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Some Physical and Chemical Properties of Shambat Farm Soil

بعض خواص تربة شمبات الفيزيائية والكيميائية

A Thesis Submitted to the Sudan University of Sciences and Technology in partial Fulfillment of the Requirements of the Degree of master of science

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March 2015

DEDICATION

To my father

To my mother

To my brothers

To my sisters and my friends

ACKNOWLEDGMENT

I would like to thank God in the before and after. Words cannot express my special appreciation and deepest gratitude to my supervisor Dr. Abdlkarim Elobid Fadl for his continuous encouragement and support.

I am also indebted to my professors at the soil laboratory, all my friends and, colleagues at the Soil and Water Sciences Department at SUST.

Thanks to the College of Agricultural Studies, Sudan University of Science and Technology for offering the facilities to conduct this research.

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ABSTRACT

This study was conducted in the farm of the Faculty of Agricultural Studies , Sudan University for Science and Technology , The soil of the farm belong to the Central Clay Plain of the Sudan that has been formed by alluvial deposit of the Nile, primarily of basaltic origin ,which are largely Vertisols .The some physical and chemical properties at five sites across the farm have been investigated during this study . The objectives of this work were the following: 1 to show similarities or differences of the sampled sites in order to provide more information on variability of the farm soil, 2 to further investigate these soil as a step toward their improvement and management, 3 to study the possibility of transferring technology and research findings from one site to another .

The results of work indicated that the soils are variably affected by salinity and sodicity. Non-saline, slightly saline and moderately saline sub soil , and non sodic to moderately sodic soil are all found in the farm. Soil texture is clayey throughout, and hydraulic conductivity is very slow to slow .The whole soil profile is compacted except at the surface layer, the average bulk density is very high when the soil is dry.

These soils are characterized by high water retention but rather narrow range of available moisture as evidenced from the difference between the moisture retained between field capacity and wilting point .

الخلاصة

اجريت هذه الدراسة لمزرعة كلية الدراسات الزراعيه جامعة السودان للعلوم والتكنولوجيا ،تربة المزرعه تنتمى للسهول الطينية الوسطى فى السودان و قد تم تشكيل هذه الترسيبات الطميئيه من النيل وذلك من التجوية الاولية للصخور البازلتية .تعتبر الى حد كبير تربه طينيه.

من خلال هذه الدراسة تم التحقق من بعض الخواص الفيزيائيه والكيمياء لخمسه مواقع عبر المزرعة؛ و كان الهدف الاساسى من هذا العمل ما يلى:

1 اظهار اوجه الشبه و الاختلاف فى مواقع العينه من اجل توفير المزيد من المعلومات حول التباين فى تربة المزرعة،2 مزيد من التحقق فى هذه التربه كخطوه نحو تحسينها وإدارتها ،3 لدراسة امكانية نقل التقانات ونتائج البحوث الزراعيه من موقع الى اخر.

وقد اشارت نتائج هذا العمل ان التربه متغيره تتأثر بالملوحة والصودية.غير مالحة ،قليلة الملوحة، متوسطه الملوحة فى التربه تحت السطحيه، غير صودية الى تربه متوسطة الصودية، قد وجدت كلها فى المزرعة . قوام التربه طينيه فى جميع انحائها، والتوصيل الهيدروليكى بطئ الى بطئ جدا. كل آفاق التربه بها انضغاط ما عدا سطح التربة، متوسط الكثافة الظاهريه للتربة عاليه جدا وهى جافه.

تتميز التربه بالاحتفاظ العالى للماء و لكن فى نطاق ضيق من الرطوبة المتاحة كما يتضح من الاختلاف بين الماء الممسوك بين السعه الحقليه و الزبول الدائم .

CHAPTER ONE

1-INTRODUCTION

Soil is a very complex system . It is made up of solid ,liquid and gaseous material . The solid phase may be mineral or organic . The mineral portion consist of particles of varying size ,shape and chemical composition .The organic fraction includes residues in different stages of decomposition .The liquid phase in the soil water which fill part or all of pores between the solid particles .The gaseous phase occupies part of the pore space. The composition and proportion of these components greatly influence soil physical properties, including texture, structure, and porosity, the fraction of pore space in a soil. In turn these properties affect air and water movement in the soil and thus the soil's ability to function; Other important physical properties of soils are color, drainage, depth, and surface features . The physical properties and chemical composition largely determine the suitability of a soil for its planned use and the management requirements to keep it most productive. (Brady and Weil, 2002) .

Soil physical, chemical and biological properties affect many processes in the soil that make it suitable for agriculture practices and other purposes . Texture ,structure ,and porosity influence the movement and retention of water ,air and solutes in the soil , which subsequently affect plant growth . Most soil chemical properties are associated with the colloid fraction and affect nutrient availability, and, in some cases, soil physical properties.

The primary physical processes associated with high sodium concentration are soil dispersion and aggregate swelling.

When sodium –induced soil dispersion causes loss of soil structure , the hydraulic conductivity is also reduced. The deterioration of the physical properties of the soil such as permeability and structure are affected by both soluble salt and exchangeable sodium. While sodicity reduces the physical properties its harmful effect is mitigated by the flocculating action of increased salt level.

The objective of this study is to indicate similarities or differences in soil chemical, physical and mechanical properties at five sites occurring within the farm of Faculty of Agriculture Studies (SUST) .

The study is expected to high light the effect of soil on the finding of field experiment conducted by version researchers within the farm.

CHAPTER TWO

2-LITERATURE REVIEW

STUDY AREA

2.1. Environment of the Study Area

2.1.1. Location and Extent

The soils used to for the study lie within Shambat research farm (LAT: 15º 40'N LONG: 32º 32'E and ALT.: 380 M),and are situated on the eastern bank of the main Nile, immediately below the junction of the Blue and White Niles. An aerial Photograph of the area is attached ; appendix 4.

2.1.2 Geology:

The solid geology of the area is composed of ancient formation of cretaceous age outcropping on the western bank of the Nile ,with an original Litho logically formation ,which is given the name of Nubian series .

From a structural point of view , the area is considered to be a gently.There might be some local variations. The Nubian series component of sandstones, mudstone and ferruginous sandstone are interbedded .However the beds, are not uniform, and they are discontinuous, usually fading into each other in an interdigitating manner.

The solid geology of this area is covered by recent deposits composed of Nile silts and sands .The silts are formed as a relatively thick continuous formation ,consequently giving a wide flood plain .The expanses of superficial deposits occurring on an elevated position to the east of this area and a bit far from the river ,has been classified as Gezira clay . Although there is a considerable variation ,the usual sequence is clay to a depth of five meters ,over silt ,over sands which are often micaceous; reaching in some cases the

Nubian series at depths of five meters .More sandy sequences are common near the river .(Saeed ,1968).

2.1.3 Topography:

From a topographical point of view, most of the area under study is flat. The land is being made more flat by the practice of leveling, before sowing of seeds, usually carried out in these fields. Variations in level were found to be very small .A depression that could hardly be noticed is occurring towards the center of the Demonstration farm ..(Saeed ,1968).

2.1.4 Climate:

The climate data was taken from Shambat Meteorological Observatory station (Tables 2.1and2.2) which is the nearest to the location of the site. Potential evapotranspiration figures are generated by programme of FAO (Adam, 2005). The classification of climate by Papadakis which is based on water balance, using monthly rainfall and potential evapotranspiration is adopted by (Kevie ,1976) for classifying climatic zones of Sudan. The area of Shambat in Papadkis classification falls in the semi-desert climate with summer rains, and warm winter. The climate is hot almost throughout the year, except the cooler short winter season (December, January). The main daily temperature is29.3°C. Average maximum temperature reaches 47.3 °C in May while the minimum temperature is 5.5 °C in February (Table2.1).The mean relative humidity is 28% and show some variation ranges from 16% in April to 45% in August. The average annual rainfall is about 147.5 mms, with most of the rain falling in June –October. The amount is quite variable and distribution is rather erratic and irregular (Table 2.2).The combined effect of high temperature and strong solar radiation caused the potential evapotranspiration to be very high and significantly exceeds the rainfall in all months (Fig. 2.1).

This means that the soil water available for plant growth is deficient and crop production must be based on irrigated farming system. The average wind speeds is about 11m/s and increases a maximum in the hot dry summer (April-May) causing dust storms (Haboob) and erosion hazards. During the period October - May winds move to south westerly direction due to the approach of inter-tropical convergence zone causing slight and variable rainfall. As a control measure, wind breaks and shelter belts are prerequisites to protect the rangelands, agricultural lands and crops.

Table: 2.1. The Climate Data from Shambat Meteorological Observatory Station

SUDAN METEOROLOGICAL AUTHORITY										
CLIMATOLOGICAL NORMALS 1981—2010										
STATION: SHAMBAT			LAT: 15º 40'N		LONG: 32º 32'E			ALT.: 380 M		
ELEM.	STAT.	AIR TEMPERATURE						MEAN DRY	BRIGHT	
	LEVEL							TEMPERTURE	SUNSHINE	
	PRESS							(MAX+MIN)/2	DURATION	
		DAILY MAXIMUM			DAILY MINIMUM			IN °C		
MONTH	HPA	MEAN	HST	DATE	MEAN	LST	DATE	IN °C	HRS	%
JAN.	968.7	30.3	41.5	26/01/2006	14.1	7.0	SEV.	22.2	9.9	88
FEB.	968.0	32.3	41.9	24/02/2005	15.2	5.5	07/02/1993	23.7	9.9	86
MAR.	966.2	36.3	44.4	30/1992,22/2003	18.2	10.0	02/03/2009	27.3	9.8	82
APR.	964.6	40.2	46.5	06/04/2003	21.6	11.0	01/04/1989	30.9	10.1	83
MAY	963.8	41.7	47.3	17/05/1991	25.5	14.6	13/05/1982	33.6	9.4	73
JUN.	964.0	41.4	46.3	20/06/1999	26.8	18.5	25/06/1984	34.1	8.6	67
JUL.	963.9	39.0	45.0	05/07/1996	26.3	20.0	23/07/2002	32.6	7.8	60
AUG.	964.0	37.6	44.0	07/08/1990	25.7	17.5	23/8/2002	31.7	8.0	62
SEP.	963.9	39.0	44.5	26/09/1996	25.9	19.0	23/09/2002	32.4	8.3	69
OCT.	965.0	39.3	43.1	01/10/1997	24.5	15.8	28/10/2000	31.9	9.5	82
NOV.	966.9	35.2	40.3	10/11/1997	20.2	11.0	11-12/11/1982	27.7	10.1	89
DEC.	968.0	31.6	40.6	07/12/1990	15.9	6.0	26/12/2002	23.7	9.9	89
YEAR	965.6	37.0	47.3	17/05/1991	21.7	5.5	07/02/1993	29.3	9.3	77

Source: Shambat Meteorological Observatory station, (2010).

Table: 2.2. The Climate Data from Shambat Meteorological Observatory Station

SUDAN METEOROLOGICAL AUTHORITY							
CLIMATOLOGICAL NORMALS 1981—2010							
STATION: SHAMBAT			LAT: 15º 40'N		LONG: 32º 32'E		
ELEM.	RELATIVE	RAINFALL IN MMS					
	HUMIDITY	TOTAL	NO. OF RAINY DAYS			MAXIMUM RAINFALL	
	R.H %	IN MMS	WHEN DAILY RAINFALL >=			IN ONE DAY	
MONTH	MEAN		0.1 MM	1.0 MM	10.0 MMS	TOTAL	DATE
JAN.	29	0.0	0.0	0.0	0.0	0.0	———
FEB.	23	0.0	0.0	0.0	0.0	0.0	———
MAR.	18	0.0	0.1	0.0	0.0	0.3	02/03/1982
APR.	16	0.2	0.1	0.1	0.0	4.8	21/04/2008
MAY	21	4.5	0.8	0.5	0.1	35.3	03/05/2006
JUN.	26	2.8	0.9	0.6	0.1	17.1	10/06/2008
JUL.	39	21.3	3.2	2.6	0.7	78.0	30/07/1988
AUG.	45	42.1	4.1	3.5	1.3	147.5	04/08/1988
SEP.	39	22.8	3.0	2.1	0.6	38.9	12/09/1988
OCT.	30	6.5	1.1	0.9	0.1	31.0	07/10/1997
NOV.	27	1.2	0.0	0.0	0.0	0.0	———
DEC.	31	0.3	0.0	0.0	0.0	0.0	———
YEAR	28	101.7	13.3	10.3	2.9	147.5	04/08/1988

Source: Shambat Meteorological Observatory station, (2010).

