0	100
2.8	56.6	56.6	28.3	71.7
1.4	9.6	66.2	33.1	66.9
0.71	15.7	81.9	40.95	59.05
0.425	14.9	96.8	48.4	51.6
0.36	4.8	101.6	50.8	49.2
0.212	5.3	106.9	53.45	46.55
0.15	6.6	113.5	56.75	43.25
0.075	10.2	123.7	61.85	38.15
Pan	1.4	125.1	62.55	37.45



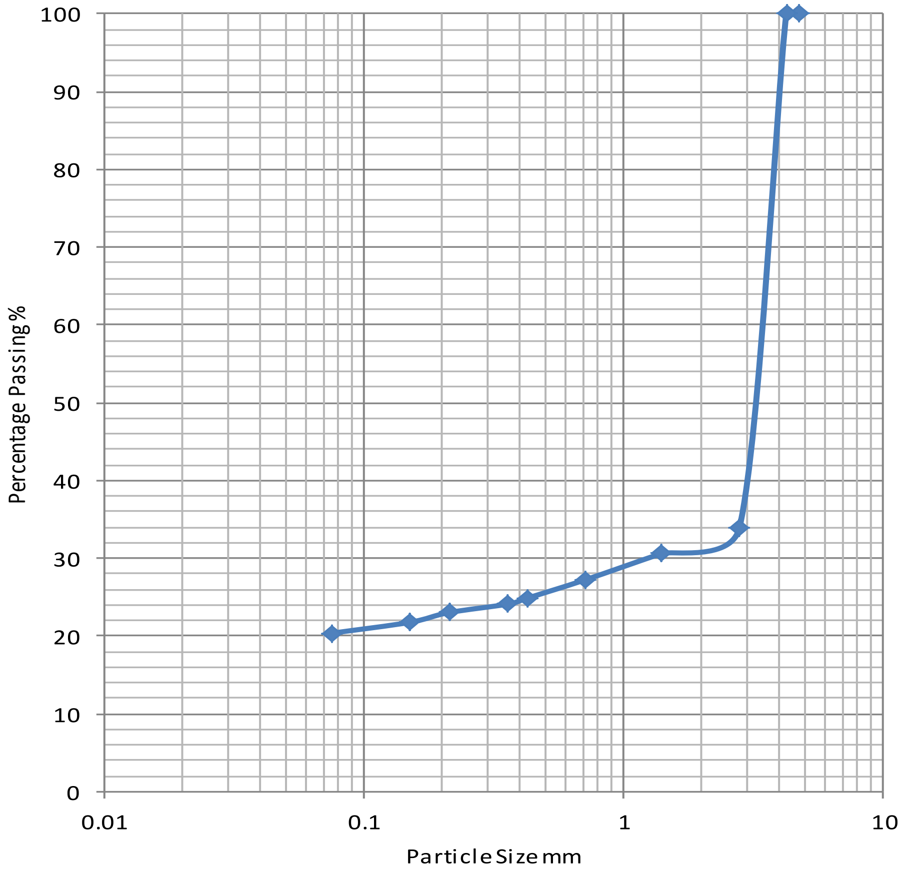
PARTICLE SIZE DISTRIBUTION

SITE	**SCM GUGA BT**	**DATE**
SAMPLE NO		
DEPTH		

DESCRIPTION OF SOIL

Total Mass of Sample g **200**

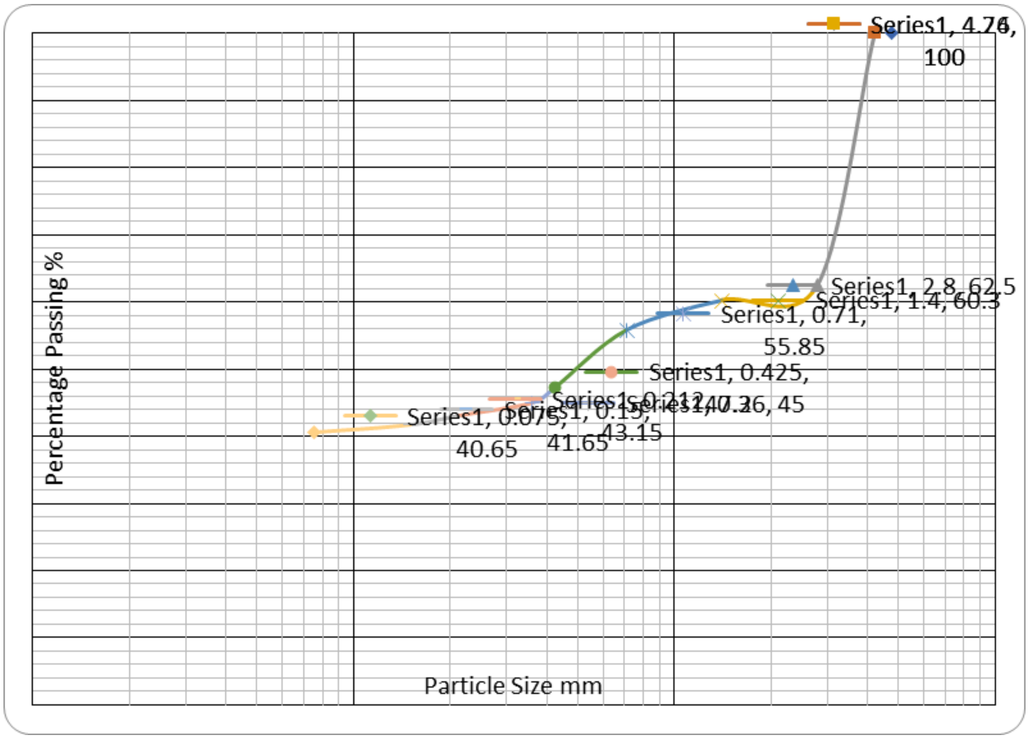
B.S Sieve Size(mm)	Mass Retained (g)	Cumulative Retained (g)	Percent Retained (%)	Percent Passing (%)
4.76	0	0	0	100
4.24	0	0	0	100
2.8	132.1	132.1	66.05	33.95
1.4	6.7	138.8	69.4	30.6
0.71	6.8	145.6	72.8	27.2
0.425	4.7	150.3	75.15	24.85
0.36	1.5	151.8	75.9	24.1
0.212	2.2	154	77	23
0.15	2.5	156.5	78.25	21.75
0.075	2.8	159.3	79.65	20.35
Pan	0.3	159.6	79.8	20.2



PARTICLE SIZE DISTRIBUTION

SITE **BS2 GIDAN WAYA** **DATE**
SAMPLE NO
DEPTH
DESCRIPTION OF SOIL
Total Mass of Sample g **200**

B.S Sieve Size(mm)	Mass Retained (g)	Cumulative Retained (g)	Percent Retained (%)	Percent Passing (%)
4.76	0	0	0	100
4.24	0	0	0	100
2.8	65.7	75	37.5	62.5
1.4	4.4	79.4	39.7	60.3
0.71	8.9	88.3	44.15	55.85
0.425	17.3	105.6	52.8	47.2
0.36	4.4	110	55	45
0.212	3.7	113.7	56.85	43.15
0.15	3	116.7	58.35	41.65
0.075	2	118.7	59.35	40.65
Pan	0	118.7	59.35	40.65



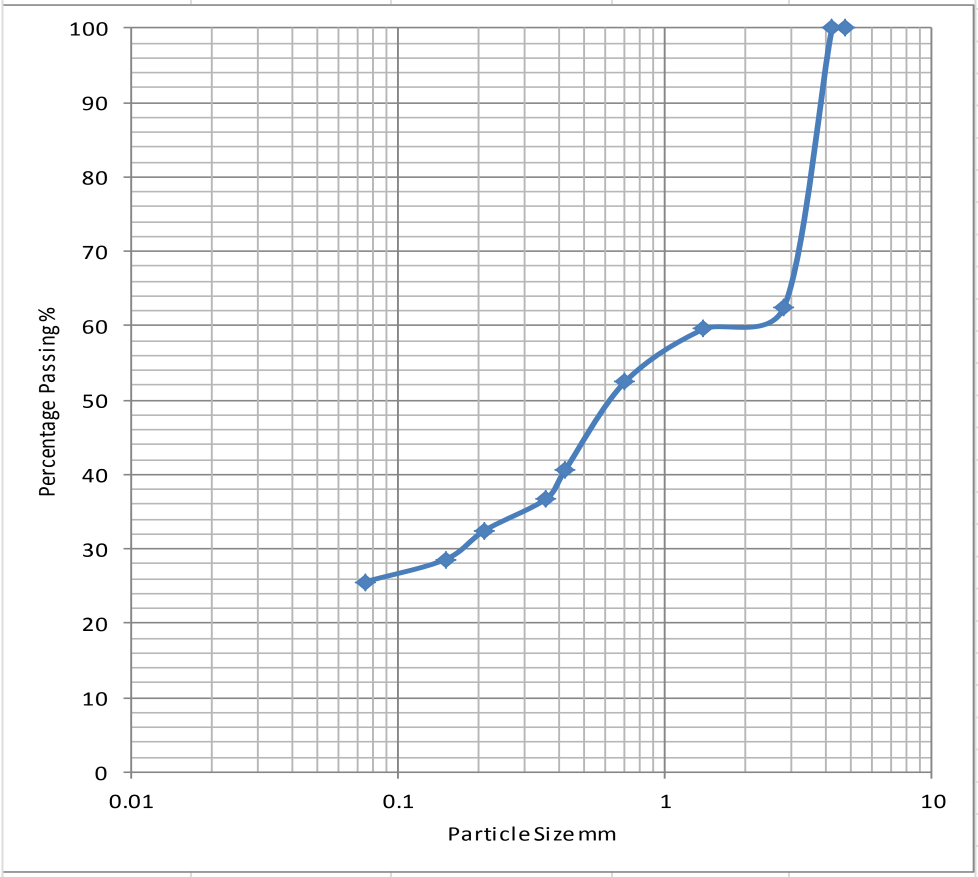
PARTICLE SIZE DISTRIBUTION

SITE	**BS1 KWOI**	**DATE**
SAMPLE NO		
DEPTH		

DESCRIPTION OF SOIL

Total Mass of Sample g **200**

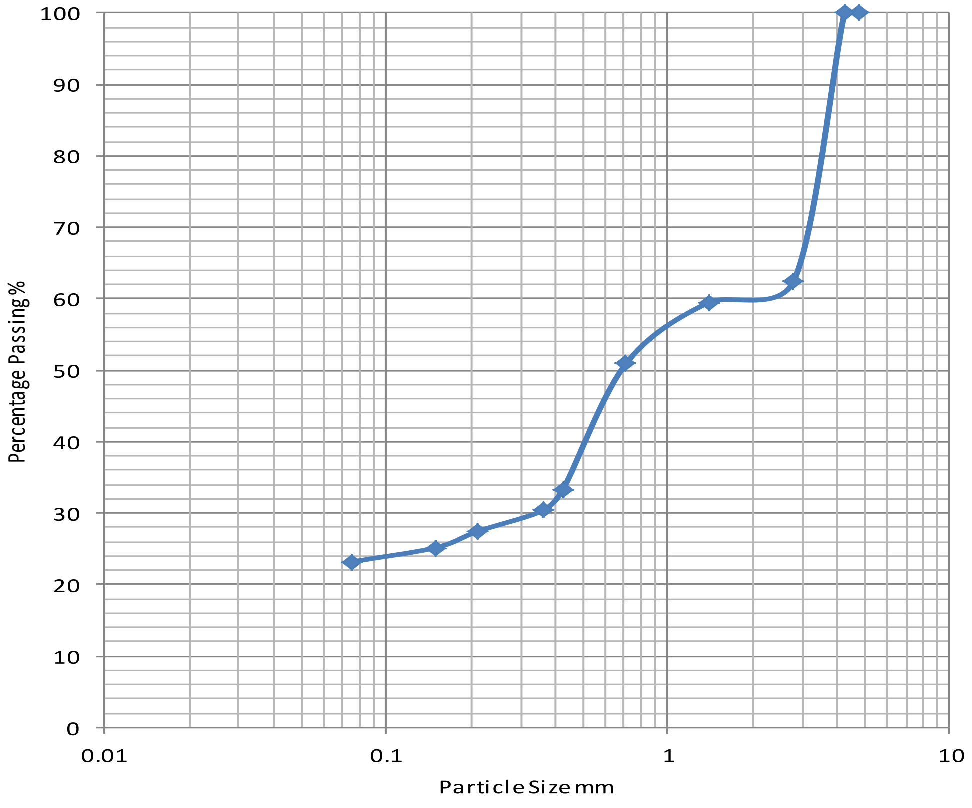
B.S Sieve Size(mm)	Mass Retained (g)	Cumulative Retained (g)	Percent Retained (%)	Percent Passing (%)
4.76	0	0	0	100
4.24	0	0	0	100
2.8	58.3	75	37.5	62.5
1.4	5.9	80.9	40.45	59.55
0.71	14.2	95.1	47.55	52.45
0.425	23.5	118.6	59.3	40.7
0.36	7.9	126.5	63.25	36.75
0.212	8.5	135	67.5	32.5
0.15	7.9	142.9	71.45	28.55
0.075	6	148.9	74.45	25.55
Pan	0.6	149.5	74.75	25.25



PARTICLE SIZE DISTRIBUTION

SITE	**BS3 JOS**	**DATE**
SAMPLE NO		
DEPTH		
DESCRIPTION OF SOIL		
Total Mass of Sample g	**200**	