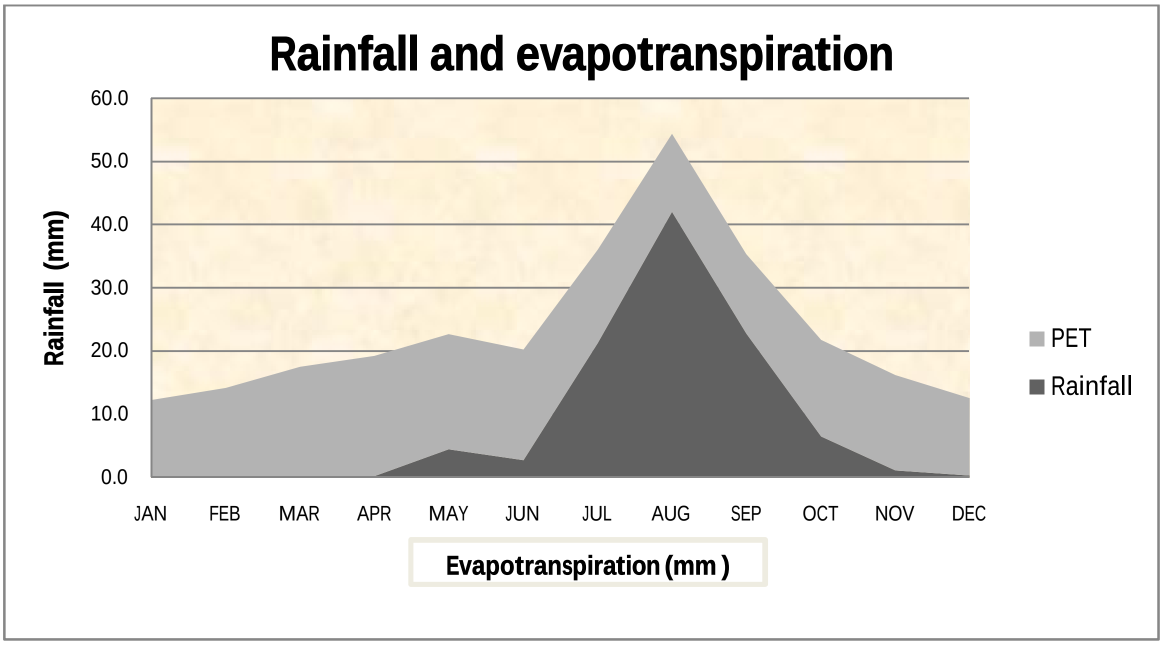


Figure 1: Rainfall and evapotranspiration

2.2: Soil physical properties :

The physical properties of soil are the result of soil parent materials being acted up on by climatic factors ,and being affected by relief (slope vegetation and direction or aspect). A change in any one of these soil forming factors usually results in a difference in the physical properties of the resulting soil .

The important physical properties of the soil are:

- **Texture**
- **Structure**
- **Moisture**
- **Aeration**
- **Consistency (Dynamic properties L.L ,P.L ,P.I).**

2.2.1Texture:

The relative amounts of the different soil size (< 2 mm)particles ,or the fineness or coarseness of mineral particles in the soil , is referred to as soil texture .Mineral grains which are (> 2 mm) in diameter are called stone and gravel are measured separately . Soil texture is determined by the relative amounts of sand , silt and clay in the fine earth (< 2 mm) fraction .

Sand particles vary in size from very fine (0.05) to very coarse (2.0mm) in average diameter according to U.S. system. Sands feel coarse and gritty when rubbed between the thumb and fingers , except for mica flakes which tend to smear when rubbed . Silt particles range in size from (0.05mm) to (0.002mm) when moistened , silt feels smooth but is not slick or sticky . When dry , it is smooth and floury and if pressed between the thumb and finger will retain the imprint . (Massoud , 1972) .

Clay is the finest soil particles smaller in size than 0.002 . Clay particles can be seen only with the aid of high magnification microscopes .They feel extremely smooth or powdery when dry and become plastic and sticky when wet . Clay will hold the form into which it is molded when moist and will form along ribon when extruded between fingers . (Soil survey Division Staff, 1993).

Texture can be estimated in the field by manipulating and feeling the soil between the thumb and fingers, but should be quantified by laboratory particle size analysis.

2.2.2 Effect of texture on soil properties:

1. Structure

2. Aeration

3. Root penetration

4. Water retention

2.3.1 Aggregation and soil structure:

Soil aggregation is the cementing of several soil particles into a secondary unit or aggregation . Soil particles are arranged or grouped together during the aggregation process to form structural units .Aggregation is important for compacting erosion, for maintaining porosity and soil water movement , and for improving fertility. (Nichols *et al*,.2004).

2.3.2 Types of soil structure:

Soil structure may be described as follows:

Granular Porous granuals held together by organic matter and some clay. Found in *A* horizons with some organic matter **.**

Blocky Roughly equidimensional pads usually higher in clay than other structural aggregates. Found in*B*horizons.

Platy Aggregates that have a thin vertical dimension with respect to lateral dimensions. Found in compacted layers.

Prismatic Structural aggregates that have a much grater vertical than lateral dimension. Found in some *B* horizons .

Structureless No definite structure or shape; usually hard. Found in horizons C or compact transported material. (Fanning, *et al* ,. 1989) .

2.3.3 Effects of structure on soil properties:

The structure of soil affects pore space size and distribution and there for, rates of air and water movement .

The size ,shape ,and strength of subsoil structural peds are important to soil productivity .Sandy soils generally have poorly developed structure relative to finer texture soils ,because of their lower clay content . When the subsoil has well developed blocky structure, there will generally be good air and water movement in the soil. If platy structure has formed in the subsoil, downward water and air movement and root development in the soil will be slowed. Distinct prismatic structure is often associated with subsoil's that swell when wet and shrink when dry, resulting in reduced air and water movement.

2.4 Porosity:

Soil porosity ,or pore space ,is the volume percentage of the total soil that is not occupied by solid particles.

Bulk density is dry mass of solid soil per unit volume of soil ,and particle density is the density of solids individual soil pareticle .Bulk density of mineral soils are usually in the range of 1.1 to 1.7g/cm^3 .A soil with a bulk density of about 1.32g/cm^3 will generally possess the ideal soil condition of 50% solids and 50% pore space .Bulk density varies depending on many factors such as water content , texture , aggregation, organic matter ,compaction ,soil management practices ,and soil horizon . (Dudal, 1965).

Under field conditions, pore space is filled with a variable mix of water and air. If soil particles are packed closely together, as in graded surface soils or compact subsoils, total porosity is low and bulk density is high. If soil particles are arranged in porous aggregates, as is often the case in medium-textured soils high in organic matter, the pore space per unit volume will be high and the bulk density will be correspondingly low.

In contrast, micropores in moist soils are typically filled with water ,and this does not permit much air movement into or out of the soil .Internal water micropores movement is also very slow thus ,the movement of air and water through a coarse- textured sandy soil can be surprisingly rapid despite its low total porosity because of the dominance of macropores.

Fine-textured clay soils, especially those without a stable granular structure, may have reduced movement of air and water even though they have a large volume of total pore space. In these fine-textured soils, micropores are dominant. Since these small pores often stay full of water, aeration, especially in the subsoil, can be inadequate for root development and microbial activity. The loosening and granulation of fine-textured soils promotes aeration by increasing the number of macropores.

The bulk density of Vertisols which cover wide area in Sudan, varies greatly because of their swelling and shrinking nature with changes in soil moisture content. The soils have high bulk density when they are dry and low values when in a swollen stage; according to.(Jewitt *et al*,. 1979).

2.5 Soil compaction:

Soil compaction occurs when soil particles are pressed together, reducing pore space between them. Heavily compacted soils contain few large pores and have a reduced rate of both water infiltration and drainage.

Soil compaction can be associated with a majority of field operations that are often performed when soils are wet and more susceptible to compaction. Heavy equipment and tillage implements can cause damage to the soil structure. Soil structure is important because it determines the ability of a soil to hold and conduct water, nutrients, and air necessary for plant root activity. Although much research has been conducted on soil compaction and its effects on yield, it is difficult to estimate an economic impact because fields vary in soil types, crop rotations, and weather conditions.

Soil compaction changes pore space size, distribution, and soil strength. One way to quantify the change is by measuring the bulk density. As the pore space is decreased within a soil, the bulk density is increased. Soils with a higher percentage of clay and silt, which naturally have more pore space, have a lower bulk density than sandier soils;(Divad , 2007) .

2.6 Consistency:

Consistency is the ability of soil to stick together and resist fragmentation. It is of rough use in predicting cultivation problems and the engineering of foundations. Consistency is measured at three moisture conditions: air-dry, moist and wet. Vertisols offer extremes of consistence; (Jewitt *et al*,. 1979). Extreme hardness when dry and stickiness and loss of trafficability when wet, permit tillage and seedbed preparation only within a very narrow range of moisture contents. The cultivation of Vertisols when too dry or too wet may therefore result in poor tilth due to cloddy or puddled structure, respectively (Dudal 1965, Krantz *et al*,. 1978) **.**

The **Atterberg limits** are basic measure of the nature of fine-grained soil. Depending on the water content of the soil, it may appear in four states: solid, semi-solid, plastic and liquid. In each state, the consistency and behavior of a soil is different and consequently so are its engineering properties. Atterberg, a Swedish scientist, considered the consistency of soil in, 1911 and proposed a series of tests for defining the properties of cohesive soils. Strength decreases as water content increases.

At a very low moisture content, soil behaves more like a solid. When the moisture content is very high, the soil and water may flow like a liquid.

Hence, on an arbitrary basis, depending on the moisture content, the behavior of soil can be divided into 4 basic states: solid, semisolid, plastic and liquid.

2.6.1 The liquid limit (LL):

The liquid limit ; is the water content at which soil cohesion is so reduced that soil mass will flow when a force is applied . In the lab, the Casagrande Liquid Limit Device is used for determining the liquid limits of soils the (LL) is defined as the moisture content(%) required to close a 2-mm wide groove in soil pat distance of 12.7 mm along the bottom of the groove after 25blows .

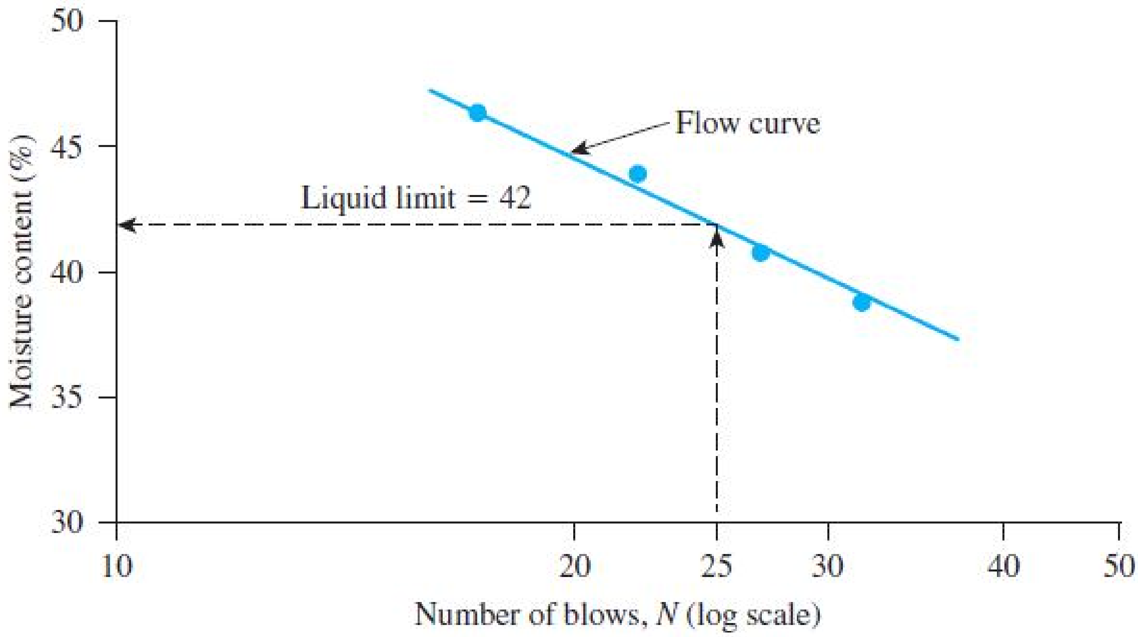


Figure 2: Flow curve for liquid limit

2.6.1.2 Importance of liquid limit:

Different soils have varying liquid limits.

2.6.2 Plastic limit:

Soil plastic limit is the moisture content at which soil consistency changes from friable to plastic ,and is taken to represent the minimum moisture content at which a soil can be puddle .

The plastic limit is determined by rolling out a thread of the fine portion of a soil on a flat, non-porous surface.

If the soil is plastic, this thread will retain its shape down to a very narrow diameter. The sample can then be remoulded and the test repeated. As the moisture content falls due to evaporation, the thread will begin to break apart at larger diameters. The plastic limit is defined as the moisture content where the thread breaks apart at a diameter of 3 mm (about 1/8 inch).

A soil is considered non-plastic if a thread cannot be rolled out down to (3 mm) at any moisture.

2.6.3 Plasticity index:

The plasticity index (PI) is a measure of the plasticity of a soil. The plasticity index is the range of water contents where the soil exhibits plastic properties. The (PI) is the difference between the liquid limit and the plastic limit (PI = LL-PL). Soils with a high PI tend to be clay, those with a lower PI tend to be silt, and those with a PI of 0 (non-plastic) tend to be sandy with little or no silt or clay.

2.6.3.1 Plasticity index and it meanings:

- Nonplastic
- Slightly plastic
- Moderately plasticity
- Strongly plasticity
- Very strongly plasticity

2.6.4 The shrinkage limit:

The shrinkage limit is the water content at which further loss of water causes no further change in soil volume .(BSI ,1975) .

2.6 Soil and water relationship:

2.6.1 Infiltration rate:

Infiltration is the process by which water on the ground surface enters the soil. Infiltration rate in soil science is a measure of the rate at which soil is able to absorb rainfall or irrigation. It is measured in inches per hour or millimeters per hour. The rate decreases as the soil becomes saturated. If the precipitation rate exceeds the infiltration rate, runoff will usually occur unless there is some physical barrier. It is related to the saturated hydraulic conductivity of the near-surface soil. The rate of infiltration can be measured using an infiltrometer.(Hogan, 2010).

Infiltration is governed by two forces: gravity and capillary action. While smaller pores offer greater resistance to gravity, very small pores pull water through capillary against the force of gravity.

The rate of infiltration is affected by soil characteristics including ease of entry, storage capacity, and transmission rate through the soil. The soil texture and structure, vegetation types and cover, water content of the soil, soil temperature..

2.6.2 Hydraulic Conductivity:

The hydraulic conductivity of a soil is a measure of the soil's ability to transmit water when submitted to a hydraulic gradient.

Hydraulic conductivity is one of the important physical properties which determine the behavior of the soil fluid within the soil system under specified conditions. More specifically, the hydraulic conductivity determines the ability of the soil fluid to flow through the soil matrix system under a specified hydraulic gradient; the soil fluid retention characteristics determine the ability of the soil system to retain the soil fluid under a specified pressure condition.

Hydraulic conductivity depends on the soil grain size, the structure of the soil matrix, the type of soil fluid, and the relative amount of soil fluid (saturation) present in the soil matrix. The important properties relevant to the solid matrix of the soil include pore size distribution, pore shape, tortuosity, specific surface, and porosity. In relation to the soil fluid, the important properties include as well fluid density, and fluid viscosity.

Hydraulic conductivity and Cumulative infiltration of water are two interrelated parameters. (Gulser and Candemir , 2008).

Hydraulic Conductivity is also useful in controlling water infiltration and surface runoff, leaching of pesticides from agricultural lands. (Bagarello and Sgroi, 2007). The hydraulic conductivity of coarse textured soils and aggregated soils decrease more rapidly than fine textured soils (Lal and Shukla, 2004). Hydraulic conductivity depends on the physical characteristics of soil such as the intrinsic permeability (soil),the degree of saturation, the type of soil , bulk density, total porosity and the configuration of the soil pores. It is influenced by the properties of the fluid being transmitted density and as well as the porous medium.

2.6.3 Coefficient of linear Extensibility :(COlE)

An expansive soil is any soil that has a potential for shrinking and swelling under changing moisture condition (Nelson and Miller ,.1992).Expansive soils experience three dimensional volume changes during wetting and drying cycles ,increasing volume when wetting and decreasing volume when drying ;hence often have some shrink-swell potential as a result of wetting-drying cycles .(Azam etal ,.2000) .Soil shrink-swell behavior is primarily governed by the dominant clay mineralogy ; (Davidson and Page ,1956).Soil shrink – swell potential is also affected by numerous other factors and soil properties ,such as soil particle shape –and pore-size distribution ,texture , water content ,rate of moisture change due to natural and man-made drainage (Komornik; 1969), specific surface area ,cation exchange capacity,organic matter

,exchangeable cations ,iron content (Davidson and Page,1956,Azam *et al,*. 2000) .In general soil shrink -swell potential increases with clay content and type of clay minerals.

2.7 Soil moisture conditions

2.7.1 Soil moisture content:

The soil moisture content indicates the amount of water present in the soil. It is commonly expressed as the amount of water (in mm of water depth) present in a depth of one meter of the soil.

2.7.2 Saturation:

During a rain shower or irrigation application, the soil pores will fill with water. If all soil pores are filled with water the soil is said to be saturated. There is no air left in the soil at saturation .Soil pores are filled with water, and since plant need air for their growth they suffer at saturation. Many crops cannot withstand saturated soil conditions for a period of more than 2-5 days. Rice is one of the exceptions to this rule. The period of saturation of the top soil usually does not last long. After the rain or the irrigation has stopped, part of the water present in the larger pores will move downward. This process is called drainage or percolation.

The water drained from the pores is replaced by air. In coarse textured sandy soils, drainage is completed within a period of a few hours. In fine textured clayey soils, drainage may take many days.

2.7.3 Field capacity

After the drainage has stopped, the large soil pores are filled with both air and water while the smaller pores are still full of water. At this stage, the soil is said to be at field capacity. At field capacity, the water and air contents of the soil are considered to be ideal for crop growth .This takes place usually between 2-3 days after irrigation ,depending on soil texture and some other soil properties .(Milford , 2001) .

2.7.4 Temporary wilting point:

One can distinguish a temporary wilting point, according to which the plant can recover in the presence of irrigation or precipation, and a permanent wilting point at which the plant dies, even if water is supplied

2.7.5 Permanent wilting point:

Little by little, the water stored in the soil is taken up by the plant roots percolated through the soil or evaporated from the topsoil into the atmosphere. If no additional water is supplied to the soil, it gradually dries out. The dryer the soil becomes, the more tightly the remaining water is retained and the more difficult it is for the plant roots to extract. At a certain stage, the uptake of water is not sufficient to meet the plant's needs. The plant looses freshness and wilts; the leaves change color from green to yellow. Finally the plant dies.

The soil water content at this stage is called permanent wilting point. The soil still contains some water, but it is too difficult **for** the roots to suck it from the soil.

2.7.6 Available water content:

The soil can be compared to a water reservoir for the plants. When the soil is saturated, the reservoir is full. However, some water drains rapidly below the root zone before the plant can use it . The available water content depends greatly on the soil texture and structure.

2.7.8 Available water capacity:

Available water capacity is the maximum amount of plant available water a soil can provide .It is an indicator of soil's ability to retain water and make it sufficiently available for plant use .

Permanent wilting point is moisture content of a soil at which plants wilt and fail to recover when supplied with sufficient moisture .Water capacity is usually expressed as a volume fraction or percentage or as a depth.

2.7.9 Factor affecting available water capacity:

Available water capacity increases with increase of fine particls textured soil, from sands to loams and silt loams; to clay coarse textured soils have lower field capacity since they are high in large pores and subject to free drainage .Fine textured soils have greater occurrence of small pores that hold water against free drainage, resulting in a comparatively higher field capacity .However, in comparison to well –aggregated loam and silt loam soils, the available water capacity of predominantly clay soils tends to be lower since these soils have increased permanent wilting point. Soil depth and root restricting layers affect total available water capacity since they can limit the volume of soil available for growth.

Root penetration is affected by presence of restrictive layers in the soil profile and hence available water for plants is also affected . Compaction reduces available water capacity through its adverse affects on water movement . Compaction reduces total pore volume ,consequently reducing water storage when the soil is at field capacity . Compaction also crushes large soil pores into much smaller micro pores. Since microspores hold water more tightly than larger pores ,more water is held in soil at its wilting point .

Soluble salts play an important role in availability of moisture for plants. Saline soils are formed during soil formation due to weathering of minerals ,or as a result of irrigation with low quality underground water. Salt concentration increases as soil water decreases .For soils high in soluble salts , moisture stress results when plants cannot uptake water across an unfavorable salt concentration gradient .Soil with high salt concentration tend to have reduced available water capacity because of its osmotic pressure effect .

CHAPTER THREE

3- MATERIAL AND METHODS

3.1 Methods of data collection:

3.1.1 Field methods and soil samples:

Five pits were opened at the experiment sites, studied in the field and described following the formats of the FAO (1975); Guide lines of soil profile Description. Soil samples were collected from the genetic horizons of profiles and the are classified according to the American System of Soil Taxonomy .USDA .(2006) .

3.2 Laboratory analyses:

For each soil sample collected from the profile pits the following analyses were made at the lab of Faculty of Agriculture Science (SUST) and the lab of Faculty of Engineering .(SUST) .

3.2.1 Soil reaction:

pH reading of soil suspension 1:5 and saturation extracts ,were determined using pH meter model 3510 .

3.2.2 Electrical conductivity:

Determined by portable E.Ce meter model 470 .

3.2.3 Soluble cations and anions:

Calcium and **magnesium** by titration with ethylene di amine tetra acetic acid. (Bray ,1984) .

Sodium and **potassium** determine by flame photometer model C410 .

Carbonate and **Bicarbonate** by titration with hydrochloric acid .(Reitemeier, 1943) .

Chloride by titration with silver nitrate method. (Reitemeier ,1943).

3.2.4 Organic Carbon and Organic matter:

Soil organic matter is oxidized with potassium dichromate in sulphuric Acid

and determined by titration with ferrous ammonium sulphate solution. A factor of 1.72 is used to convert organic carbon into organic matter .(Walkley Black,1965) .

3.2.5 Total nitrogen:

Micro-Kjeldahl was used. Pre-moistened soil treated with concentrated sulphuric acid for digestion. Saturated solution of NaOH was used for distillation and liberated ammonia was received in 2% boric acid and titrated with hydrochloric acid .

3.2.6 Available phosphors:

Determined by Olsen sodium bicarbonate extract method and color intensity measured by spectrophotometer model 6305.

3.2.7 Cation Exchange Capacity:

The colloidal complex of the soil is first saturated with sodium using sodium acetate , washed with ethanol to remove excess sodium and absorbed sodium was then replaced by ammonium acetate ,(Bower ,1952) .

3.2.8 Exchangeable cations:

Extracted with ammonium acetate and corrected for the soluble fraction as measured in saturation extract .(Bower ,1952).

3.2.9Exchangeable Sodium Percentage:

was calculated according to the following formula:

$ESP = (\text{Exchangeable Na} \div CEC) \times 100$

3.2.10 Sodium Adsorption Ratio:

Obtained by calculation from the values of soluble Na, Ca, and Mg using the well know Rachides equation:

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$

3.2.11 Calcium carbonate content :

Using Eijkelkamp calcimeter:

$CaCo_3$: Soil is treated with dilute HCL and the volume of CO_2 evolved in measured at atmospheric temperature and pressure . Accurate weight of pure $CaCo_3$ is also treated with HCL and the volume of CO_2 evolved is measured ,

And percent $CaCo_3$ is calculated to according to the following equation :

$$\%CaCO_3 = \frac{Wt.2(V1-V3)}{Wt.S(V2-V3)} \times 100$$

Where :

Wt.2 =Weight of pure $CaCo_3$

Wt. S= Weight of soil sample

V_1= Volume of CO_2 evolved from soil sample

V_2= Volume of CO_2 evolved from $CaCo_3$

V_3= Volume of CO_2due to a blank sample

Final results are expressed on oven dry basic by multiplying the result by the following factor :

$$\frac{100+m\%}{100}$$ m%= moisture percent

3.2.12 Mechanical analysis:

The pipette method is used in this research .