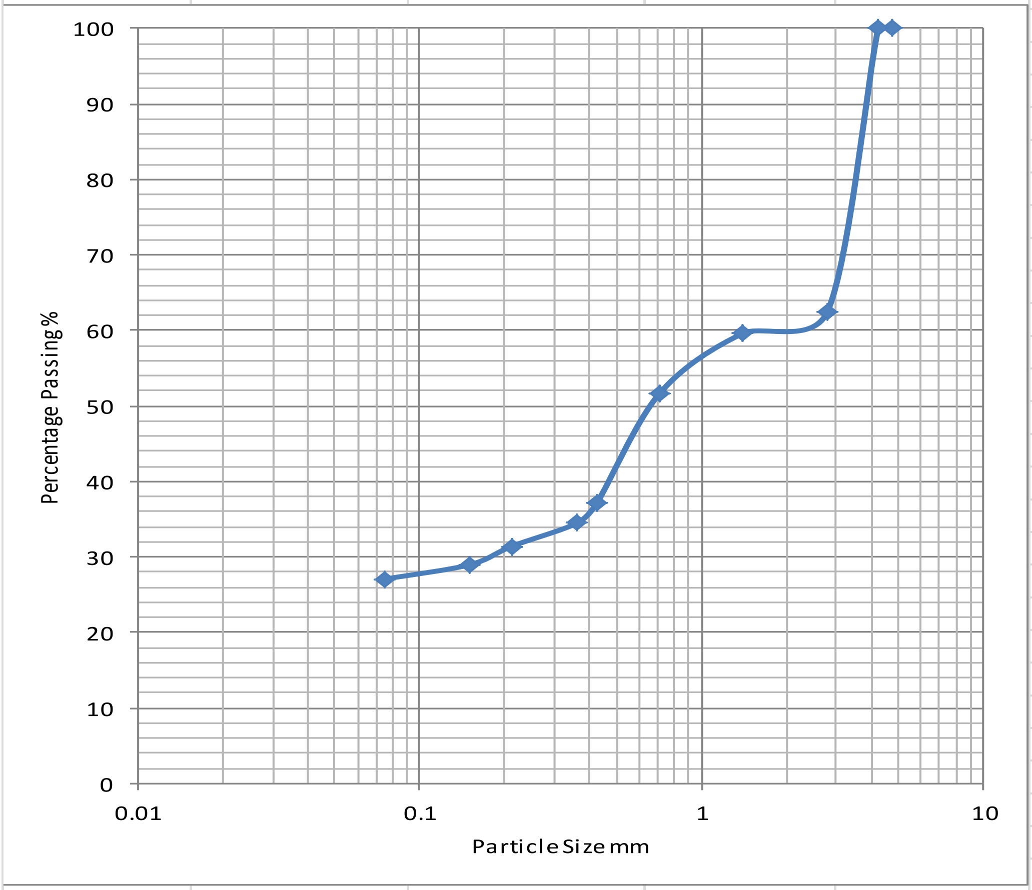
B.S Sieve Size(mm)	**Mass Retained (g)**	**Cumulative Retained (g)**	**Percent Retained (%)**	**Percent Passing (%)**
4.76	0	0	0	100
4.24	0	0	0	100
2.8	29.1	75	37.5	62.5
1.4	6	81	40.5	59.5
0.71	17.2	98.2	49.1	50.9
0.425	35.1	133.3	66.65	33.35
0.36	6	139.3	69.65	30.35
0.212	5.8	145.1	72.55	27.45
0.15	4.6	149.7	74.85	25.15
0.075	4	153.7	76.85	23.15
Pan	0.5	154.2	77.1	22.9



PARTICLE SIZE DISTRIBUTION

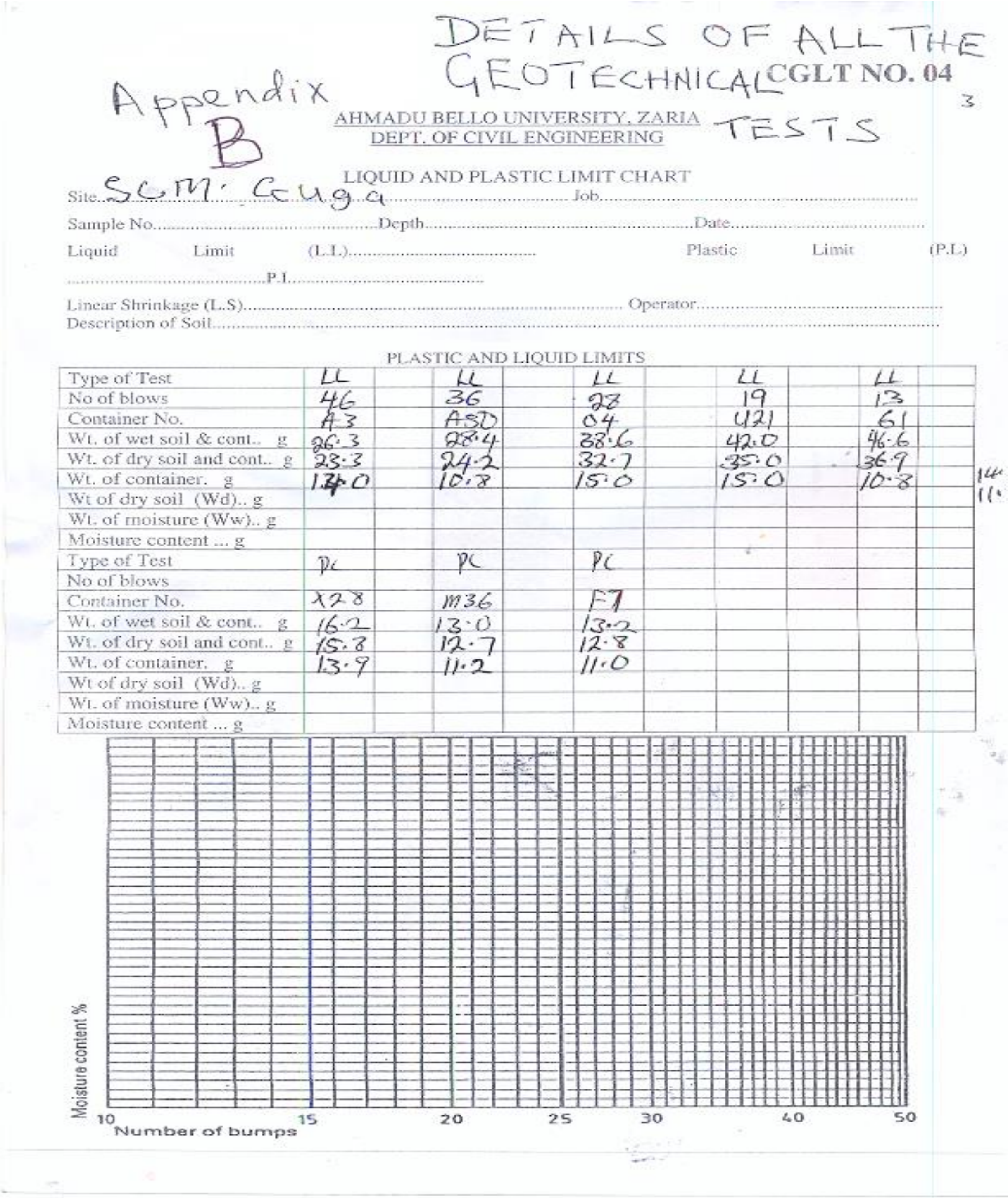
SITE	**BS4 J0S**	**DATE**
SAMPLE NO		
DEPTH		
DESCRIPTION OF SOIL		
Total Mass of Sample g	**200**	

B.S Sieve Size(mm)	Mass Retained (g)	Cumulative Retained (g)	Percent Retained (%)	Percent Passing (%)
4.76	0	0	0	100
4.24	0	0	0	100
2.8	47.4	75	37.5	62.5
1.4	5.8	80.8	40.4	59.6
0.71	15.9	96.7	48.35	51.65
0.425	29	125.7	62.85	37.15
0.36	5.4	131.1	65.55	34.45
0.212	6.1	137.2	68.6	31.4
0.15	4.9	142.1	71.05	28.95
0.075	3.8	145.9	72.95	27.05
Pan	0.5	146.4	73.2	26.8



APPENDIX C

DETAILS OF ALL THE GEOTECHNICAL TESTS



DETAILS OF ALL THE GEOTECHNICAL TESTS

Appendix B

CGLT NO. 04

3

AHMADU BELLO UNIVERSITY, ZARIA
DEPT. OF CIVIL ENGINEERING

LIQUID AND PLASTIC LIMIT CHART

Site SCM: Guga Job

Sample No. Depth Date

Liquid Limit (L.L.) Plastic Limit (P.L)

P.I.

Linear Shrinkage (L.S) Operator

Description of Soil

PLASTIC AND LIQUID LIMITS

Type of Test	LL		LL		LL		LL		LL	
No of blows	46		36		28		19		13	
Container No.	A3		ASD		04		421		61	
Wt. of wet soil & cont.. g	26.3		28.4		38.6		42.0		46.6	
Wt. of dry soil and cont.. g	23.3		24.2		32.7		35.0		36.9	
Wt. of container. g	13.0		10.8		15.0		15.0		10.8	
Wt of dry soil (Wd).. g										
Wt. of moisture (Ww).. g										
Moisture content ... g										
Type of Test	PL		PL		PL					
No of blows										
Container No.	X28		M36		F7					
Wt. of wet soil & cont.. g	16.2		13.0		13.2					
Wt. of dry soil and cont.. g	15.8		12.7		12.8					
Wt. of container. g	13.9		11.2		11.0					
Wt of dry soil (Wd).. g										
Wt. of moisture (Ww).. g										
Moisture content ... g										

14
11

CGLT NO. 04

6

AHMADU BELLO UNIVERSITY, ZARIA
DEPT. OF CIVIL ENGINEERING

LIQUID AND PLASTIC LIMIT CHART

Site OL1 Biye ~~Biyenga~~ Job

Sample No. Depth Date

Liquid Limit (L.L) Plastic Limit (P.L)

P.I.