The sample is treated with HCL to remove $CaCo_3$,washed off the soluble salts and then dispersed with calgon . The pipette is used to sample the clay fraction ,coarse sand, and fine sand separated by wet sieving and silt obtained by different as follows :

Silt% =[100-(%clay+%c.s. +f.s .)]

3.2.13 Hydraulic conductivity:

Measured according to Richard method on disturbed soil sample. (Richard; 1952).

3. 2.14 Liquid Limit (LL):

The liquid limit (LL) is the water content at which a soil changes from plastic to liquid behavior. The original liquid limit test of Atterberg's involved mixing a part of clay in a round-bottomed porcelain bowl of 10–12 cm diameter.(BSI ;1975) .

3. 2.15 Plastic Limit (PL):

The plastic limit (PL) is defined as the moisture content (%) at which the soil when rolled into threads of 3.2mm in diameter, will crumble. It is the lower limit of the plastic stage of soil. (BSI ,1975) .

3.2.16 Bulk density:

The bulk density of clods, or coarse peds, is calculated from their mass and volume. The volume is determined by coating the clod with a water – repellent substance and by weighing it first in air ,then again while immersed in a liquid of known density ,making use of Archimedes, principle . (Blake and Hartge ,1986) .

3.2.17 Field Capacity:

After the soil profile is thoroughly wetted with irrigation water soil sample were collected after 1-3 days; dried at105c° for 24 hours , to get field moisture content . (Richard ,1952) .

3.2.18 soil moisture: 1/3 and 15 bar:

The 1/3 bar pressure plate extractor with small volume pressure vessel used for extraction and measurement of soil water

The 15 bar pressure plate extractor can be used for extraction and measurement of soil water . (Sivakumar ,*.et al* 2009).

CHAPTER FOUR

4- RESULTS AND DISCUSSIONS

The description of the five sampled soil profiles is given in Appendix 1.They all meet the requirements of classification as Vertisols .Weighted average of clay content to a depth of more than 50cm is more than 30 percent .They all have cracks at a depth of 50cm or more that are more than 1cm wide .Distinct pressure faces have been described in all pits .

Physical and mechanical properties:

Soil texture:

The result of particles size distribution analysis for all profiles are given in Table 1.The data indicate the following points :

(1) Clay content dominantly varies between 31-49% , silt between 38-63% and sand between 6-25% .
(2) The highest clay content was reported at pit No .1 and pit No.4 .

Infiltration rate:

Optimum basic infiltration rate for irrigation are considered to be in the range of 6.5 cm/h ;according to(BIA, 1979) The infiltration category in shambat farm are slow (2.0cm/h).In general ,permeability decreases with increasing density, and is affected by saline and sodic condition . In addition, the pore size distribution influences the rate of change of infiltrability . When the wetting front in the soil reaches a layer with either a coarser or a finer texture, there is a decrease or increase in the infiltration rate. Appendix 2.

Hydraulic conductivity:

The values obtained for hydraulic conductivity vary between slow to very slow (0.02-0.3cm/h) ; according to(FAO ,1963) . Hydraulic conductivity values are related to textural and structural characteristics of the soil ;Table 2.

Bulk density:

The value of bulk density of the dry soil samples varies between 1.5-1.8g/cm^3 . Bulk density is affected by moisture content and type of clay mineral. The top soil is a slightly compacted at all sites .The sub soil is markedly very compacted in all pits except pit No 2 ;(Table 2) .This compaction is believed to be inherited during soil formation .This investigation clearly suggests that all sites are so dense that some difficulty in their management can be anticipated .It has been shown that when the bulk density of medium to fine textured sub soil exceeds about 1.7gm/cm^3, hydraulic conductivity values will be so low that drainage problems can be expected. (Richard , 1954).

Soil porosity:

The total porosity of the studied soils lies between 32-43% which is by far less than the capacity of the soil to retain water at saturation (SP) . This could be due to creation of more space during sample preparation as a result of crushing and sieving; (Table 2) .

Soil –water relations:

The values of field capacity range between 39-35;and values of the wilting point range between 22-19 . Available water capacity is very high . Available water capacity is affected by organic matter, compaction ,and salt concentration ; (Brady and Weil, 2002) Table 3.

Soil consistency :

The value of plastic limits of the soil samples varies between 15-26 and liquid limits were ranging between 36-55; resulting in a relatively high plasticity index .The Vertisols offer extremes of consistence -they are very hard when dry and very sticky and plastic when wet according to (Jewitt *et al* ,.1979). Appendix 3

Chemical properties:

Soil reaction:

pH (paste) of the surface soil samples ranges between 7.3 and 7.9;These values are mildly alkaline and are found in pits 1-2-3 and 4. In pit 5 ,reaction to moderately alkaline (pH= 7.9). (Richard ,1954) . Higher pH values were obtained in 1:5 soil water suspensions ;(7.5 to 9.0) . which may indicate presence of a relatively high salt content. Table 1

Soluble salt:

The electrical conductivity values of the saturation extracts range between (0.4 - 12.0 ds/m).The weighted average of the soluble salts within the depth 200cm indicate slight level of salinity(0.57 ds/m) in (pit 4);and moderate (3.1 ds/m) salinity in (pits 1-2-5) and high (9.3 ds/m) salinity in (pit 3).Table1.

The ESP value of 15 is often regarded as the boundary between sodic and non-sodic soil .In general term ,high ESP values have a greater deterious effect on soils with 2:1lattice clays .Although the onset of adverse physical condition occurs more generally at higher ESP levels in montmorillonitic clays ; as indicate by (Richards, 1954) ;Table1.

Sodium Adsorption Ratio (SAR) is another concept of sodicity .It is calculated for concentration of Na ,Ca and Mg in the soil solution where they are in equilibrium with their exchangeable forms .The critical value of SAR that indicate problem is slightly lower than ESP .SAR value of only 12 is considered harmful .

Values of cation exchange capacity ranged from 31to 66meq/100g.soil .There is considerable variation from sample to sample and the results confirm that percent clay is directly related to C.E.C as expressed in meq/100g soil . Actually C.E.C values are associated with both clay content, type of minerals and organic matter . In addition silt has a slight effect on C.E.C value; According to (Brady and. Weil, 2001).Table 1 .

The value of exchangeable sodium ranged from 0.9 to 18.The general pattern is one of non sodic soil. However , in certain places the top soil is slightly affected with sodium (ESP = 6). The subsoil is markedly sodic in pits 1-2-3-5 (ESP =24) ;Table 1.

The values of phosphorus for these samples range between 2-8.0 ppm . which may Indicate that available phosphorus is very poor in these soils .Those sample containing more than 7 ppm are considered reasonably supplied with phosphorus; according to (Cooke ,1967); Table 1.

Total nitrogen varies between (0.08-0.18ppm) which might indicate a very low level of this important element in all soil tested ; Table 1(Metson ,1961) .

Similarly ,organic matter is very low and the result obtained for organic carbon is in between (0.4-1.0%) ; Table 1.

The values of calcium carbonate range from 2-9% .Calcium carbonate has an

effect on most of the physical properties of soil including ;particle size distribution, bulk density ,permeability and available moisture ; more important is the effect of calcium carbonate on availability of nutrients specially phosphorus and microelements; (Massoud, 1972).Table 1.

Soil genesis :

Refers Genesis these soil were formed from the basic igneous rocks of the Ethiopian high land . The solid geology of the area is composed of ancient formation of cretaceous age outcropping on the western bank of the Nile, with an original Litho logically formation ,which is given the name of Nubian series; From a topographic point of view ,most of the area under study is flat . The climate of Shambat area is classified by papadkis ,semi-desert climatic zone with summer rains, and warm winter; in (Table 2.2) .The combined effect of high temperature and strong solar radiation caused the potential evapotranspiration to be very high and significantly exceeds the rainfall in all months (Fig. 2.1).

Table 1. Chemical and Physical Analysis:

Pit	Lab.	Depth	C.Sand	F.Sand	Silt	Clay	Lab.	ECe	pH	pH	Exchangeable cations, cmol(+) kg-1				CEC
No.	No.	Cm	%	%	%	%	Texture	dS/m	paste	1:5	Ca+Mg	K	Na	sum	cmol(+) kg-1
1	1	0-15	3	13	46	38	ZCL	1.00	7.3	7.5	40.5	1.6	0.9	43.0	43
	2	15-45	3	6	46	45	ZC	1.60	7.4	8.2	35.2	1.3	6.5	43.0	43
	3	45-75	3	13	38	46	C	2.30	7.5	8.3	26.5	1.6	7.9	36.0	36
	4	75-120	2	13	41	44	ZC	2.20	7.5	8.4	21.7	1.2	8.1	31.0	31
	5	120-200	2	10	49	39	ZCL	4.90	7.4	8.0	20.4	1.6	14.0	36.0	36
2	6	0-15	5	17	48	30	CL	0.7	7.7	7.8	32.5	1.7	3.8	38.0	38
	7	15-35	5	17	46	32	CL	0.70	7.6	8.2	29.6	1.4	5.0	36.0	36
	8	35-80	5	20	47	28	CL	1.6	7.7	8.6	26.3	1.8	8.9	37.0	37
	9	80-130	2	19	48	31	ZCL	8.0	7.5	8.3	25.2	2.1	11.7	39.0	39
	10	130-200	1	5	55	39	ZCL	3.0	8.0	9.0	28.9	1.9	8.2	39.0	39

O.M	OC	Total N	C:N	CaCO3	Olsen P	ESP	SAR	Soluble cations (meq/l)				Soluble anions (meq/l)					Sp
%	%	%		%	PPm			Ca+Mg	K	Na	sum	CO3	HCO3	Cl	SO4	sum	%
1.6	0.9	0.12	7.5	4	7.8	2	4	3.7	0.5	5.0	9.2		6.9	0.5	1.8	9.2	69
1.4	0.8	0.10	8.0	4	3.2	15	9	3.5	0.3	12.1	15.9		5.5	0.5	9.9	15.9	72
1.2	0.7	0.09	7.8	4	4.3	22	9	4.9	0.4	14.0	19.3		5.3	0.4	13.6	19.3	70
1.0	0.6	0.11	5.5	4	3.5	26	12	4.0	0.6	17.6	22.2		5.0	0.8	16.4	22.2	69
0.9	0.5	0.06	8.3	3	7.8	39	15	11.1	0.4	36.2	47.4		5.3	1.0	41.1	47.4	73
1.6	0.9	0.13	6.9	6	8.0	10	3	2.6	0.4	3.1	7.6		7.2	0.4		7.6	56
1.2	0.7	0.20	3.5	6	2.7	14	7	1.8	0.1	7.0	8.9		6.4	0.5	2.0	8.9	53
1.2	0.7	0.10	7.0	5	3.4	24	12	2.5	0.4	13.3	16.2	0.6	6.7	0.4	8.5	16.2	62
1.0	0.6	0.08	7.5	3	3.5	30	25	13.9	0.8	67.0	81.7		5.6	1.0	75.1	81.7	78
0.7	0.4	0.06	6.7	2	3.6	28	17	4.0	0.8	24.0	28.8		5.8	0.3	22.7	28.8	80

C. :coarse , F:fine ,C:clay ,Z :silt ,L :loam ,Sp :saturation percent ,O.M :organic matter ,O.C:organic carbon, N:nitrogen,P:phosphor ESP: exchangeable sodium percent SAR :sodium adsorption ratio

Cont… Table (1)

Pit	Lab.	Depth	C.Sand	F.Sand	Silt	Clay	Lab.	ECe	pH	pH	Exchangea	
No.	No.	Cm	%	%	%	%	Texture	dS/m	paste	1:5		Ca+Mg
3	11	0-15	7	14	52	27	ZCL	1.1	7.8	8.1		36.8
	12	15-35	12	8	39	41	C	1.4	7.7	8.5		34.9
	13	35-55	6	11	39	44	C	5.7	7.4	8.2		26.1
	14	55-120	3	5	77	15	ZL	11.4	7.3	7.9		32.5
	15	120-200	3	5	71	21	ZL	12.0	7.4	8.0		40.1
4	16	0-30	4	9	55	32	ZCL	0.4	7.7	8.1		41.5
	17	30-60	3	9	39	49	C	0.4	7.7	8.3		43.8
	18	60-100	2	6	51	41	ZC	0.7	7.6	8.4		45.6
	19	100-170	6	13	63	18	ZL	0.8	7.6	8.2		49.7