Linear Shrinkage (L.S) Operator

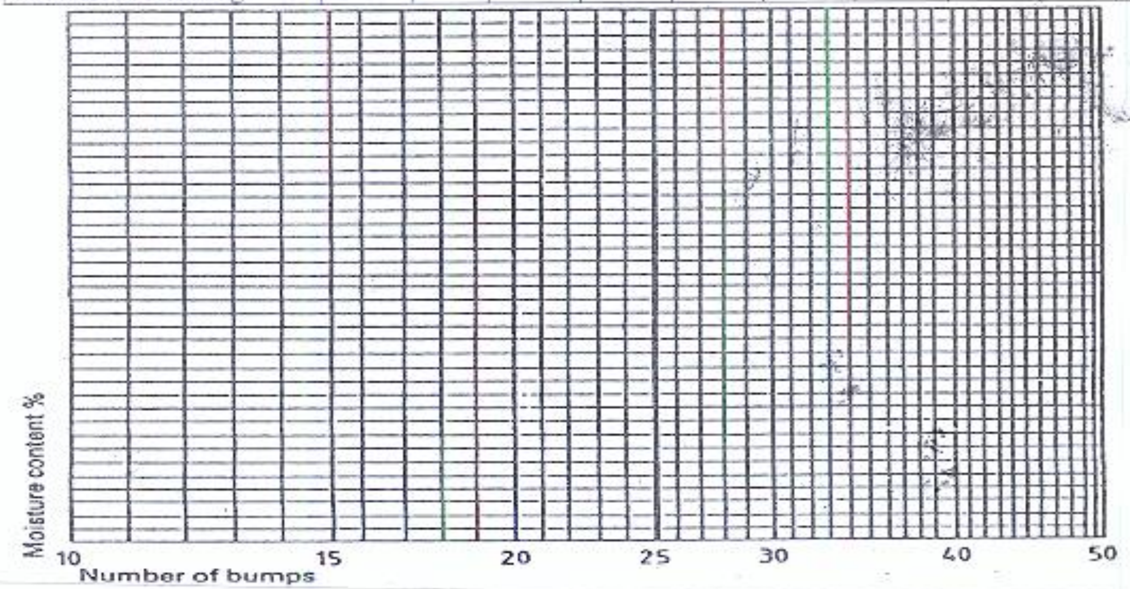
Description of Soil

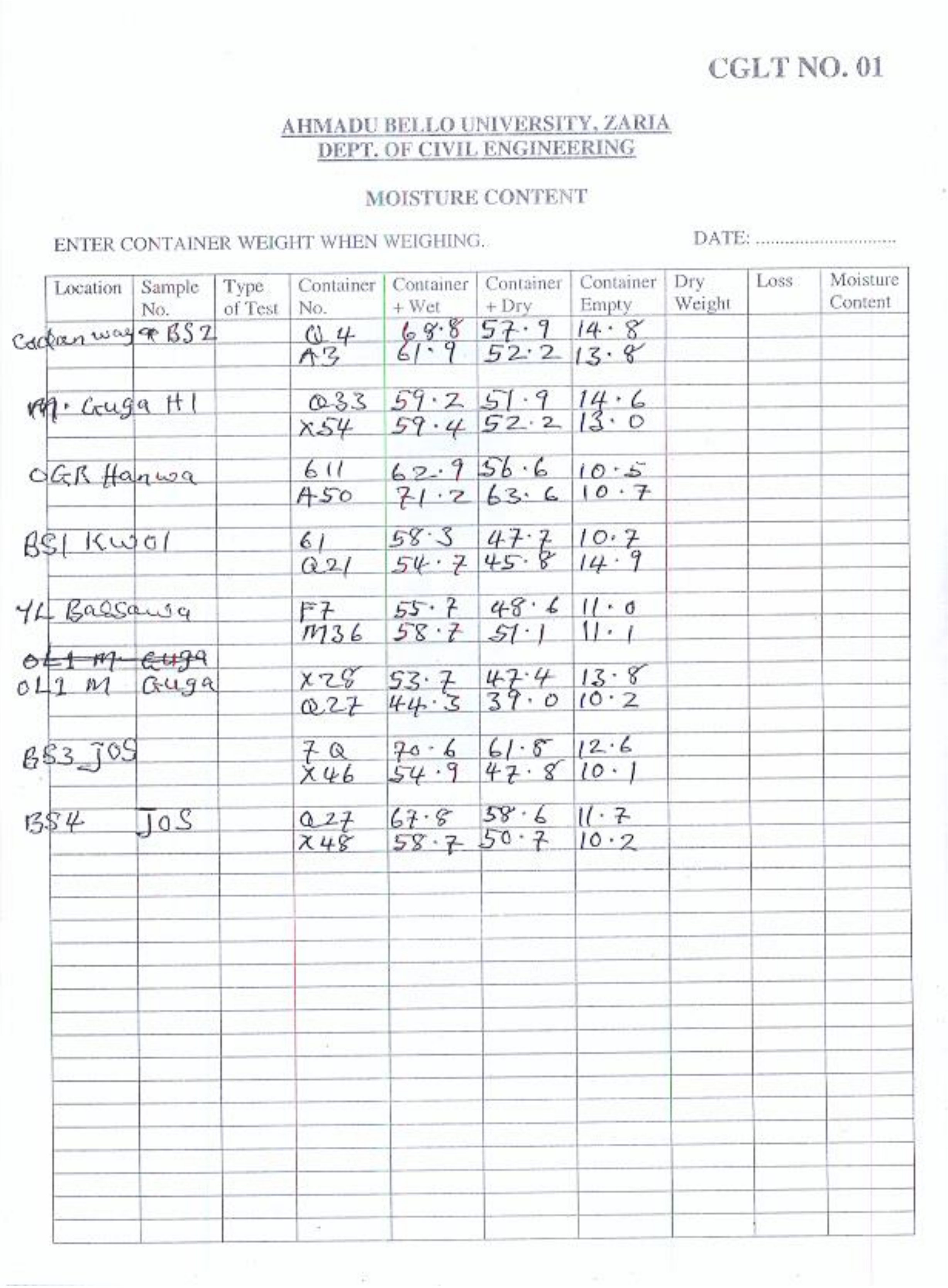
PLASTIC AND LIQUID LIMITS

Type of Test	LL		LL		LL		LL		LL	
No of blows	48		37		27		18		12	
Container No.	135		Q94		X60		Q16		14B	
Wt. of wet soil & cont.. g	26.9		30.3		37.6		42.7		52.3	
Wt. of dry soil and cont.. g	23.1		25.0		31.0		33.0		40.0	
Wt. of container. g	12.1		10.3		13.9		9.7		11.7	
Wt of dry soil (Wd).. g										
Wt. of moisture (Ww).. g										
Moisture content ... g										
Type of Test	PL		PL		PL					
No of blows										
Container No.	18		Q70		M17					
Wt. of wet soil & cont.. g	12.6		16.8		13.3					
Wt. of dry soil and cont.. g	12.3		16.5		13.0					
Wt. of container. g	10.9		14.9		11.4					
Wt of dry soil (Wd).. g										
Wt. of moisture (Ww).. g										
Moisture content ... g										

14

11·





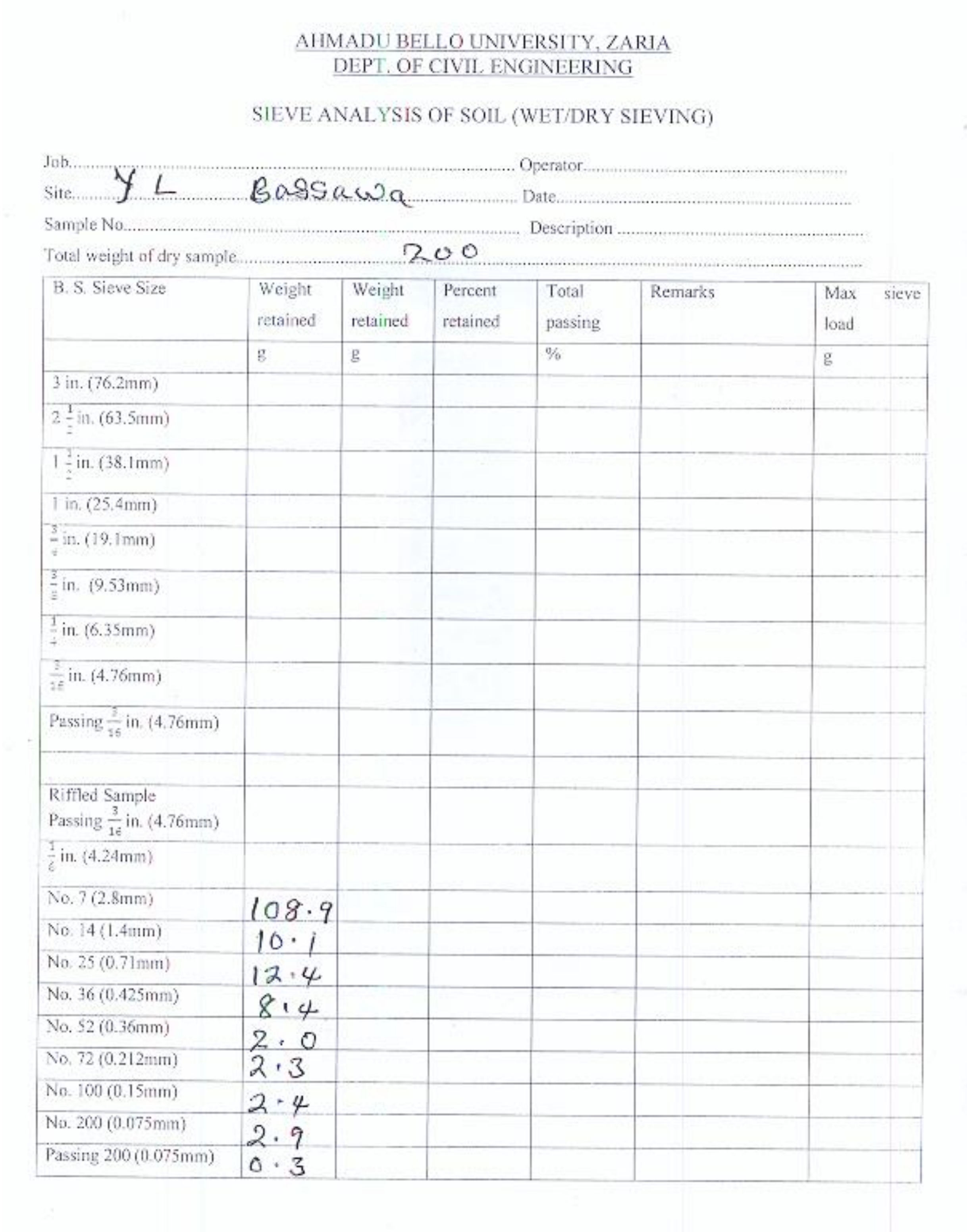
CGLT NO. 01

AHMADU BELLO UNIVERSITY, ZARIA
DEPT. OF CIVIL ENGINEERING

MOISTURE CONTENT

ENTER CONTAINER WEIGHT WHEN WEIGHING. DATE: ....

Location	Sample No.	Type of Test	Container No.	Container + Wet	Container + Dry	Container Empty	Dry Weight	Loss	Moisture Content
Cadanway	BS2		Q4	68.8	57.9	14.8			
			A3	61.9	52.2	13.8			
M. Guga	H1		Q33	59.2	51.9	14.6			
			X54	59.4	52.2	13.0			
OGR Hanwa			611	62.9	56.6	10.5			
			A50	71.2	63.6	10.7			
BS1 Kwoi			61	58.3	47.7	10.7			
			Q21	54.7	45.8	14.9			
YL Badsawa			F7	55.7	48.6	11.0			
			M36	58.7	51.1	11.1			
~~OL1 M~~	~~Guga~~								
OL1 M	Guga		X28	53.7	47.4	13.8			
			Q27	44.3	39.0	10.2			
BS3_JOS			7Q	70.6	61.8	12.6			
			X46	54.9	47.8	10.1			
BS4	JOS		Q27	67.8	58.6	11.7			
			X48	58.7	50.7	10.2			

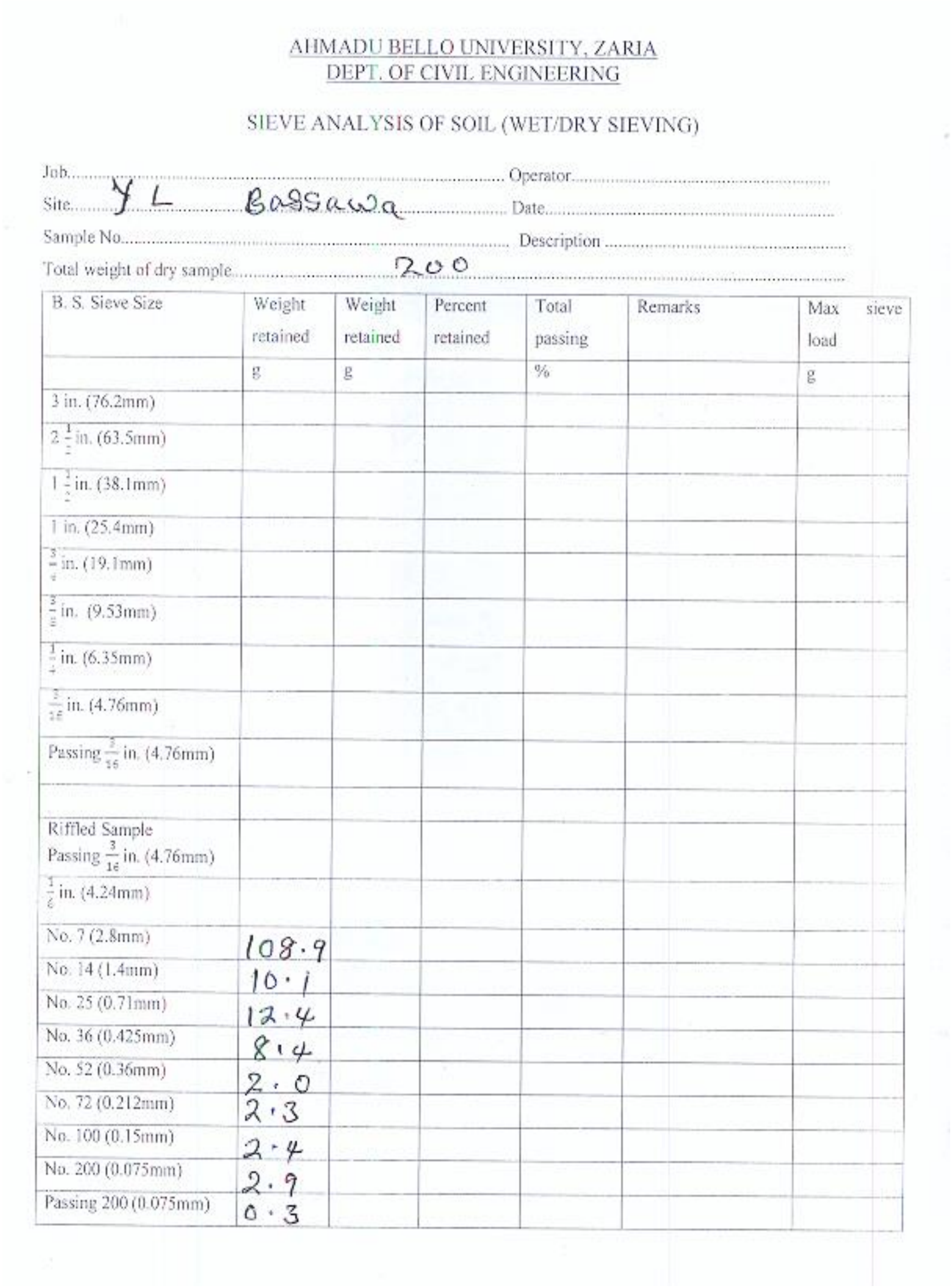


AHMADU BELLO UNIVERSITY, ZARIA
DEPT. OF CIVIL ENGINEERING

SIEVE ANALYSIS OF SOIL (WET/DRY SIEVING)

Job.................................... Operator....................................
Site...... Y L ...... Bassawa .... Date....................................
Sample No.................................... Description ....
Total weight of dry sample.................. 200 ....

B. S. Sieve Size	Weight retained	Weight retained	Percent retained	Total passing	Remarks	Max sieve load
	g	g		%		g
3 in. (76.2mm)						
$2\frac{1}{2}$ in. (63.5mm)						
$1\frac{1}{2}$ in. (38.1mm)						
1 in. (25.4mm)						
$\frac{3}{4}$ in. (19.1mm)						
$\frac{3}{8}$ in. (9.53mm)						
$\frac{1}{4}$ in. (6.35mm)						
$\frac{3}{16}$ in. (4.76mm)						
Passing $\frac{3}{16}$ in. (4.76mm)						
Riffled Sample Passing $\frac{3}{16}$ in. (4.76mm)						
$\frac{1}{6}$ in. (4.24mm)						
No. 7 (2.8mm)	108.9					
No. 14 (1.4mm)	10.1					
No. 25 (0.71mm)	12.4					
No. 36 (0.425mm)	8.4					
No. 52 (0.36mm)	2.0					
No. 72 (0.212mm)	2.3					
No. 100 (0.15mm)	2.4					
No. 200 (0.075mm)	2.9					
Passing 200 (0.075mm)	0.3					



AHMADU BELLO UNIVERSITY, ZARIA
DEPT. OF CIVIL ENGINEERING

SIEVE ANALYSIS OF SOIL (WET/DRY SIEVING)

Job........................ Operator........................
Site.......Y L Bassawa....... Date........................
Sample No........................ Description........................
Total weight of dry sample.......200.......

B. S. Sieve Size	Weight retained	Weight retained	Percent retained	Total passing	Remarks	Max sieve load
	g	g		%		g
3 in. (76.2mm)						
2 $\frac{1}{2}$ in. (63.5mm)						
1 $\frac{1}{2}$ in. (38.1mm)						
1 in. (25.4mm)						
$\frac{3}{4}$ in. (19.1mm)						
$\frac{3}{8}$ in. (9.53mm)						
$\frac{1}{4}$ in. (6.35mm)						
$\frac{3}{16}$ in. (4.76mm)						
Passing $\frac{3}{16}$ in. (4.76mm)						
Riffled Sample Passing $\frac{3}{16}$ in. (4.76mm)						
$\frac{1}{6}$ in. (4.24mm)						
No. 7 (2.8mm)	108.9					
No. 14 (1.4mm)	10.1					
No. 25 (0.71mm)	12.4					
No. 36 (0.425mm)	8.4					
No. 52 (0.36mm)	2.0					
No. 72 (0.212mm)	2.3					
No. 100 (0.15mm)	2.4					
No. 200 (0.075mm)	2.9					
Passing 200 (0.075mm)	0.3					

AHMADU BELLO UNIVERSITY, ZARIA
DEPT. OF CIVIL ENGINEERING

SIEVE ANALYSIS OF SOIL (WET/DRY SIEVING)

Job.. Operator..