O.M	OC	Total N	C:N	CaCO3	Olsen P	ESP	SAR	Soluble cations (meq/l)					Soluble	
%	%	%		%	PPm				Ca+Mg	K	Na	sum	CO3	
1.6	0.9	0.13	6.9	6	4.9	7	4		4.8	0.5	5.7	11.0	0.8	
1.4	0.8	0.12	6.7	7	5.2	14	9		3.0	0.2	11.3	14.5		
1.2	0.7	0.11	6.4	9	5.8	27	14		16.7	1.2	39.2	57.0		
1.0	0.6	0.08	7.5	4	5.9	22	23		28.0	2.86	85.0	115.9		
0.7	0.4	0.13	3.1	3	3.8	24	20		34.8	2.2	82.6	119.6		
1.6	0.9	0.14	6.4	4	4.1	3	3		1.8	0.1	2.5	4.4		
1.2	0.7	0.09	7.8	5	3.3	2	1		2.5	0.1	1.5	4.1		
1.0	0.6	0.08	7.5	5	3.6	6	5		2.3	0.03	5.1	7.4		
0.9	0.5	0.10	5.0	8	2.4	2	4		3.4	0.3	5.5	9.2		

Cont… Table (1)

Pit	Lab.	Depth	C.Sand	F.Sand	Silt	Clay	Lab.	ECe	pH	pH		Exchangeable cations, cmc		
No.	No.	Cm	%	%	%	%	Texture	dS/m	paste	1:5			Ca+Mg	K
5	20	0-5	5	1	72	22	ZL	1.7	7.9	8.2			49.3	1.8
	21	5-25	5	10	57	28	ZCL	1.3	7.7	8.7			53.1	1.4
	22	25-70	5	15	39	41	C	3.0	7.7	8.6			25.3	1.4
	23	70-130	4	13	47	38	ZCL	5.5	7.6	8.3			41.2	2.1
	24	130-200	1	9	64	26	ZL	2.8	7.8	9.0			51.3	1.5

O.M	OC	Total N	C:N	CaCO3	Olsen P	ESP	SAR	Soluble cations (meq/l)					Solub
%	%	%		%	Ppm				Ca+Mg	K	Na	sum	CO3
1.7	1.0	0.08	12.5	4	3.6	7	10		3.2	0.1	12.8	16.1	0.6
1.6	0.9	0.18	5.0	5	4.8	6	8		2.9	0.1	10.1	13.1	
1.4	0.8	0.12	6.7	6	2.2	10	16		4.6	1.1	24.6	30.3	
1.0	0.6	0.08	7.5	4	1.6	24	18		11.7	1.0	44.0	56.7	
0.7	0.4	0.12	3.3	4	1.6	20	20		3.0	0.1	24.6	27.7	

Table 2. Physical Analysis:

Pit No	Lab No	Depth Cm	Bulk Density g/cm^3	Porosity %	H.C cm^3/h
	1	0-15	1.6	29	0.09
	2	15-45	1.7	22	0.05
1	3	45-75	1.7	29	0.04
	4	75-120	1.8	22	0.03
	5	120-200	1.8	25	0.02
	6	0-15	1.5	38	0.3
	7	15-35	1.6	33	0.3
2	8	35-80	1.6	33	0.05
	9	80-130	1.6	33	0.05
	10	130-200	1.8	25	0.06
	11	0-15	1.6	29	0.08
	12	15-35	1.7	22	0.05
3	13	35-55	1.8	22	0.08
	14	55-120	1.6	33	0.08
	15	120-200	1.6	33	0.07
	16	0-30	1.6	33	0.2
4	17	30-60	1.8	25	0.09
	18	60-100	1.7	29	0.06
	19	100-170	1.5	33	0.05
	20	0-5	1.6	36	0.2
	21	5-25	1.7	29	0.15
5	22	25-70	1.8	22	0.05
	23	70-130	1.8	25	0.06
	24	130-200	1.6	33	0.07

Particle density=2.65g/cm^3 H.C :Hydraulic conductivity

Table 3. Soil Moisture Content:

Profile No	Depth cm	Moist After (1) days	Moist After (2) days	Moist After (3) days	1/3bar Moist %	15bar Moist %	A.W.C %
S1	0-30	40	29	22	13	6	7
S1	30-50	38	27	23	14	7	7
S2	0-30	32	26	20	11	5	6
S2	30-50	30	24	19	12	5	7
S3	0-30	36	25	21	13	5	8
S3	30-50	34	23	20	13	6	7
S4	0-30	39	29	24	12	5	7
S4	30-50	37	28	22	14	6	8
S5	0-30	40	31	25	15	8	7
S5	30-50	38	29	23	16	7	9

A.W.C :Available water capacity

Conclusion

The study was carried out to show, physical and chemical similarities or differences between five sites included in the farm of the College . The results of this work have indicated that the soil are variably affected by salinity and sodicity. Non-saline, slightly saline, and moderately saline ,sub soil, non sodic to moderately sodic soils are all found in the farm. Soil texture is clay throughout ,and hydraulic conductivity is very slow to slow. The whole soil profile is compacted except at the surface layer and average bulk density is very high when the soil is dry , these soil are characterized by high water retention but rather narrow range of available moisture as evidenced from the difference between the moisture retained between field capacity and wilting point .They generally have mildly alkaline reaction.

References

Azam, S., S.N. Abduljauwad, N.A. Al-Shayea, and O.S.B. Al-Amoudi. (2000). Effects of calcium sulfate on swelling potential of expansive clay.

Bagarello, V., Sgroi, A., (2007). Soil &Tillage Research 94, 283–294.

BIA (1979) Kano River project phase II .Unpublished soil and land capability Rep ,London .

Black, C.A. (1965): Methods of Soil Analysis. Part 1, American Society of Agronomy.

Blake, G.R., Hartge, K.H. (1986): Bulk Density. Methods of Soil Analysis, Part 1, Soil Sci. Soc.

Bower (1952) Exchangeable cation Analysis of saline and alkali soils.

Bower C.A.(1969) .The chemical amendments for improving sodium soils. Agric Info Bull NO195 .USDA, Washington DC .

Brady, N. and R. Weil. (2002). The Nature and Properties of Soils, 13th Edition. Prentice Hall. Upper Saddle River, New Jersey. 960 p.

Bray NC(1984) .The nature and properties of soil Ninth Edition .Macmillan , New York .

British standards Institution ,London BSI .(1975) Methods of testing soils for civil engineering purpose .British standard 1377 . BSI

Cooke GW (1967) .Control of soil fertility corsby ,lock wood ,London .

David F. (2007). *Essentials of Soil Mechanics and Foundations*. Upper Saddle River, NJ: Pearson Prentice Hall.

Davidson, S.E., and J.B. Page. (1956). Factors influencing swelling and shrinking in soils. Soil Sci. Soc.

Dudal, R. (1965); Dark Clay Soils of Tropical and Subtropical Regions. Agric. Dev. Paper 83, FAO, Rome, Italy. 161 p.

Fanning, D.S., and M.C.B. Fanning. (1989). Soil morphology, genesis, and classification. John Wiley and Sons, New York.

FAO (1963) .High dam soil survey project .Deb BC .FAO , Rome .

FAO (1975) Si units and nomenclature in soil science .Soil Bull No 22 .

Greene-Kelley, R. (1974). Shrinkage of clay soils: A statistical correlation with other soil properties.

Gulser, C., Candemir, F. (2008). Prediction of Saturated Hydraulic Conductiv ity Using Some
Moisture Constants and Soil Physical Properties. Samsun 55139

Jewitt, T.N., Law, R.D. & Virgo, K.J. (1979). Outlook on Agriculture 10, 33.

Komornik, A. (1969). Proceedings of the second international research and engineering conference on expansive clay soils. Texas.

Krantz, B.A., Kampen, J. & Russell, M.B. (1978). the Diversity of soils in the tropics.

L.A. Richard .Diagnosis and Improvement of Saline and Alkaline soil .U.S.D.A. Hand book 60(1954) .

Lal, R. and M. K. Shukla, eds. (2004). Principles of Soil Physics. Marcel Dek ker, Inc., New York.

Massoud, F. (1972). Some physical properties of highly calcareous soils and their related management practices. FAO/UNDP Regional Seminar on Reclamation and Management of Calcareous Soils.

Metson (1961).Methods of chemical analysis for soil survey sample .

Michael Hogan C. 2010. *Abiotic factor*. Encyclopedia of Earth. eds Emily Monosson and C. Cleveland. National Council for Science and the Environment. Washington DC

Milford,H.B., A.J.E. McGaw and K.J. Nixon,(2001). Soil Data Entry Handbook for the NSW Soil and Land Information System .

Nelson, J.D., and D.J. Miller. 1992. Expansive soils: Problems and practice in foundation and pavement engineering. John Wiley & Sons, NY.

Nichols, K.A., S.F. Wright, M.A. Liebig, and J.L. Pikul Jr. 2004. Functional significance of glomalin to soil fertility.

Reitemeier ,RF (1943) Semimicro Analysis of saline soil solution .

Richards ,L.A.(1952) Handbook No. 18. U.S. Govt. Printing Office, Washington, DC.

Richards.(1954) Saline and alkali soils U.S. Salinity Laboratory Staff .

Saeed, A. M., 1968. Some Physical and Chemical Properties of Certain Shambat Soils, MSc. Thesis. University of Khartoum, Faculty of Agriculture, Sudan.

Sivakumar, V., Glynn, D., Cairns, P. & Black, J. A.(2009), A new method of measuring plastic limit of fine materials. Géotechnique 59, No. 10,. 813-823

Soil Survey Division Staff. (1993). Soil survey manual. U.S. Dept. of Agriculture . Soil Taxonomy .USDA .(2006) .

Stanchies E.Bifacio EZ & perfect E(2008) .Chemical and physical treatment effects on aggregate break up in the 0 to 2mm size range .Soil science society of American Journal 72(5) :1418-1421.

Walker, W.R.; Skogerboe, G.V. (1987). *Surface irrigation: Theory and practice*. Prentice-Hall, Englewood Cliffs.

Appendices

Appendix 1. Profile description No 1

Survey area	Shambat
Profile No.	1
Date	7.4.2011
Author	Moamer and Hajhamad
GPS E	448378
GPS N	1730562
Topography	F
Slope, %	0-1%
Site	F
Landform	P
Surface cracks	50mm
Mulch	10mm
Other	0
Micro- relief	0
Termitaria per ha	0
Water erosion	0
Wind erosion	0
Land use	F
Water table, cm	None
Drainage class	M
Parent material	Alluvium deposite.
Other	0

Depth, cm	**Profile description**
0-15 A1	Dry;dark brown (10YR3/3); clay ; hard dry; friable moist; sticky and plastic wet; moderate medium and coarse sub-angular blocky structure; cracks width 40 mm; few fine pores;very few fine calcium carbonate concertion;very few fine rootes; moderate calcareous; clear smooth boundary.
15-45 A12	Dry;dark brown (10YR3/3); clay ; hard dry; friable moist; sticky and plastic wet; weak fine and medium sub-angular blocky structure; cracks width 30 mm; very few fine pores;very few fine calcium carbonate concertion;very few fine rootes; slightly calcareous; gradual wavy boundary.
45-75 C1	Dry;very dark greyish brown (10YR3/2); clay ; hard dry; friable moist; sticky and plastic wet; weak fine sub-angular blocky structure;distinct pressure faces; cracks width 20 mm;very few fine calcium carbonate concertion; slightly calcareous; gradual wavy boundary.
75-120 C2	Dry;very dark greyish brown (10YR3/2); clay ; hard dry; firm moist; sticky and plastic wet; massive structure;distinct pressure faces; slightly calcareous; gradual wavy boundary.
120-200 C3	Dry;very dark greyish brown (10YR3/2); clay ; hard dry; firm moist;very sticky and very plastic wet; massive structure;distinct pressure faces; slightly calcareous.

.

Profile description No 2

Survey area	Shambat
Profile No.	2
Date	8.4.2011
Author	Moamer-HajHamad
GPS E	448009
GPS N	1730691
Topography	F
Slope, %	0-1%
Site	F
Landform	P
Surface cracks	30mm
Mulch	10mm
Other	0
Micro- relief	0
Termitaria per ha	0
Water erosion	0
Wind erosion	0
Land use	SG
Water table, cm	None
Drainage class	M
Parent material	Alluvium deposite
Other	0

Depth, cm	**Profile description**
0-15A11	Dry;dark brown (10YR3/3); clay; slightly hard dry; friable moist;slightly sticky and slightly plastic wet; strong and medium angular blocky and sub-angular blocky structure; cracks width30mm; very few fine pores;very few fine calcium carbonate concertion;very few fine roots; moderate calcareous; clear wavy boundary.
15-35A12	Dry;dark brown (10YR3/3); clay; slightly hard dry; friable moist;slightly sticky and slightly plastic wet; moderate and fine platty structure; cracks width20mm; very few fine pores;very few fine calcium carbonate concertion;very few fine roots; moderate calcareous; gradual wavy boundary.
35-80AC	Dry;very dark greyish brown (10YR3/2); clay; hard dry; friable moist;slightly sticky and slightly plastic wet; weak and very fine platty structure;distinct pressure faces; few fine calcium carbonate concertion;slightly calcareous; gradual wavy boundary.
80-130 C1	Dry;very dark greyish brown (10YR3/2); clay; hard dry; firm moist;slightly sticky and slightly plastic wet; weak and fine sub-angular blocky structure;distinct pressure faces; few fine calcium carbonate concertion;slightly calcareous; gradual wavy boundary.
130-200 C2	Dry; dark brown (10YR3/3);silty clay; hard dry; firm moist;slightly sticky and slightly plastic wet; massive structure;distinct pressure faces;very few fine calcium carbonate concertion;slightly calcareous.

Profile description No 3

Survey area	Shambat
Profile No.	3
Date	8.4.2011
Author	Moamer-HajHamad
GPS E	448013
GPS N	1730229
Topography	F
Slope, %	0-1%
Site	F
Landform	P
Surface cracks	30mm
Mulch	10mm
Other	0
Micro- relief	0
Termitaria per ha	0
Water erosion	0
Wind erosion	0
Land use	FRUIT
Water table, cm	None
Drainage class	M
Parent material	Alluvium deposite
Other	0

Depth, cm	**Profile description**
0-15A11	Dry;dark brown (10YR3/3); clay; hard dry; friable moist; sticky and plastic wet; moderate and fine sub-angular blocky structure; cracks width20mm; very few fine pores;very few fine calcium carbonate concertion;common medium roots; slightly calcareous; clear smooth boundary.
15-35A12	Dry;dark brown (10YR3/3); clay; hard dry; friable moist; sticky and plastic wet; strong medium blocky and sub-angular blocky structure; cracks width10mm; very few fine pores;very few fine calcium carbonate concertion;few fine roots; slightly calcareous; gradual wavy boundary.
35-55A13	Dry;dark brown (10YR3/3); clay; hard dry; friable moist;slightly sticky and plastic wet;moderate very fine sub-angular blocky structure; distinct pressure faces; few fine calcium carbonate concertion;few fine roots; slightly calcareous; gradual wavy boundary.
55-120AC	Dry;very dark greyish brown (10YR3/2); clay; hard dry; firm moist;slightly sticky and slightly plastic wet;massive structure; distinct pressure faces; common fine calcium carbonate concertion segregates;very few fine roots; slightly calcareous; gradual wavy boundary.
120-200C	Dry;dark brown (10YR3/3); clay; hard dry; firm moist;slightly sticky and slightly plastic wet;massive structure; distinct pressure faces; few fine calcium carbonate segregates;very few fine roots; slightly calcareous.

Profile description No 4

Survey area	Shambat
Profile No.	4
Date	8.4.2011
Author	Moamer-hajhamad
GPS E	448290
GPS N	1730322
Topography	F
Slope, %	0-1%
Site	F
Landform	P
Surface cracks	45mm
Mulch	10mm
Other	0
Micro- relief	0
Termitaria per ha	0
Water erosion	0
Wind erosion	0
Land use	F
Water table, cm	None
Drainage class	M
Parent material	Alluvium deposite
Other	0

Depth, cm	**Profile description**
0-30A11	Dry;dark brown (10YR3/3); clay; hard dry; friable moist; sticky and plastic wet; strong very coarse sub-angular blocky structure; cracks width30mm; very few fine pores;very few fine calcium carbonate concertion;common find and medium roots; moderate calcareous; clear wavy boundary.
30-60A12	Dry;very dark greyish brown (10YR3/2); clay; hard dry; friable moist; sticky and plastic wet; moderate medium and coarse sub-angular blocky structure;distinct pressure faces; cracks width20mm;very few fine pores; few fine calcium carbonate concertion;few find and medium roots; moderate calcareous; clear wavy boundary.
60-100C11	Dry;very dark greyish brown (10YR3/2); clay;very hard dry;very firm moist; sticky and plastic wet;weak find sub-angular blocky structure;distinct pressure faces; cracks width10mm; few fine calcium carbonate concertion;few find roots; moderate calcareous; gradual wavy boundary.
100-170C12	Dry;very dark greyish brown (10YR3/2); clay; hard dry; firm moist; sticky and plastic wet;massive structure;distinct pressure faces;very few fine calcium carbonate concertion;very few find roots; moderate calcareous.

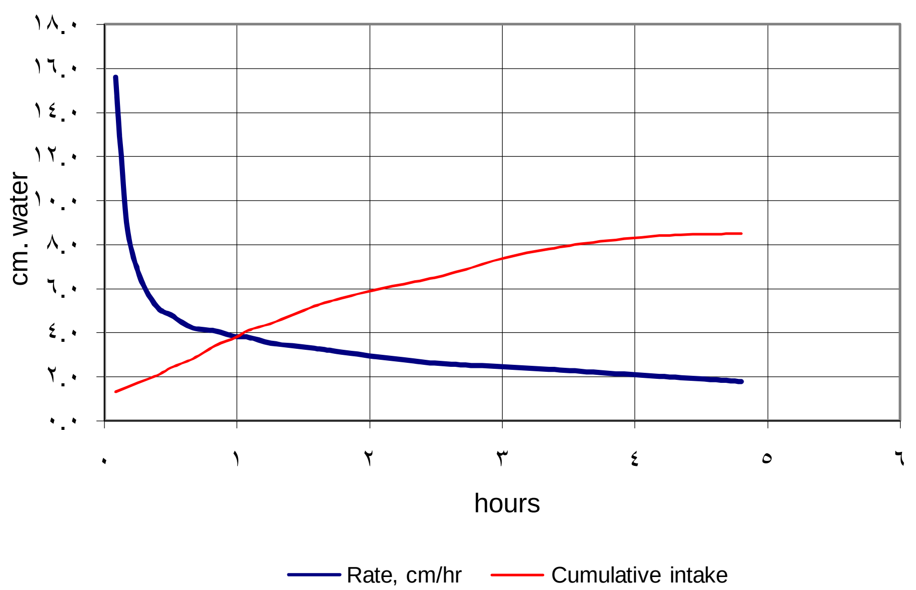
Profile description No 5

Survey area	Shambat
Profile No.	5
Date	8.4.2011
Author	Moamer-hajhamad
GPS E	448187
GPS N	17303143
Topography	F
Slope, %	0-1%
Site	F
Landform	P
Surface cracks	35mm
Mulch	10mm
Other	0
Micro- relief	0
Termitaria per ha	0
Water erosion	0
Wind erosion	1
Land use	MANGO
Water table, cm	None
Drainage class	M
Parent material	Alluvium deposite
Other	0

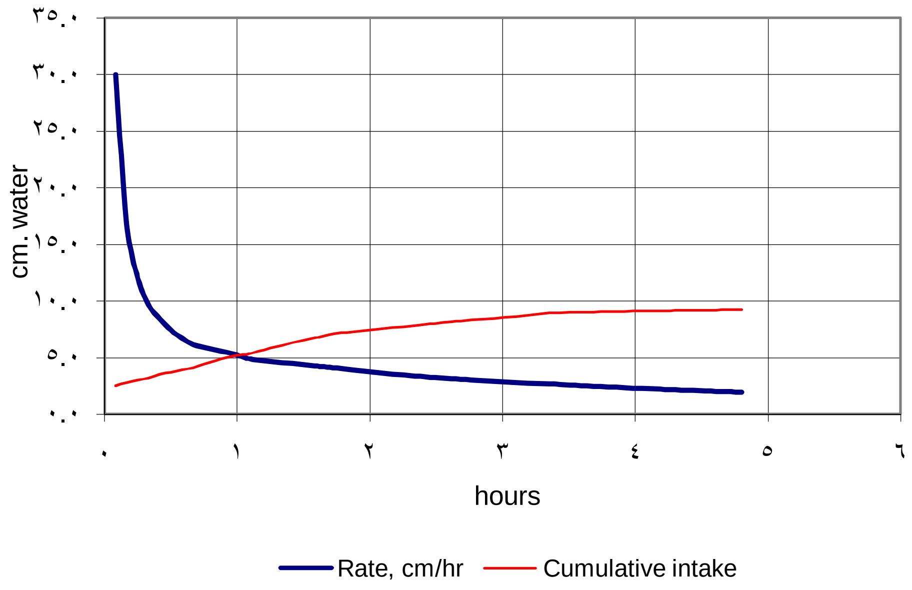
Depth, cm	**Profile description**
0-5A11	Dry;dark brown (10YR3/3); clay;few find gravel coarse fragments;slightly hard dry; friable moist; sticky and plastic wet; weak very find sub-angular blocky structure; cracks width30mm; very few fine pores;very few fine calcium carbonate concertion;few find roots; moderate calcareous; clear smooth boundary.
5-25A12	Dry;dark brown (10YR3/3); clay; hard dry; friable moist; sticky and plastic wet; moderate very find sub-angular blocky structure; cracks width15mm; very few fine pores;very few fine calcium carbonate concertion;very few find roots; moderate calcareous; clear wavy boundary.
25-70A13	Dry;very dark greyish brown (10YR3/2); clay; hard dry; friable moist; sticky and plastic wet; weak very find sub-angular blocky structure;distinct pressure faces; cracks width10mm;very few fine calcium carbonate concertion;very few find roots; moderate calcareous; gradual wavy boundary.
70-130C1	Dry;very dark greyish brown (10YR3/2); clay; hard dry; firm moist; sticky and plastic wet; weak very find sub-angular blocky structure;distinct pressure faces; common fine calcium carbonate concertion and segregates;slightly calcareous; gradual wavy boundary.
130-200C2	Dry; dark brown (10YR3/3);silty clay; hard dry; firm moist;slightly sticky and slightly plastic wet; massive structure;distinct pressure faces; common fine calcium carbonate concertion and segregate;slightly calcareous.