Site........ BS4 JOS .... Date..

Sample No.. Description..

Total weight of dry sample........................ 200 ....

B. S. Sieve Size	Weight retained	Weight retained	Percent retained	Total passing	Remarks	Max sieve load
	g	g		%		g
3 in. (76.2mm)						
$2\frac{1}{2}$ in. (63.5mm)						
$1\frac{1}{2}$ in. (38.1mm)						
1 in. (25.4mm)						
$\frac{3}{4}$ in. (19.1mm)						
$\frac{3}{8}$ in. (9.53mm)						
$\frac{1}{4}$ in. (6.35mm)						
$\frac{3}{16}$ in. (4.76mm)						
Passing $\frac{3}{16}$ in. (4.76mm)						
Riffled Sample Passing $\frac{3}{16}$ in. (4.76mm)						
$\frac{1}{6}$ in. (4.24mm)						
No. 7 (2.8mm)	47·0					
No. 14 (1.4mm)	5·8					
No. 25 (0.71mm)	15·9					
No. 36 (0.425mm)	29·0					
No. 52 (0.36mm)	5·4					
No. 72 (0.212mm)	6·1					
No. 100 (0.15mm)	4·9					
No. 200 (0.075mm)	3·8					
Passing 200 (0.075mm)	0·5					

AHMADU BELLO UNIVERSITY, ZARIA
DEPT. OF CIVIL ENGINEERING

SIEVE ANALYSIS OF SOIL (WET/DRY SIEVING)

Job.. Operator..

Site........B S 3 .... JOS................ Date..

Sample No.. Description ....

Total weight of dry sample.................. 200 ....

B. S. Sieve Size	Weight retained	Weight retained	Percent retained	Total passing	Remarks	Max sieve load
	g	g		%		g
3 in. (76.2mm)						
$2\frac{1}{2}$ in. (63.5mm)						
$1\frac{1}{2}$ in. (38.1mm)						
1 in. (25.4mm)						
$\frac{3}{4}$ in. (19.1mm)						
$\frac{3}{8}$ in. (9.53mm)						
$\frac{1}{4}$ in. (6.35mm)						
$\frac{3}{16}$ in. (4.76mm)						
Passing $\frac{3}{16}$ in. (4.76mm)						
Riffled Sample Passing $\frac{3}{16}$ in. (4.76mm)						
$\frac{1}{6}$ in. (4.24mm)						
No. 7 (2.8mm)	29.1					
No. 14 (1.4mm)	6.0					
No. 25 (0.71mm)	17.2					
No. 36 (0.425mm)	35.1					
No. 52 (0.36mm)	6.0					
No. 72 (0.212mm)	5.8					
No. 100 (0.15mm)	4.6					
No. 200 (0.075mm)	4.0					
Passing 200 (0.075mm)	0.5					

AHMADU BELLO UNIVERSITY, ZARIA
DEPT. OF CIVIL ENGINEERING

SIEVE ANALYSIS OF SOIL (WET/DRY SIEVING)

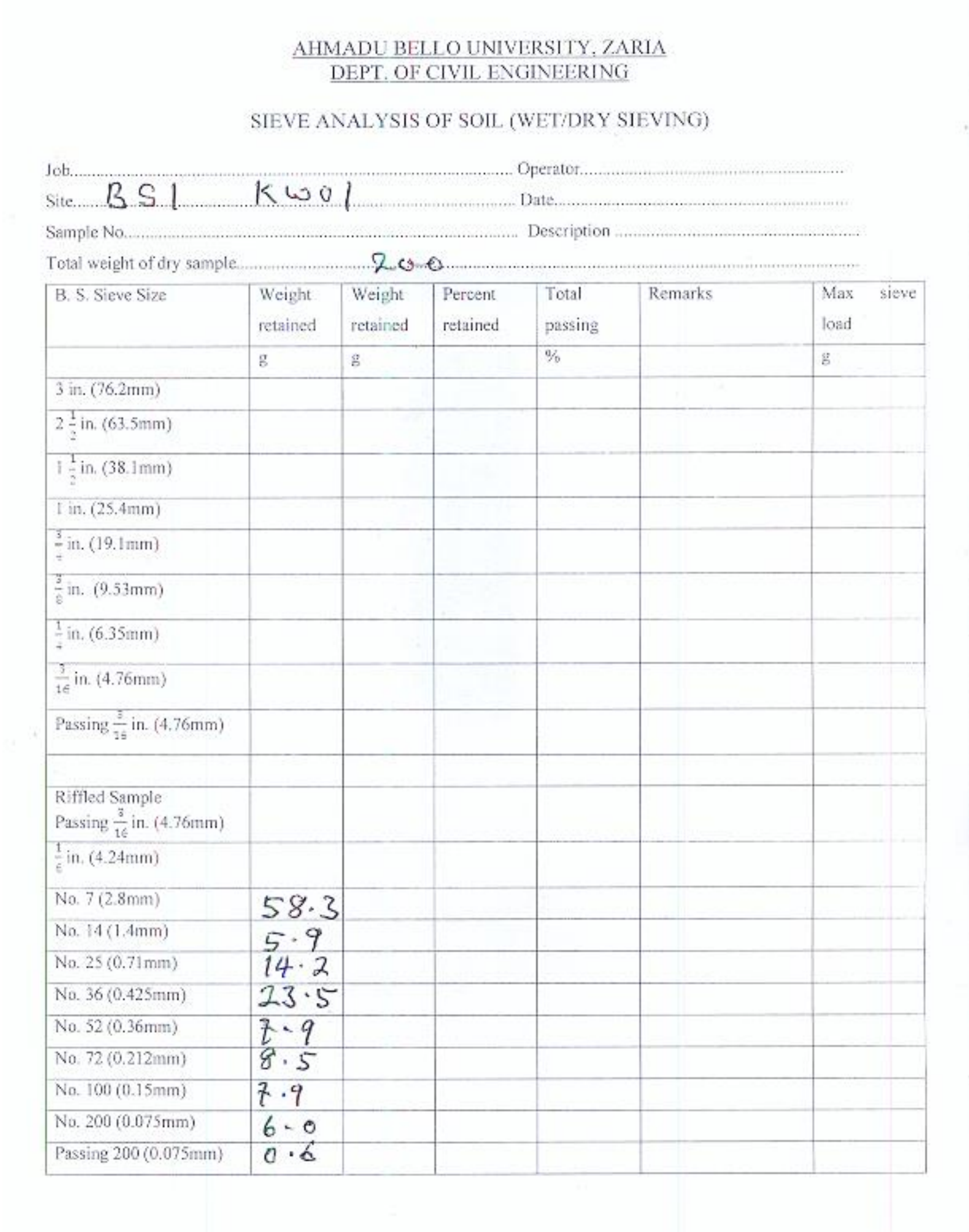
Job.. Operator..

Site BS 2 Gidan waya Date..

Sample No.. Description ....

Total weight of dry sample 200

B. S. Sieve Size	Weight retained	Weight retained	Percent retained	Total passing	Remarks	Max sieve load
	g	g		%		g
3 in. (76.2mm)						
$2\frac{1}{2}$ in. (63.5mm)						
$1\frac{1}{2}$ in. (38.1mm)						
1 in. (25.4mm)						
$\frac{3}{4}$ in. (19.1mm)						
$\frac{3}{8}$ in. (9.53mm)						
$\frac{1}{4}$ in. (6.35mm)						
$\frac{3}{16}$ in. (4.76mm)						
Passing $\frac{3}{16}$ in. (4.76mm)						
Riffled Sample Passing $\frac{3}{16}$ in. (4.76mm)						
$\frac{1}{6}$ in. (4.24mm)						
No. 7 (2.8mm) Gravel	75.0					
No. 14 (1.4mm) V. coarse sand	8.4					
No. 25 (0.71mm) Coarse sand	13.0					
No. 36 (0.425mm) medium sand	44.2					
No. 52 (0.36mm) Fine sand	4.8					
No. 72 (0.212mm) V fine sand	6.4					
No. 100 (0.15mm) Silt	7.8					
No. 200 (0.075mm) Clay	5.7	[illegible]				
Passing 200 (0.075mm) Clay	0.4					



AHMADU BELLO UNIVERSITY, ZARIA
DEPT. OF CIVIL ENGINEERING

SIEVE ANALYSIS OF SOIL (WET/DRY SIEVING)

Job.................................... Operator....................................
Site...BS1 KW01.................... Date....................................
Sample No.................................... Description....................................
Total weight of dry sample..........200..........

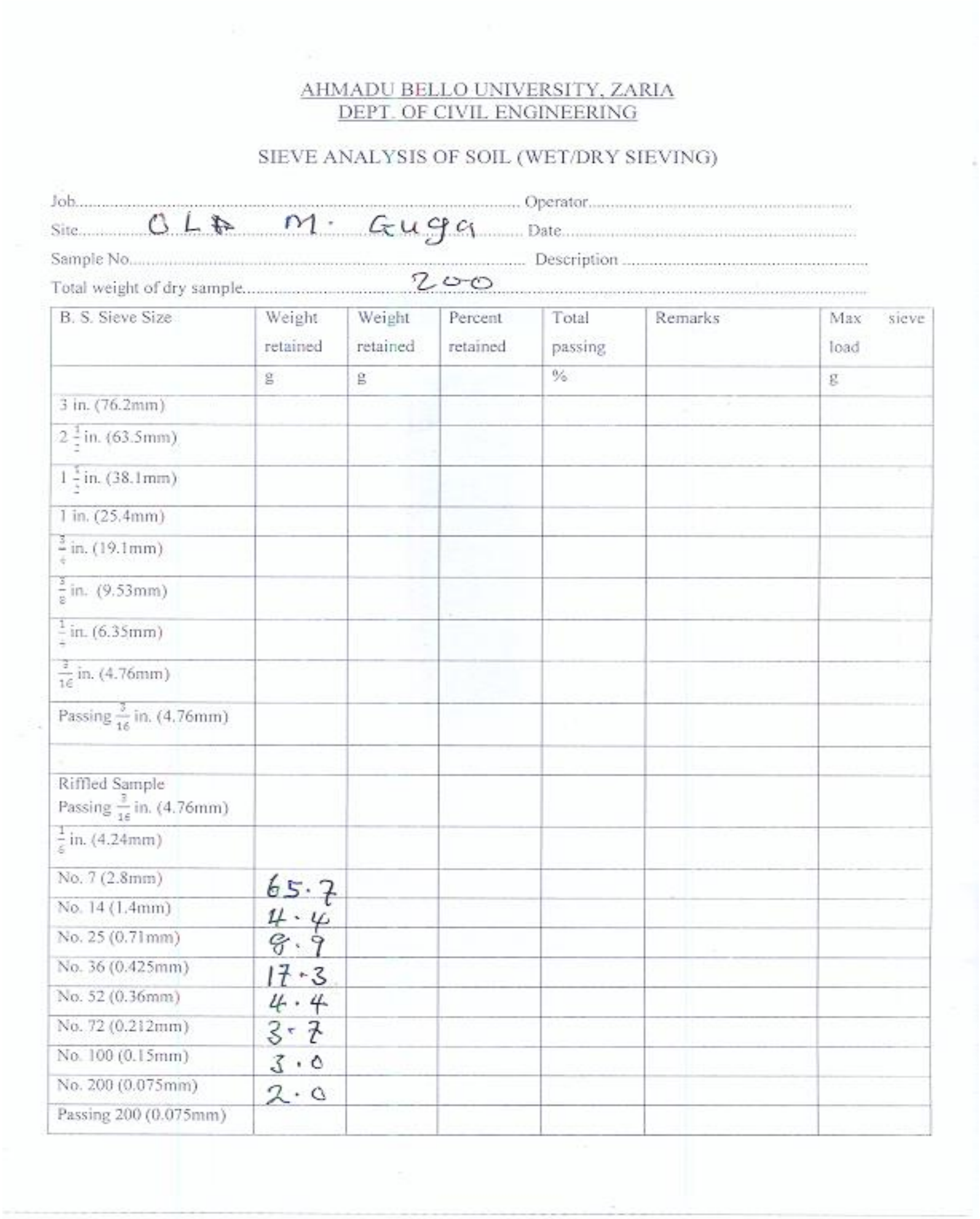
B. S. Sieve Size	Weight retained	Weight retained	Percent retained	Total passing	Remarks	Max sieve load
	g	g		%		g
3 in. (76.2mm)						
$2\frac{1}{2}$ in. (63.5mm)						
$1\frac{1}{2}$ in. (38.1mm)						
1 in. (25.4mm)						
$\frac{3}{4}$ in. (19.1mm)						
$\frac{3}{8}$ in. (9.53mm)						
$\frac{1}{4}$ in. (6.35mm)						
$\frac{3}{16}$ in. (4.76mm)						
Passing $\frac{3}{16}$ in. (4.76mm)						
Riffled Sample Passing $\frac{3}{16}$ in. (4.76mm)						
$\frac{1}{6}$ in. (4.24mm)						
No. 7 (2.8mm)	58.3					
No. 14 (1.4mm)	5.9					
No. 25 (0.71mm)	14.2					
No. 36 (0.425mm)	23.5					
No. 52 (0.36mm)	7.9					
No. 72 (0.212mm)	8.5					
No. 100 (0.15mm)	7.9					
No. 200 (0.075mm)	6.0					
Passing 200 (0.075mm)	0.6					

AHMADU BELLO UNIVERSITY, ZARIA
DEPT. OF CIVIL ENGINEERING

SIEVE ANALYSIS OF SOIL (WET/DRY SIEVING)

Job.......................... Operator..........................
Site O GR Hanwa Date..........................
Sample No.......................... Description ....
Total weight of dry sample 200

B. S. Sieve Size	Weight retained	Weight retained	Percent retained	Total passing	Remarks	Max sieve load
	g	g		%		g
3 in. (76.2mm)						
2 $\frac{1}{2}$ in. (63.5mm)						
1 $\frac{1}{2}$ in. (38.1mm)						
1 in. (25.4mm)						
$\frac{3}{4}$ in. (19.1mm)						
$\frac{3}{8}$ in. (9.53mm)						
$\frac{1}{4}$ in. (6.35mm)						
$\frac{3}{16}$ in. (4.76mm)						
Passing $\frac{3}{16}$ in. (4.76mm)						
Riffled Sample Passing $\frac{3}{16}$ in. (4.76mm)						
$\frac{1}{6}$ in. (4.24mm)						
No. 7 (2.8mm)	56.6					
No. 14 (1.4mm)	9.6					
No. 25 (0.71mm)	15.7					
No. 36 (0.425mm)	14.9					
No. 52 (0.36mm)	4.8					
No. 72 (0.212mm)	5.3					
No. 100 (0.15mm)	6.6					
No. 200 (0.075mm)	10.2					
Passing 200 (0.075mm)	1.4					

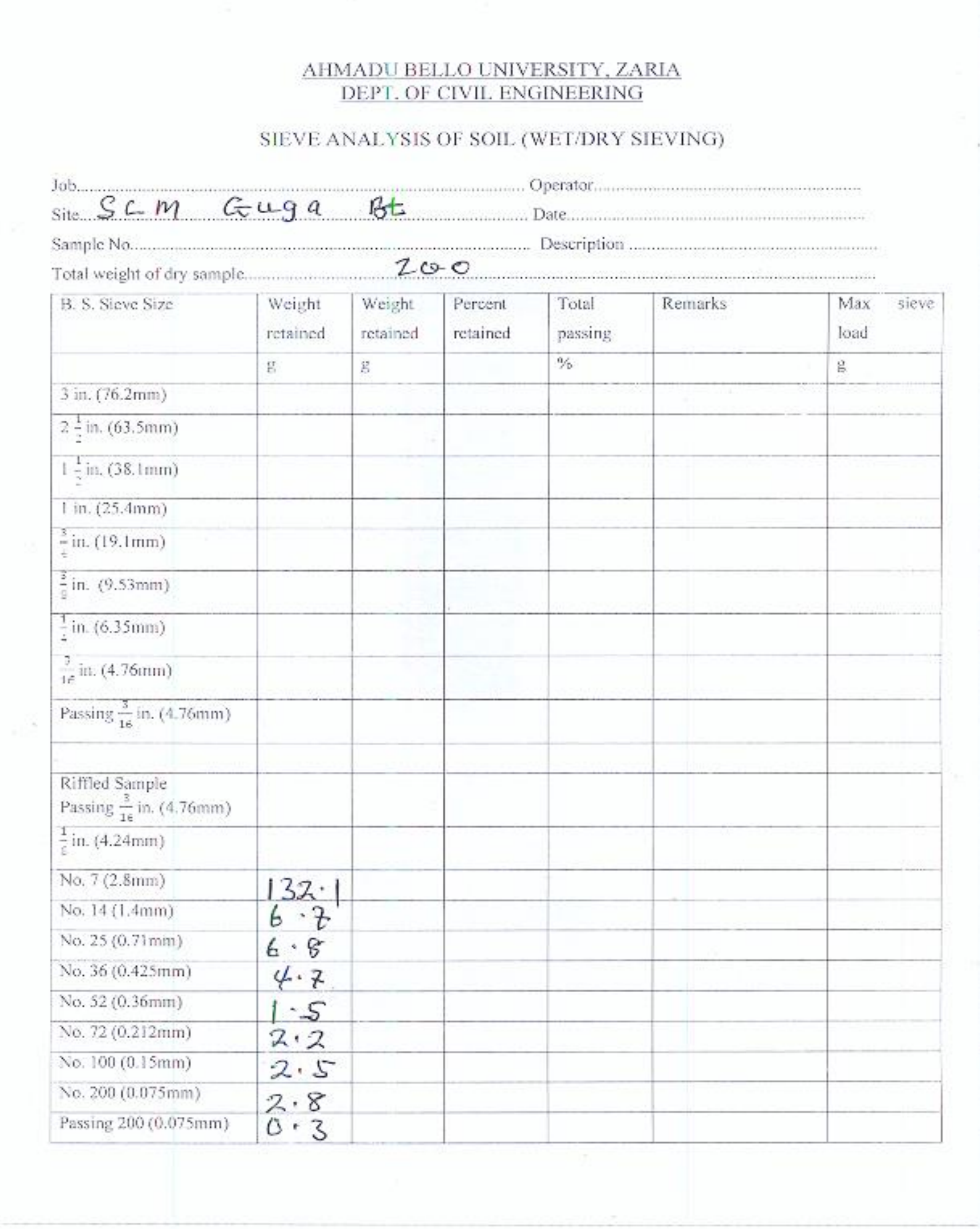


AHMADU BELLO UNIVERSITY, ZARIA
DEPT. OF CIVIL ENGINEERING

SIEVE ANALYSIS OF SOIL (WET/DRY SIEVING)

Job........................ Operator........................
Site........ OLA M. Guga .... Date........................
Sample No........................ Description........................
Total weight of dry sample........ 200 ....

B. S. Sieve Size	Weight retained	Weight retained	Percent retained	Total passing	Remarks	Max sieve load
	g	g		%		g
3 in. (76.2mm)						
$2\frac{1}{2}$ in. (63.5mm)						
$1\frac{1}{2}$ in. (38.1mm)						
1 in. (25.4mm)						
$\frac{3}{4}$ in. (19.1mm)						
$\frac{3}{8}$ in. (9.53mm)						
$\frac{1}{4}$ in. (6.35mm)						
$\frac{3}{16}$ in. (4.76mm)						
Passing $\frac{3}{16}$ in. (4.76mm)						
Riffled Sample Passing $\frac{3}{16}$ in. (4.76mm)						
$\frac{1}{6}$ in. (4.24mm)						
No. 7 (2.8mm)	65.7					
No. 14 (1.4mm)	4.4					
No. 25 (0.71mm)	8.9					
No. 36 (0.425mm)	17.3					
No. 52 (0.36mm)	4.4					
No. 72 (0.212mm)	3.7					
No. 100 (0.15mm)	3.0					
No. 200 (0.075mm)	2.0					
Passing 200 (0.075mm)						



AHMADU BELLO UNIVERSITY, ZARIA
DEPT. OF CIVIL ENGINEERING

SIEVE ANALYSIS OF SOIL (WET/DRY SIEVING)

Job.. Operator..
Site.... SCM Guga Bt .... Date..
Sample No.. Description ....
Total weight of dry sample............ 200 ....

B. S. Sieve Size	Weight retained	Weight retained	Percent retained	Total passing	Remarks	Max sieve load
	g	g		%		g
3 in. (76.2mm)						
$2\frac{1}{2}$ in. (63.5mm)						
$1\frac{1}{2}$ in. (38.1mm)						
1 in. (25.4mm)						
$\frac{3}{4}$ in. (19.1mm)						
$\frac{3}{8}$ in. (9.53mm)						
$\frac{1}{4}$ in. (6.35mm)						
$\frac{3}{16}$ in. (4.76mm)						
Passing $\frac{3}{16}$ in. (4.76mm)						
Riffled Sample Passing $\frac{3}{16}$ in. (4.76mm)						
$\frac{1}{6}$ in. (4.24mm)						
No. 7 (2.8mm)	132.1					
No. 14 (1.4mm)	6.7					
No. 25 (0.71mm)	6.8					
No. 36 (0.425mm)	4.7					
No. 52 (0.36mm)	1.5					
No. 72 (0.212mm)	2.2					
No. 100 (0.15mm)	2.5					
No. 200 (0.075mm)	2.8					
Passing 200 (0.075mm)	0.3					

CGLT – NO. 05

AHMADU BELLO UNIVERSITY, ZARIA
DEPT. OF CIVIL ENGINEERING

DETERMINATION OF THE MOISTURE/DENSITY RELATION OF SOIL USING STANDARD / HEAVY COMPACTION

Job........................ Sample No........................

Operator........................

Site.... BS4 JOS ....Depth........................

Date. 16/8/2012 ....

Amount retained on 20mm B.S. Sieve........................g. Total weight of sample ..3000.......................g.

B.S./C.B.R. Mould........................Delete the inappropriate word

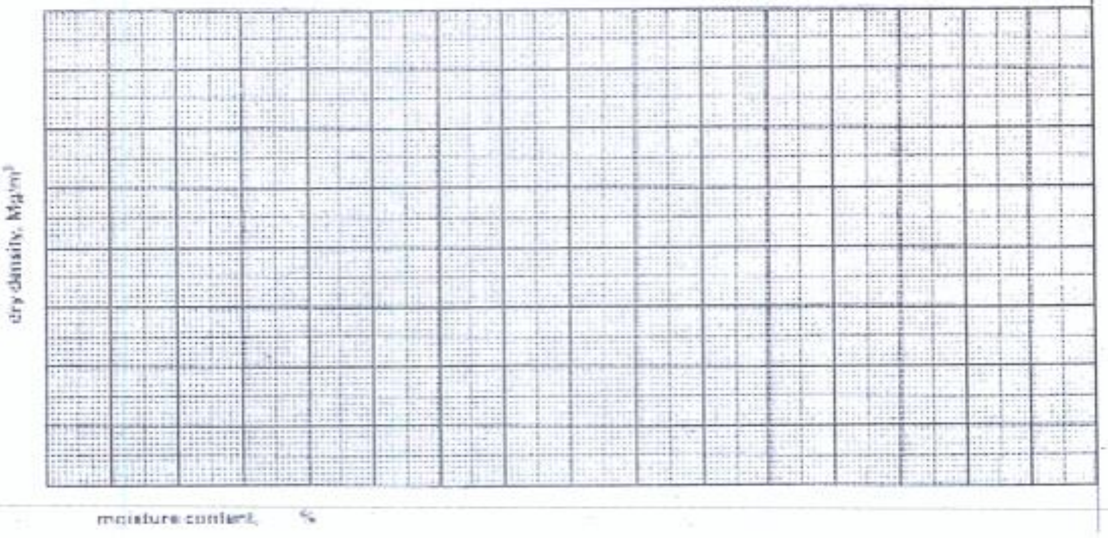
Wt. of mould and wet soil ....(W$_2$) g.	6180	6500	6540	6440	6390		
Wt. of mould ....(W$_1$) g.	4560	4560	4560	4560	4560		
Wt. of wet soil .... (W$_2$ – W$_1$) g.							
Bulk Density (ρ_b) ......Mg/m^3							

MOISTURE CONTENT DETERMINATION

Container No.	m63	A10	Q31	X13	65	Sm2	67	20	200	B		
Wt. of wet soil & cont.. g	48.0	46.8	46.9	48.5	63.3	67.7	74.9	79.8	79.7	83.0		
Wt. of dry soil and cont.. g	44.5	43.1	41.9	43.4	54.2	58.6	61.9	66.2	63.2	65.3		
Wt. of container. g	13.2	10.9	11.3	10.9	11.3	12.6	13.0	14.5	11.5	11.4		
Wt of dry soil .. g												
Wt. of moisture.. g												
Moisture content ... %												
Average moisture Content %												
Dry Density = $\rho_b \frac{100}{100+m}$ (Mg/m^3)												
C.B.R. (mean of top and bottom)												

Maximum dry density Mg/m^3

Optimum moisture content %



CGLT – NO. 05

AHMADU BELLO UNIVERSITY, ZARIA
DEPT. OF CIVIL ENGINEERING

DETERMINATION OF THE MOISTURE/DENSITY RELATION OF SOIL USING STANDARD / HEAVY COMPACTION

Job.. Sample No..................................

Operator...

Site.BSS3 JOS.........................Depth..

Date.18/8/2012.........................

Amount retained on 20mm B.S. Sieve.........................g. Total weight of sample ..3000.......................................g.