Appendix 2. Infiltration rate

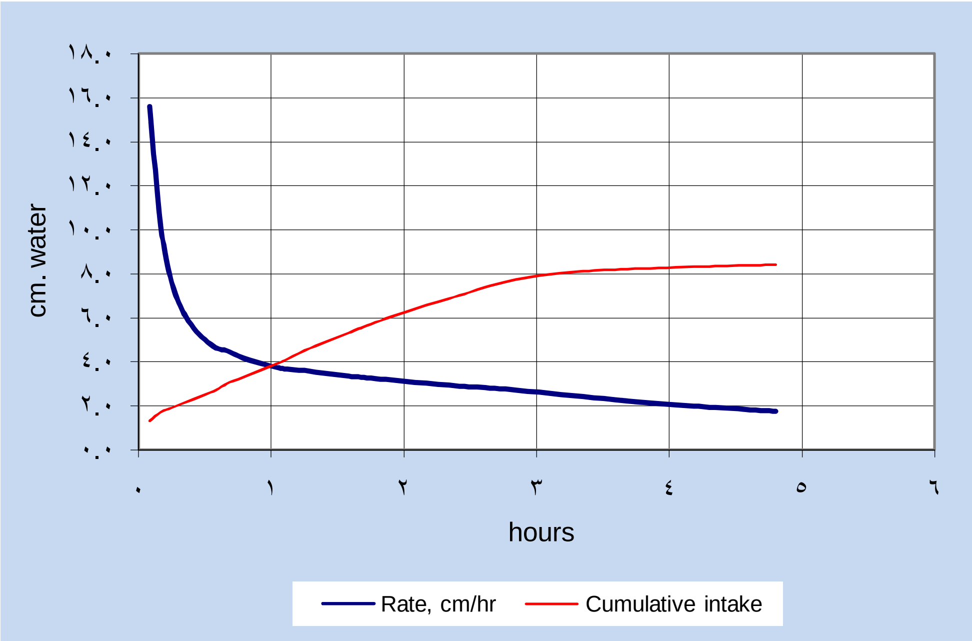
Double-ring infiltrometer test								
shambat								
Profile number:		**p 1**			**Soil Unit:**		**Replicate:**	
Time			***Depth to water***		***Water intake, cm***		***Infiltration***	
interval	***min.***	***hr.***	***cm***		***immediate***	***cumulative***	***cm/hr***	
0	0	0.0	0.0	0.0	0.0	0.0	0.0	
5	5	0.1	1.3	1.3	1.3	1.3	15.6	
5	10	0.2	1.5	1.5	0.2	1.5	9.0	
5	15	0.3	1.7	1.7	0.2	1.7	6.8	
5	20	0.3	1.9	1.9	0.2	1.9	5.7	
5	25	0.4	2.1	2.1	0.2	2.1	5.0	
5	30	0.5	2.4	2.4	0.3	2.4	4.8	
5	35	0.6	2.6	2.6	0.2	2.6	4.5	
5	40	0.7	2.8	2.8	0.2	2.8	4.2	
5	45	0.8	3.1	3.1	0.3	3.1	4.1	
5	50	0.8	3.4	3.4	0.3	3.4	4.1	
5	55	0.9	3.6	3.6	0.2	3.6	3.9	
5	60	1.0	3.8	3.8	0.2	3.8	3.8	
5	65	1.1	4.1	4.1	0.3	4.1	3.8	
10	75	1.3	4.4	4.4	0.3	4.4	3.5	
10	85	1.4	4.8	4.8	0.4	4.8	3.4	
10	95	1.6	5.2	5.2	0.4	5.2	3.3	
10	105	1.8	5.5	5.5	0.3	5.5	3.1	
20	125	2.1	6.0	6.0	0.5	6.0	2.9	
20	145	2.4	6.4	6.4	0.4	6.4	2.6	
16	161	2.7	6.8	6.8	0.4	6.8	2.5	
20	181	3.0	7.4	7.4	0.6	7.4	2.5	
20	201	3.4	7.8	7.8	0.4	7.8	2.3	
20	221	3.7	8.1	8.1	0.3	8.1	2.2	
30	251	4.2	8.4	8.4	0.3	8.4	2.0	I.R :1.8
37	288	4.8	8.5	8.5	0.1	8.5	1.8	Wetting front :41



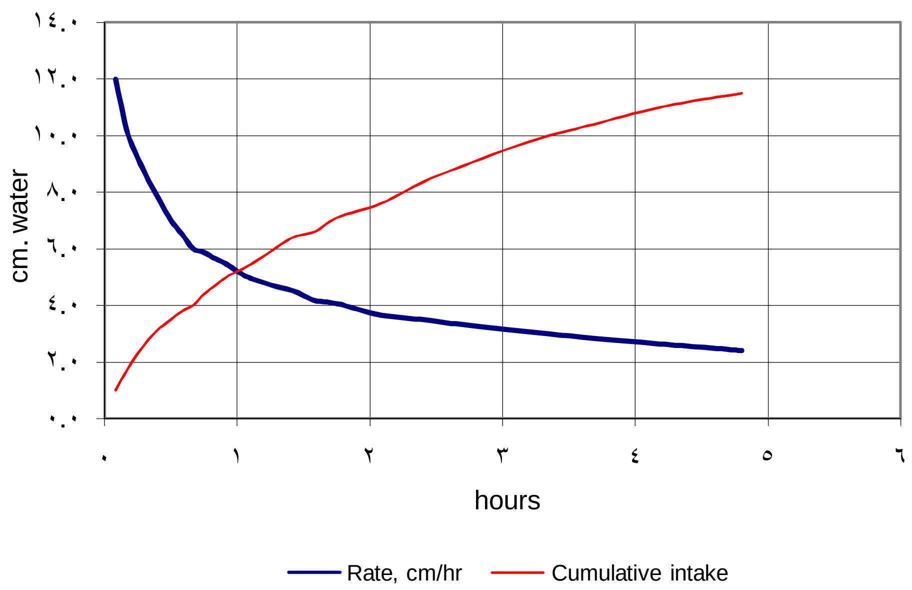
Double-ring infiltrometer test								
Profile number:		**p2**			**Soil Unit:**		**Replicate:**	
Time			***Depth to water***		***Water intake, cm***		***Infiltration***	
interval	***min.***	***hr.***	***cm***		***immediate***	***cumulative***	***cm/hr***	
0	0	0.0	0.0	0.0	0.0	0.0	0.0	
5	5	0.1	2.5	2.5	2.5	2.5	30.0	
5	10	0.2	2.8	2.8	0.3	2.8	16.8	
5	15	0.3	3.0	3.0	0.2	3.0	12.0	
5	20	0.3	3.2	3.2	0.2	3.2	9.6	
5	25	0.4	3.5	3.5	0.3	3.5	8.4	
5	30	0.5	3.7	3.7	0.2	3.7	7.4	
5	35	0.6	3.9	3.9	0.2	3.9	6.7	
5	40	0.7	4.1	4.1	0.2	4.1	6.2	
5	45	0.8	4.4	4.4	0.3	4.4	5.9	
5	50	0.8	4.7	4.7	0.3	4.7	5.6	
5	55	0.9	5.0	5.0	0.3	5.0	5.5	
5	60	1.0	5.2	5.2	0.2	5.2	5.2	
5	65	1.1	5.3	5.3	0.1	5.3	4.9	
10	75	1.3	5.8	5.8	0.5	5.8	4.6	
10	85	1.4	6.3	6.3	0.5	6.3	4.4	
10	95	1.6	6.7	6.7	0.4	6.7	4.2	
10	105	1.8	7.1	7.1	0.4	7.1	4.1	
20	125	2.1	7.5	7.5	0.4	7.5	3.6	
20	145	2.4	7.9	7.9	0.4	7.9	3.3	
16	161	2.7	8.2	8.2	0.3	8.2	3.1	
20	181	3.0	8.5	8.5	0.3	8.5	2.8	
20	201	3.4	8.9	8.9	0.4	8.9	2.7	
20	221	3.7	9.0	9.0	0.1	9.0	2.4	
30	251	4.2	9.1	9.1	0.1	9.1	2.2	I.R :1.9
37	288	4.8	9.2	9.2	0.1	9.2	1.9	Wetting front :43



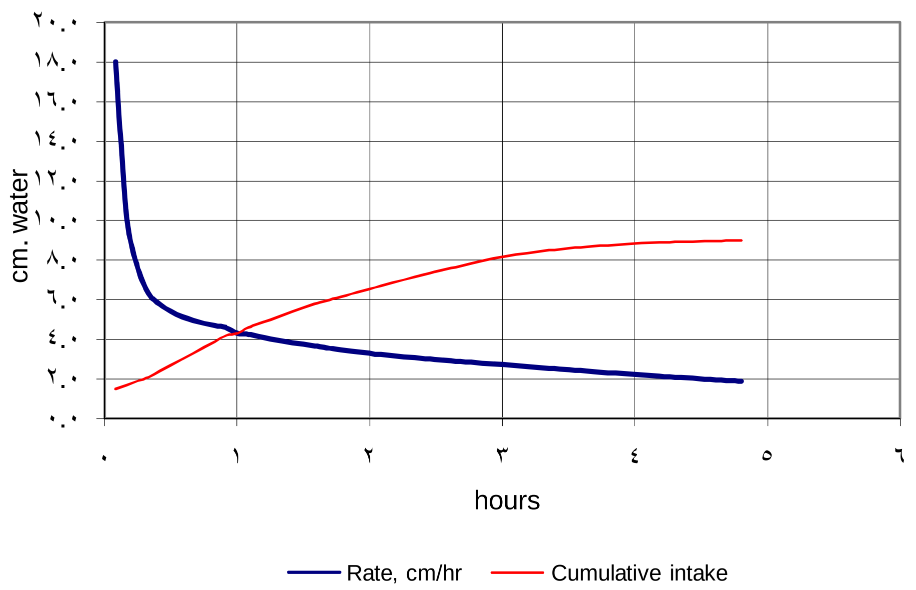
Profile number:	3	AR	Double ring infiltrometer test					
	P3							
Time			*Depth to water*		*Water intake, cm*			
interval	*min.*	*hr.*	*cm*		*immediate*	*cumulative*	*cm/hr*	
0	0	0.0	0.0	0.0	0.0	0.0	0.0	
5	5	0.1	1.3	1.3	1.3	1.3	15.6	
5	10	0.2	1.7	1.7	0.4	1.7	10.2	
5	15	0.3	1.9	1.9	0.2	1.9	7.6	
5	20	0.3	2.1	2.1	0.2	2.1	6.3	
5	25	0.4	2.3	2.3	0.2	2.3	5.5	
5	30	0.5	2.5	2.5	0.2	2.5	5.0	
5	35	0.6	2.7	2.7	0.2	2.7	4.6	
5	40	0.7	3.0	3.0	0.3	3.0	4.5	
5	45	0.8	3.2	3.2	0.2	3.2	4.3	
5	50	0.8	3.4	3.4	0.2	3.4	4.1	
5	55	0.9	3.6	3.6	0.2	3.6	3.9	
5	60	1.0	3.8	3.8	0.2	3.8	3.8	
5	65	1.1	4.0	4.0	0.2	4.0	3.7	
10	75	1.3	4.5	4.5	0.5	4.5	3.6	
10	85	1.4	4.9	4.9	0.4	4.9	3.5	
10	95	1.6	5.3	5.3	0.4	5.3	3.3	
10	105	1.8	5.7	5.7	0.4	5.7	3.3	
20	125	2.1	6.4	6.4	0.7	6.4	3.1	
20	145	2.4	7.0	7.0	0.6	7.0	2.9	
16	161	2.7	7.5	7.5	0.5	7.5	2.8	
20	181	3.0	7.9	7.9	0.4	7.9	2.6	
20	201	3.4	8.1	8.1	0.2	8.1	2.4	
20	221	3.7	8.2	8.2	0.1	8.2	2.2	
30	251	4.2	8.3	8.3	0.1	8.3	2.0	I.R :1.8
37	288	4.8	8.4	8.4	0.1	8.4	1.8	Wetting front :40