B.S./C.B.R. Mould..Delete the inappropriate word

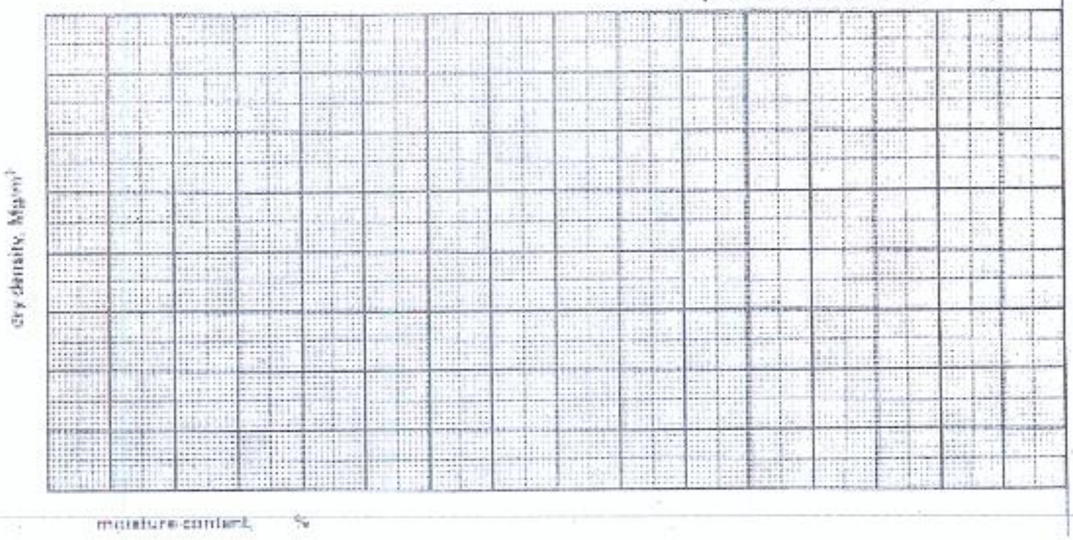
Wt. of mould and wet soil ....(W_2) g.	6180	6420	6580	6480	6390		
Wt. of mould ....(W_1) g.	4560	4560	4560	4560	4560		
Wt. of wet soil .... ($W_2 - W_1$) g.							
Bulk Density (ρ_b) ......Mg/m^3							

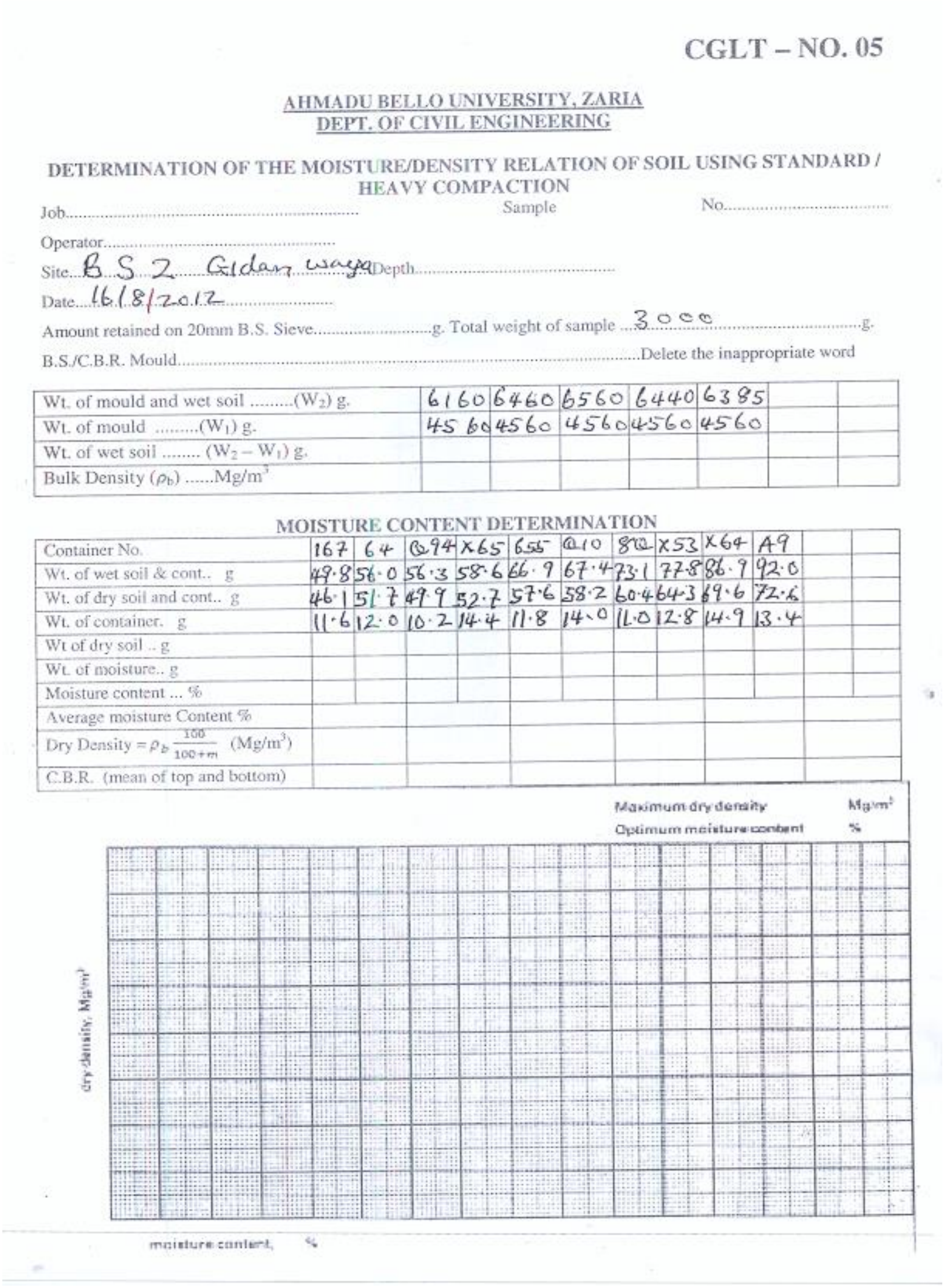
MOISTURE CONTENT DETERMINATION

Container No.	1Q	m63	611	X54	A9	X64	X53	655	64	Q94		
Wt. of wet soil & cont.. g	49.9	54.6	54.6	55.7	61.8	68.2	65.9	75.3	89.5	97.9		
Wt. of dry soil and cont.. g	46.8	51.0	49.4	50.5	54.0	59.6	55.5	63.3	71.8	76.6		
Wt. of container. g	11.5	13.1	10.4	13.0	13.4	14.8	12.8	11.7	12.0	10.3		
Wt of dry soil .. g												
Wt. of moisture.. g												
Moisture content ... %												
Average moisture Content %												
Dry Density = $\rho_b \frac{100}{100+m}$ (Mg/m^3)												
C.B.R. (mean of top and bottom)												

Maximum dry density Mg/m^3

Optimum moisture content %





CGLT – NO. 05

AHMADU BELLO UNIVERSITY, ZARIA
DEPT. OF CIVIL ENGINEERING

DETERMINATION OF THE MOISTURE/DENSITY RELATION OF SOIL USING STANDARD / HEAVY COMPACTION

Job........................ Sample No........................

Operator........................

Site B S 2 Gidan waya Depth........................

Date 16/8/2012

Amount retained on 20mm B.S. Sieve....................g. Total weight of sample 3000 g.

B.S./C.B.R. Mould....................Delete the inappropriate word

Wt. of mould and wet soil ....(W_2) g.	6160	6460	6560	6440	6385		
Wt. of mould ....(W_1) g.	45 60	4560	4560	4560	4560		
Wt. of wet soil .... ($W_2 - W_1$) g.							
Bulk Density (ρ_b) ......Mg/m³							

MOISTURE CONTENT DETERMINATION

Container No.	167	64	@94	X65	655	@10	8@	X53	X64	A9		
Wt. of wet soil & cont.. g	49.8	56.0	56.3	58.6	66.9	67.4	73.1	77.8	86.9	92.0		
Wt. of dry soil and cont.. g	46.1	51.7	49.9	52.7	57.6	58.2	60.4	64.3	69.6	72.6		
Wt. of container. g	11.6	12.0	10.2	14.4	11.8	14.0	11.0	12.8	14.9	13.4		
Wt of dry soil .. g												
Wt. of moisture.. g												
Moisture content ... %												
Average moisture Content %												
Dry Density = $\rho_b \frac{100}{100+m}$ (Mg/m³)												
C.B.R. (mean of top and bottom)												

Maximum dry density Mg/m³
Optimum moisture content %

CGLT – NO. 05

AHMADU BELLO UNIVERSITY, ZARIA
DEPT. OF CIVIL ENGINEERING

DETERMINATION OF THE MOISTURE/DENSITY RELATION OF SOIL USING STANDARD / HEAVY COMPACTION

Job.. Sample No..

Operator..

Site.... BS1 KWO1 ....Depth..

Date.. 16/8/2012 ....

Amount retained on 20mm B.S. Sieve..........................g. Total weight of sample .. 3000 ....g.

B.S./C.B.R. Mould..Delete the inappropriate word

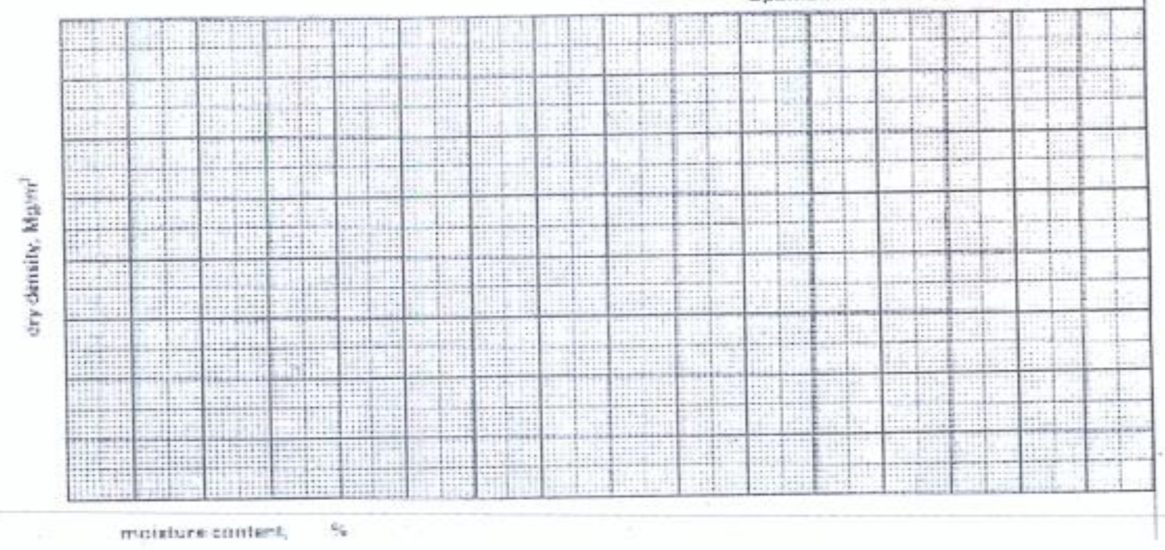
Wt. of mould and wet soil ....(W₂) g.	6080	6240	6480	6460	6380		
Wt. of mould ....(W₁) g.	4560	4560	4560	4560	4560		
Wt. of wet soil .... (W₂ – W₁) g.							
Bulk Density (ρ_b) ......Mg/m³							

MOISTURE CONTENT DETERMINATION

Container No.	611	X54	X68	X39	X6	N28	1Q	20	A50	63		
Wt. of wet soil & cont.. g	47·4	51·3	56·9	59·5	63·6	63·7	69·8	80·3	88·5	89·5		
Wt. of dry soil and cont.. g	44·7	48·8	51·7	54·3	55·9	56·1	58·8	67·4	70·2	72·6		
Wt. of container. g	10·5	13·0	10·4	14·4	11·2	14·3	11·5	14·4	10·8	12·1		
Wt of dry soil .. g												
Wt. of moisture.. g												
Moisture content ... %												
Average moisture Content %												
Dry Density = $\rho_b \frac{100}{100+m}$ (Mg/m³)												
C.B.R. (mean of top and bottom)												

Maximum dry density Mg/m³

Optimum moisture content %



CGLT – NO. 05

AHMADU BELLO UNIVERSITY, ZARIA
DEPT. OF CIVIL ENGINEERING

DETERMINATION OF THE MOISTURE/DENSITY RELATION OF SOIL USING STANDARD / HEAVY COMPACTION

Job.................................. Sample No..................................

Operator..................................

Site X L Bassawa Depth..................................

Date 18/8/2012

Amount retained on 20mm B.S. Sieve..................g. Total weight of sample 3000 g.

B.S./C.B.R. Mould..................................Delete the inappropriate word

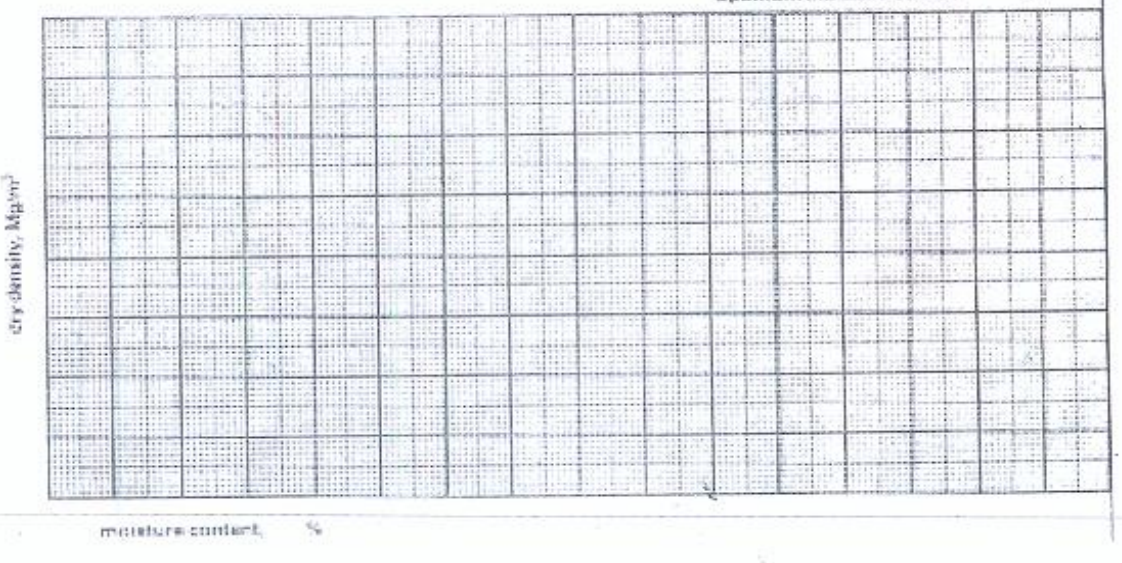
Wt. of mould and wet soil ....(W₂) g.	6320	6520	6640	6560	6480		
Wt. of mould ....(W₁) g.	4560	4560	4560	4560	4560		
Wt. of wet soil .... (W₂ – W₁) g.							
Bulk Density (ρ_b) ......Mg/m³							

MOISTURE CONTENT DETERMINATION

Container No.	63	N28	X6	X39	67	X68	X13	SM2	A10	Q31		
Wt. of wet soil & cont.. g	47.2	57.0	51.3	57.6	66.8	72.0	79.5	85.0	88.9	93.2		
Wt. of dry soil and cont.. g	45.1	55.8	47.2	53.6	59.9	63.2	67.1	72.5	71.7	75.9		
Wt. of container. g	12.1	14.2	11.1	14.3	12.9	10.4	109	12.6	10.9	11.4		
Wt of dry soil .. g												
Wt. of moisture.. g												
Moisture content ... %												
Average moisture Content %												
Dry Density = $\rho_b \frac{100}{100+m}$ (Mg/m³)												
C.B.R. (mean of top and bottom)												

Maximum dry density Mg/m³

Optimum moisture content %



CGLT – NO. 05

AHMADU BELLO UNIVERSITY, ZARIA
DEPT. OF CIVIL ENGINEERING

DETERMINATION OF THE MOISTURE/DENSITY RELATION OF SOIL USING STANDARD / HEAVY COMPACTION

Job.. Sample No..................................

Operator.......Biye.......

Site..OL1 M-Guga.........Depth..

Date...15/8/2012.........................

Amount retained on 20mm B.S. Sieve.........................g. Total weight of sample ....3000.............................g.

B.S./C.B.R. Mould...Delete the inappropriate word

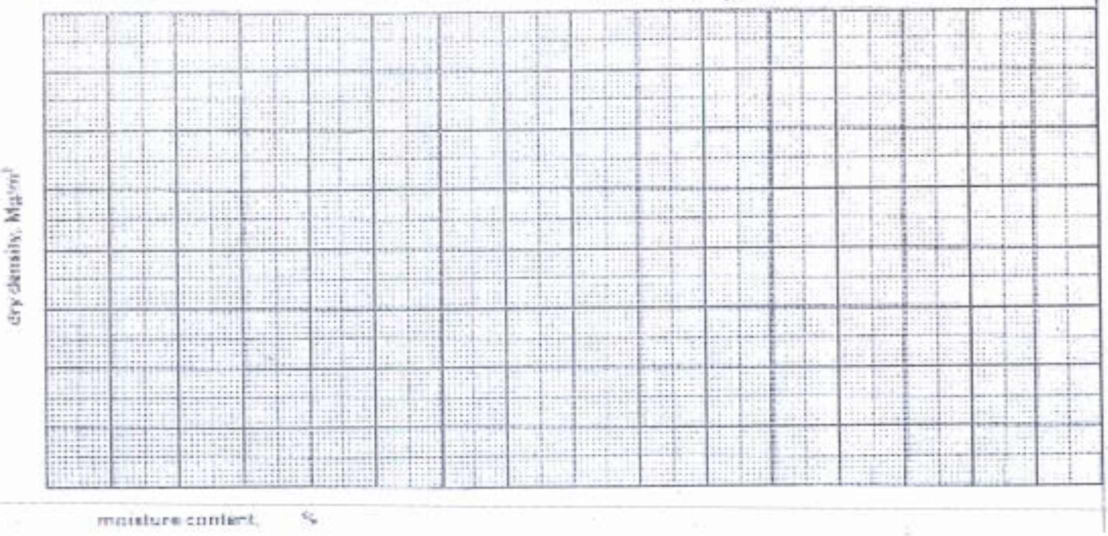
Wt. of mould and wet soil ....(W$_2$) g.	6160	6320	6580	6520	6490		
Wt. of mould ....(W$_1$) g.	6560	6560	6560	6560	6560		
Wt. of wet soil .... (W$_2$ – W$_1$) g.							
Bulk Density (ρ_b) ......Mg/m^3							

MOISTURE CONTENT DETERMINATION

Container No.	611	X54	X68	X39	X6	N28	20	10	63	A50		
Wt. of wet soil & cont.. g	42.4	46.8	42.7	58.7	61.4	65.0	72.0	82.9	78.0	98.3		
Wt. of dry soil and cont.. g	40.6	44.9	48.8	54.4	54.6	57.9	61.9	69.2	63.6	80.5		
Wt. of container. g	10.5	13.0	10.4	14.3	11.1	14.2	14.6	11.5	12.1	10.8		
Wt of dry soil .. g												
Wt. of moisture.. g												
Moisture content ... %												
Average moisture Content %												
Dry Density = $\rho_b \frac{100}{100+m}$ (Mg/m^3)												
C.B.R. (mean of top and bottom)												

Maximum dry density Mg/m^3

Optimum moisture content %



CGLT – NO. 05

AHMADU BELLO UNIVERSITY, ZARIA
DEPT. OF CIVIL ENGINEERING

DETERMINATION OF THE MOISTURE/DENSITY RELATION OF SOIL USING STANDARD / HEAVY COMPACTION

Job.. Sample No.....................................

Operator...

Site. Scm Guga Bt ....Depth...

Date. 15/8/2012 ....

Amount retained on 20mm B.S. Sieve...........................g. Total weight of sample 3000 ....g.

B.S./C.B.R. Mould...Delete the inappropriate word

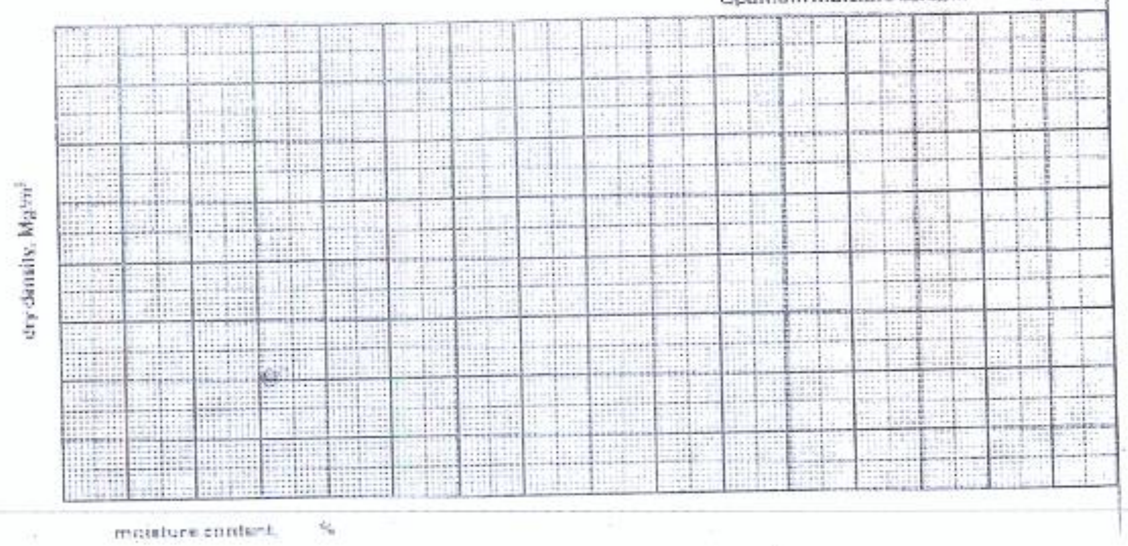
Wt. of mould and wet soil ....(W$_2$) g.	6360	6720	6760	6660	6580		
Wt. of mould ....(W$_1$) g.	4560	4560	4560	4560	4560		
Wt. of wet soil .... (W$_2$ – W$_1$) g.							
Bulk Density (ρ_b) ......Mg/m^3							

MOISTURE CONTENT DETERMINATION

Container No.	XL3	Q31	65	SM2	67	20	B	200	64	167		
Wt. of wet soil & cont.. g	41·4	46·2	57·0	63·6	73·5	81·6	90·3	92·9	97·4	99·2		
Wt. of dry soil and cont.. g	39·2	44·1	52·0	58·0	64·9	72·2	75·9	78·4	80·3	82·2		
Wt. of container. g	10·9	11·4	11·3	12·6	12·9	14·4	11·6	11·4	12·0	11·2		
Wt of dry soil .. g												
Wt. of moisture.. g												
Moisture content ... %												
Average moisture Content %												
Dry Density = $\rho_b \frac{100}{100+m}$ (Mg/m^3)												
C.B.R. (mean of top and bottom)												

Maximum dry density Mg/m^3

Optimum moisture content %



CGLT NO. 04 2

AHMADU BELLO UNIVERSITY, ZARIA
DEPT. OF CIVIL ENGINEERING

LIQUID AND PLASTIC LIMIT CHART

Site BS4 JOS Job

Sample No. Depth Date

Liquid Limit (L.L) Plastic Limit (P.L)

P.I

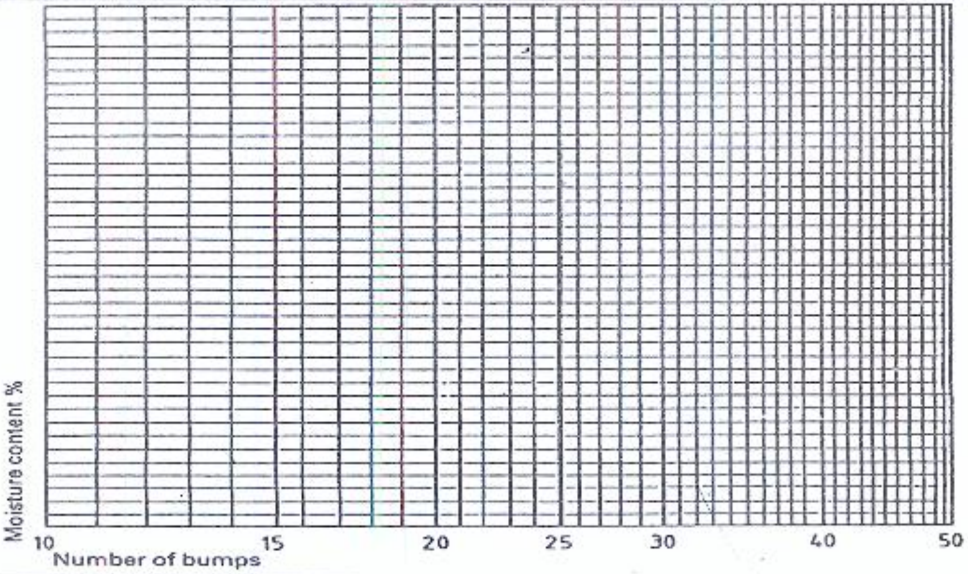
Linear Shrinkage (L.S) Operator

Description of Soil

PLASTIC AND LIQUID LIMITS

Type of Test	LL	LL	LL	LL	LL
No of blows	48	37	28	18	12
Container No.	20	65	20Y	X68	X13
Wt. of wet soil & cont.. g	27.6	29.6	39.8	41.1	48.1
Wt. of dry soil and cont.. g	23.7	24.2	32.3	31.3	35.6
Wt. of container. g	14.6	11.4	14.5	10.4	10.9
Wt of dry soil (Wd).. g					
Wt. of moisture (Ww).. g					
Moisture content ... g					
Type of Test	PL	PL	PL		
No of blows					
Container No.	8Q	Q33	Q00		
Wt. of wet soil & cont.. g	12.5	16.4	15.9		
Wt. of dry soil and cont.. g	12.2	16.0	15.5		
Wt. of container. g	10.9	14.7	14.0		
Wt of dry soil (Wd).. g					
Wt. of moisture (Ww).. g					
Moisture content ... g					

14
11



CGLT NO. 04

4

AHMADU BELLO UNIVERSITY, ZARIA
DEPT. OF CIVIL ENGINEERING

LIQUID AND PLASTIC LIMIT CHART

Site BS3 JOS .... Job........................

Sample No........................ Depth........................ Date........................

Liquid Limit (L.L)........................ Plastic Limit (P.L) .... P.I........................

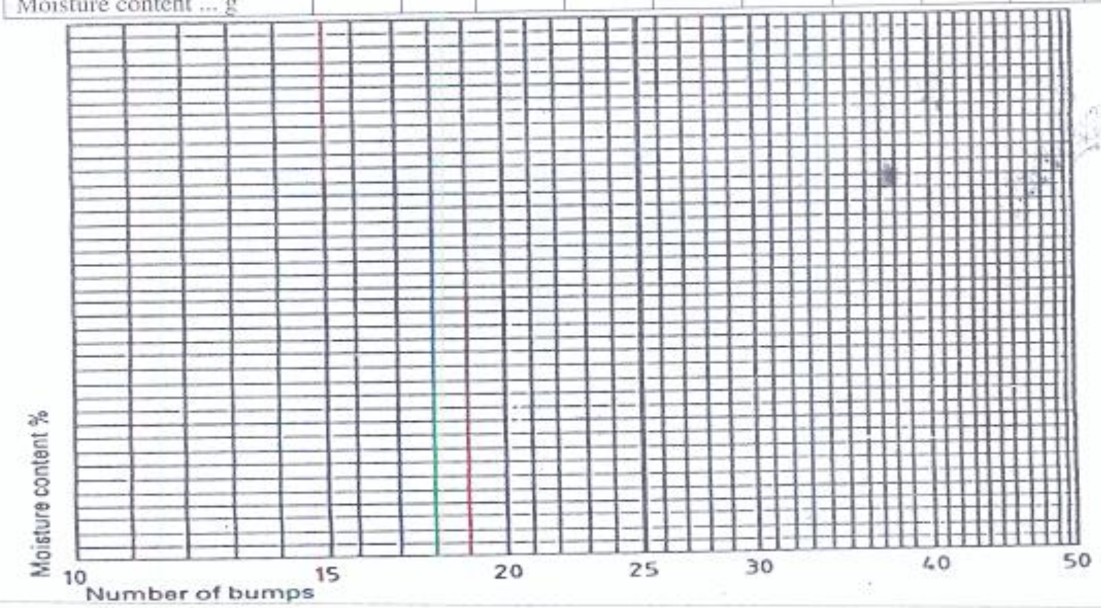
Linear Shrinkage (L.S)........................ Operator........................

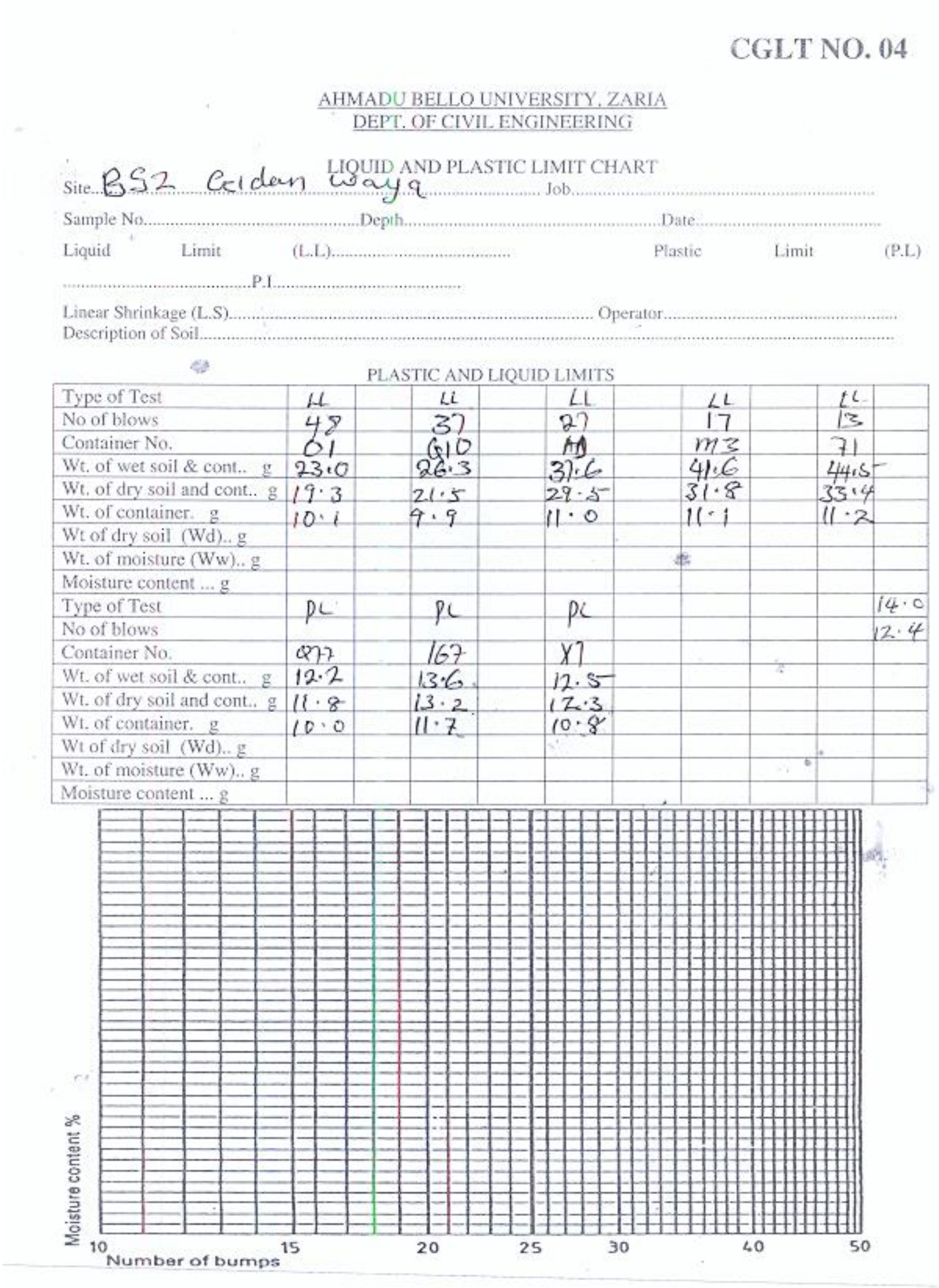
Description of Soil........................

PLASTIC AND LIQUID LIMITS

Type of Test	LL		LL		LL		LL		LL	
No of blows	47		38		28		19		14	
Container No.	X46		7Q		Q27		X48		SM2	
Wt. of wet soil & cont.. g	25.2		31.3		38.1		41.1		49.1	
Wt. of dry soil and cont.. g	20.7		25.8		30.1		31.4		37.3	
Wt. of container. g	10.1		12.7		11.7		10.2		12.6	
Wt of dry soil (Wd).. g										
Wt. of moisture (Ww).. g										
Moisture content ... g										
Type of Test	PL		PL		PL					
No of blows										
Container No.	1Q		Q31		A10					
Wt. of wet soil & cont.. g	12.7		13.6		12.4					
Wt. of dry soil and cont.. g	12.5		13.0		12.1					
Wt. of container. g	11.5		11.5		10.9					
Wt of dry soil (Wd).. g										
Wt. of moisture (Ww).. g										
Moisture content ... g										

M.
11





CGLT NO. 04

AHMADU BELLO UNIVERSITY, ZARIA
DEPT. OF CIVIL ENGINEERING

LIQUID AND PLASTIC LIMIT CHART

Site BS2 Gidan Waya Job

Sample No. Depth Date

Liquid Limit (L.L) Plastic Limit (P.L)

P.I

Linear Shrinkage (L.S) Operator
Description of Soil

PLASTIC AND LIQUID LIMITS

Type of Test	LL		LL		LL		LL		LL	
No of blows	48		37		27		17		13	
Container No.	01		G10		A1		M3		71	
Wt. of wet soil & cont.. g	23.0		26.3		37.6		41.6		44.5	
Wt. of dry soil and cont.. g	19.3		21.5		29.5		31.8		33.4	
Wt. of container. g	10.1		9.9		11.0		11.1		11.2	
Wt of dry soil (Wd).. g										
Wt. of moisture (Ww).. g										
Moisture content ... g										
Type of Test	PL		PL		PL					14.0
No of blows										12.4
Container No.	Q77		167		X7					
Wt. of wet soil & cont.. g	12.2		13.6		12.5					
Wt. of dry soil and cont.. g	11.8		13.2		12.3					
Wt. of container. g	10.0		11.7		10.8					
Wt of dry soil (Wd).. g										
Wt. of moisture (Ww).. g										
Moisture content ... g										

CGLT NO. 04 7

AHMADU BELLO UNIVERSITY, ZARIA
DEPT. OF CIVIL ENGINEERING

LIQUID AND PLASTIC LIMIT CHART

Site BS1 Kw01 Job

Sample No. Depth Date

Liquid Limit (L.L) Plastic Limit (P.L)

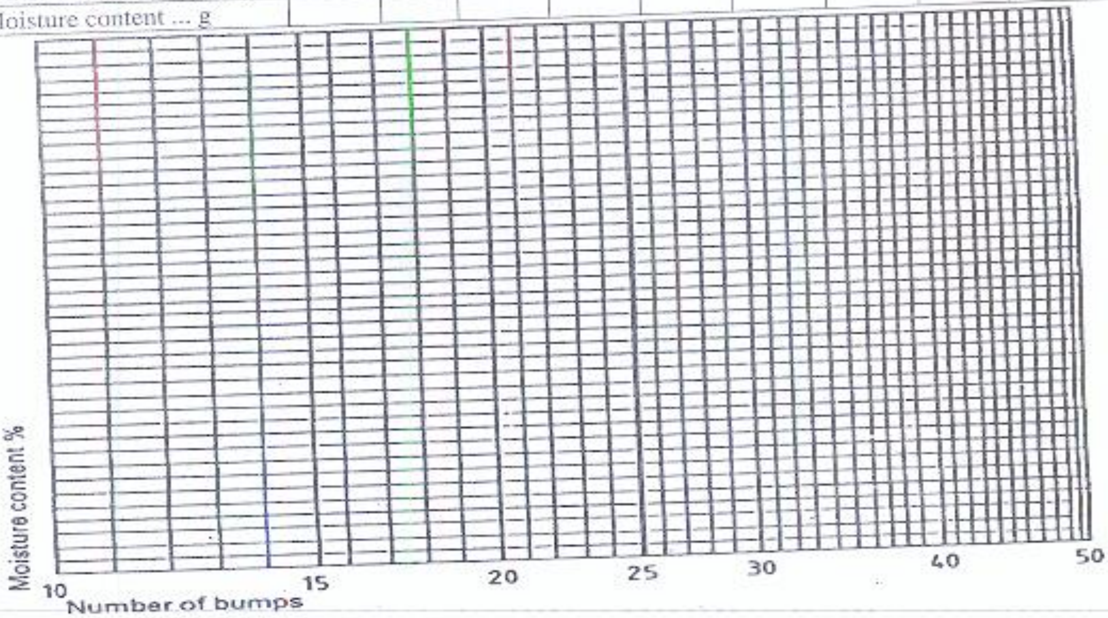
P.I.

Linear Shrinkage (L.S) Operator

Description of Soil

PLASTIC AND LIQUID LIMITS

Type of Test	LL		LL		LL		LL		LL	
No of blows	48		38		28		17		12	
Container No.	F44		Q110		44		299		189	
Wt. of wet soil & cont.. g	23·2		31·1		38·5		43·0		50·5	
Wt. of dry soil and cont.. g	29·6		26·3		29·5		32·4		36·8	
Wt. of container. g	10·9		15·0		10·8		11·4		11·2	
Wt of dry soil (Wd).. g										
Wt. of moisture (Ww).. g										
Moisture content ... g										14·0
Type of Test	PL		PL		PL					12·3
No of blows										
Container No.	M63		S2		P25					
Wt. of wet soil & cont.. g	13·2		12·8		13·2					
Wt. of dry soil and cont.. g	12·8		12·7		12·9					
Wt. of container. g	11·2		11·1		11·1					
Wt of dry soil (Wd).. g										
Wt. of moisture (Ww).. g										
Moisture content ... g										



CGLT NO. 04

AHMADU BELLO UNIVERSITY, ZARIA
DEPT. OF CIVIL ENGINEERING

LIQUID AND PLASTIC LIMIT CHART

Site YL Bassawa .... Job............

Sample No............ Depth............ Date............

Liquid Limit (L.L)............ Plastic Limit (P.L)

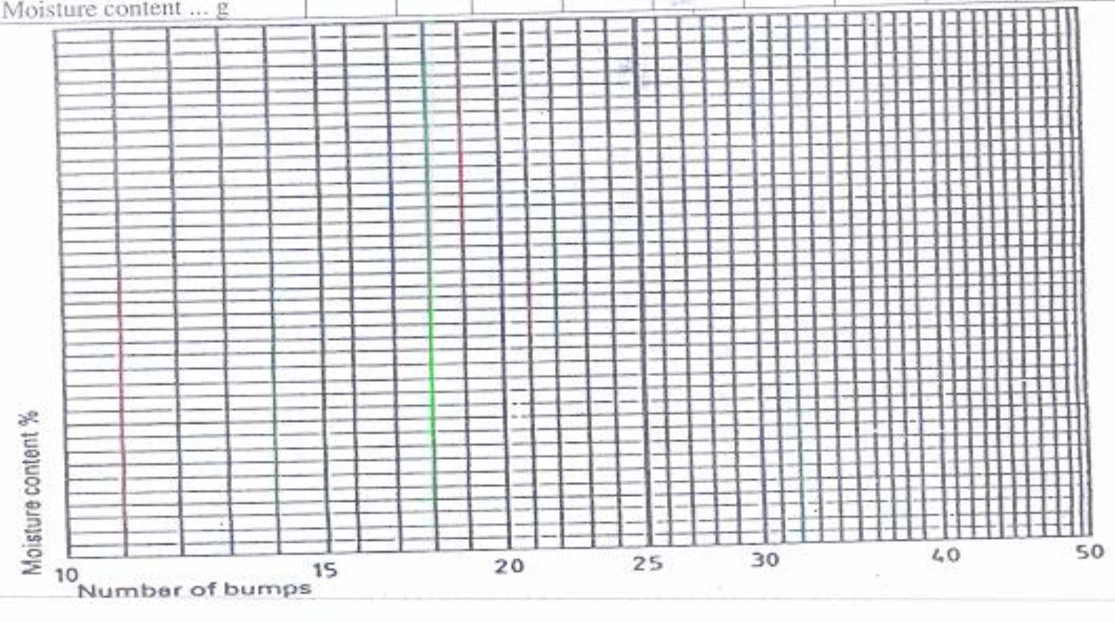
............P.I............

Linear Shrinkage (L.S)............ Operator............

Description of Soil............

PLASTIC AND LIQUID LIMITS

Type of Test	LL		LL		LL		LL		LL	
No of blows	48		37		28		18		14	
Container No.	200		X6s-		N28		63		B	
Wt. of wet soil & cont.. g	23·9		29·6		32·5		37·4		45·2	
Wt. of dry soil and cont.. g	20·2		25·2		27·1		29·8		34·0	
Wt. of container. g	11·4		14·4		14·3		12·1		11·6	
Wt of dry soil (Wd).. g										
Wt. of moisture (Ww).. g										
Moisture content ... g										
Type of Test	PL		PL		PL					
No of blows										
Container No.	67		X39		X6					
Wt. of wet soil & cont.. g	14·8		16·3		13·6					
Wt. of dry soil and cont.. g	14·5		16·0		13·1					
Wt. of container. g	12·9		14·3		11·1					
Wt of dry soil (Wd).. g										
Wt. of moisture (Ww).. g										
Moisture content ... g										



CGLT NO. 04

AHMADU BELLO UNIVERSITY, ZARIA
DEPT. OF CIVIL ENGINEERING

5

LIQUID AND PLASTIC LIMIT CHART

Site: O G R Hanwa Job:

Sample No: Depth: Date:

Liquid Limit (L.L): Plastic Limit (P.L)

P.I:

Linear Shrinkage (L.S): Operator:

Description of Soil:

PLASTIC AND LIQUID LIMITS

Type of Test	LL		LL		LL		LL		LL	
No of blows	47		38		27		18		13	
Container No.	A9		X54		611		m63		X64	
Wt. of wet soil & cont.. g	30·9		34·4		38·5		40·8		54·3	
Wt. of dry soil and cont.. g	27·7		30·2		33·0		35·1		45·2	
Wt. of container. g	13·4		13·0		10·5		13·1		14·9	
Wt of dry soil (Wd).. g										
Wt. of moisture (Ww).. g										
Moisture content ... g										
Type of Test	PL		PL		PL					
No of blows										
Container No.	X53		655		64					
Wt. of wet soil & cont.. g	15·9		14·6		14·6					
Wt. of dry soil and cont.. g	15·2		14·3		14·3					
Wt. of container. g	12·9		11·3		12·0					
Wt of dry soil (Wd).. g										
Wt. of moisture (Ww).. g										
Moisture content ... g										

14
12