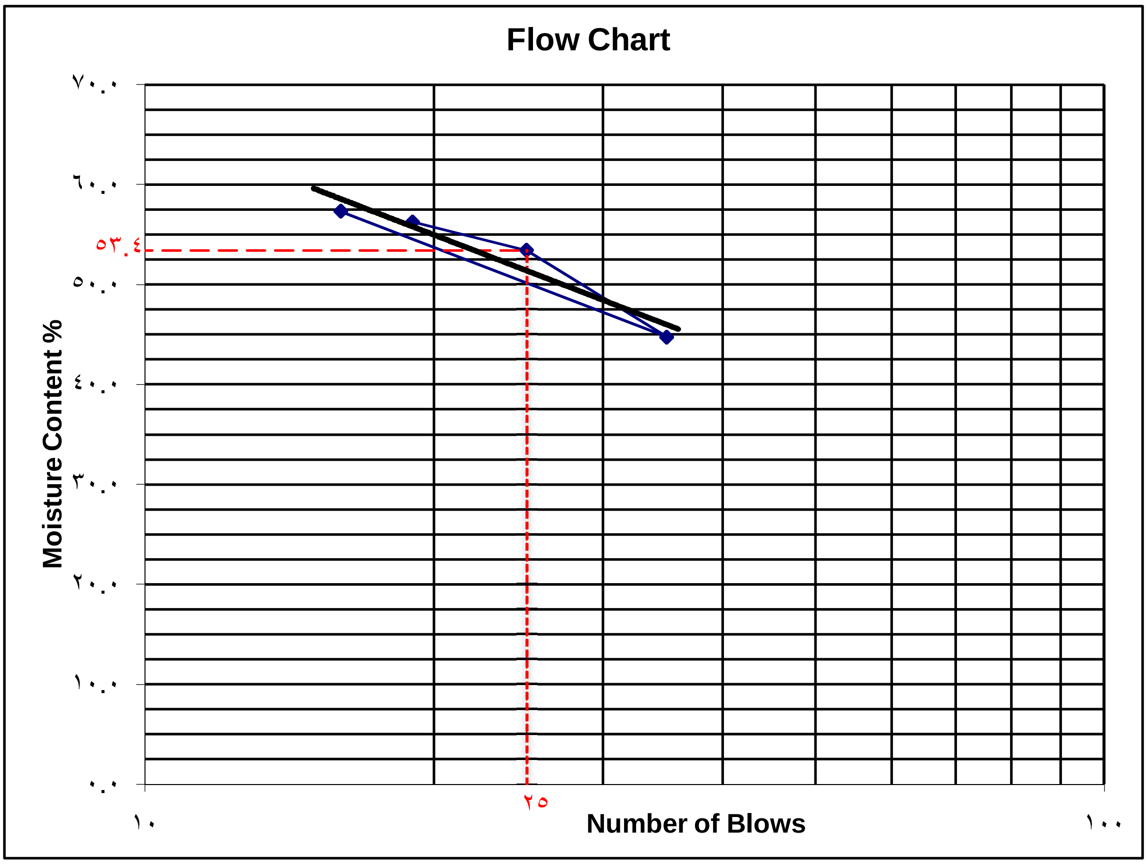
Double-ring infiltrometer test								
Profile number:		**p4**			**Soil Unit:**		**Replicate:**	
Time			***Depth to water***		***Water intake, cm***		***Infiltration***	
interval	***min.***	***hr.***	***cm***		***immediate***	***cumulative***	***cm/hr***	
0	0	0.0	0.0	0.0	0.0	0.0	0.0	
5	5	0.1	1.0	1.0	1.0	1.0	12.0	
5	10	0.2	1.7	1.7	0.7	1.7	10.2	
5	15	0.3	2.3	2.3	0.6	2.3	9.2	
5	20	0.3	2.8	2.8	0.5	2.8	8.4	
5	25	0.4	3.2	3.2	0.4	3.2	7.7	
5	30	0.5	3.5	3.5	0.3	3.5	7.0	
5	35	0.6	3.8	3.8	0.3	3.8	6.5	
5	40	0.7	4.0	4.0	0.2	4.0	6.0	
5	45	0.8	4.4	4.4	0.4	4.4	5.9	
5	50	0.8	4.7	4.7	0.3	4.7	5.6	
5	55	0.9	5.0	5.0	0.3	5.0	5.5	
5	60	1.0	5.2	5.2	0.2	5.2	5.2	
5	65	1.1	5.4	5.4	0.2	5.4	5.0	
10	75	1.3	5.9	5.9	0.5	5.9	4.7	
10	85	1.4	6.4	6.4	0.5	6.4	4.5	
10	95	1.6	6.6	6.6	0.2	6.6	4.2	
10	105	1.8	7.1	7.1	0.5	7.1	4.1	
20	125	2.1	7.6	7.6	0.5	7.6	3.6	
20	145	2.4	8.4	8.4	0.8	8.4	3.5	
16	161	2.7	8.9	8.9	0.5	8.9	3.3	
20	181	3.0	9.5	9.5	0.6	9.5	3.1	
20	201	3.4	10.0	10.0	0.5	10.0	3.0	
20	221	3.7	10.4	10.4	0.4	10.4	2.8	
30	251	4.2	11.0	11.0	0.6	11.0	2.6	I.R :2.4
37	288	4.8	11.5	11.5	0.5	11.5	2.4	Wetting front :44



Double-ring infiltrometer test								
Profile number:		**p5**			**Soil Unit:**		**Replicate:**	
Time			***Depth to water***		***Water intake, cm***		***Infiltration***	
interval	***min.***	***hr.***	***cm***		***immediate***	***cumulative***	***cm/hr***	
0	0	0.0	0.0	0.0	0.0	0.0	0.0	
5	5	0.1	1.5	1.5	1.5	1.5	18.0	
5	10	0.2	1.7	1.7	0.2	1.7	10.2	
5	15	0.3	1.9	1.9	0.2	1.9	7.6	
5	20	0.3	2.1	2.1	0.2	2.1	6.3	
5	25	0.4	2.4	2.4	0.3	2.4	5.8	
5	30	0.5	2.7	2.7	0.3	2.7	5.4	
5	35	0.6	3.0	3.0	0.3	3.0	5.1	
5	40	0.7	3.3	3.3	0.3	3.3	5.0	
5	45	0.8	3.6	3.6	0.3	3.6	4.8	
5	50	0.8	3.9	3.9	0.3	3.9	4.7	
5	55	0.9	4.2	4.2	0.3	4.2	4.6	
5	60	1.0	4.3	4.3	0.1	4.3	4.3	
5	65	1.1	4.6	4.6	0.3	4.6	4.2	
10	75	1.3	5.0	5.0	0.4	5.0	4.0	
10	85	1.4	5.4	5.4	0.4	5.4	3.8	
10	95	1.6	5.8	5.8	0.4	5.8	3.7	
10	105	1.8	6.1	6.1	0.3	6.1	3.5	
20	125	2.1	6.7	6.7	0.6	6.7	3.2	
20	145	2.4	7.3	7.3	0.6	7.3	3.0	
16	161	2.7	7.7	7.7	0.4	7.7	2.9	
20	181	3.0	8.2	8.2	0.5	8.2	2.7	
20	201	3.4	8.5	8.5	0.3	8.5	2.5	
20	221	3.7	8.7	8.7	0.2	8.7	2.4	
30	251	4.2	8.9	8.9	0.2	8.9	2.1	I.R :1.9
37	288	4.8	9.0	9.0	0.1	9.0	1.9	Wetting front :42

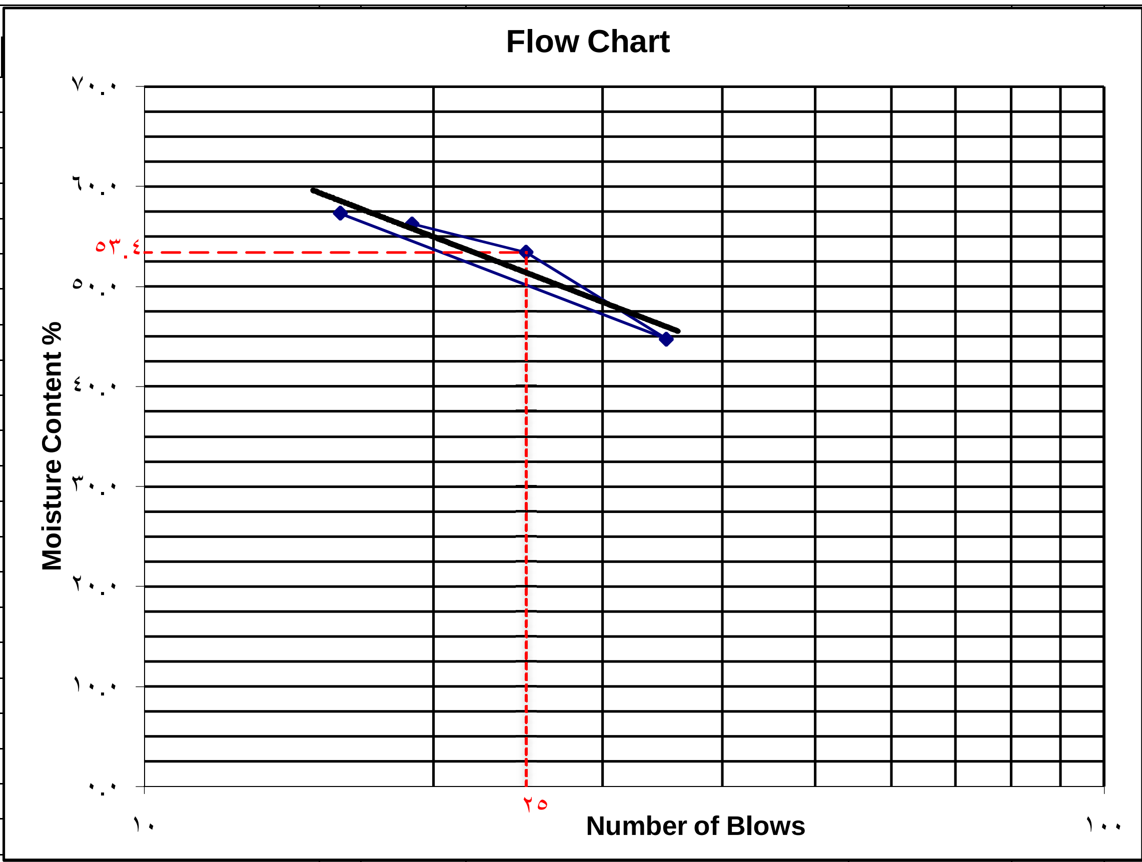


Appendix 3liquid limit and Plastic limit S1A



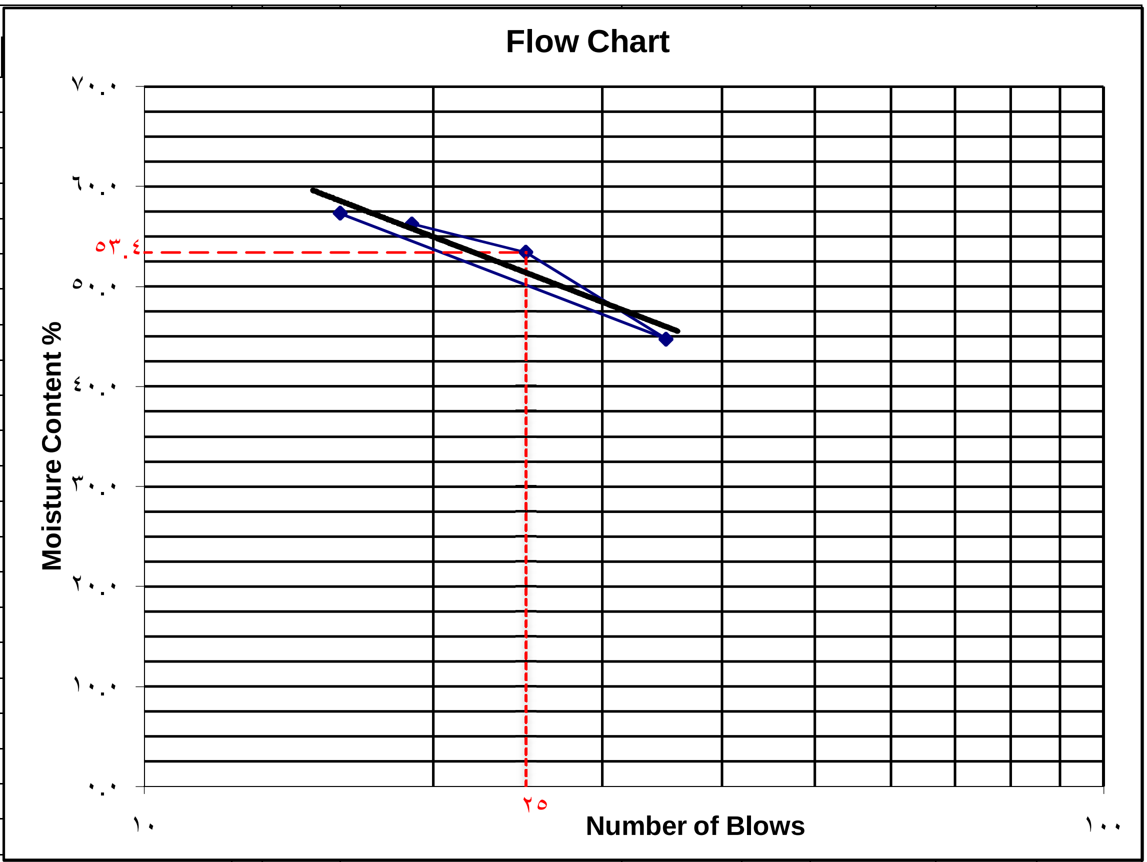
Liquid Limit %	55	Note : = pi*%Passing 200(0.075)
Plastic Limit %	27	PI = 28 %Pass 0.075 = 10
Plasticity Index %	28	pp = 70
S1A		

liquid limit and Plastic limit S1B



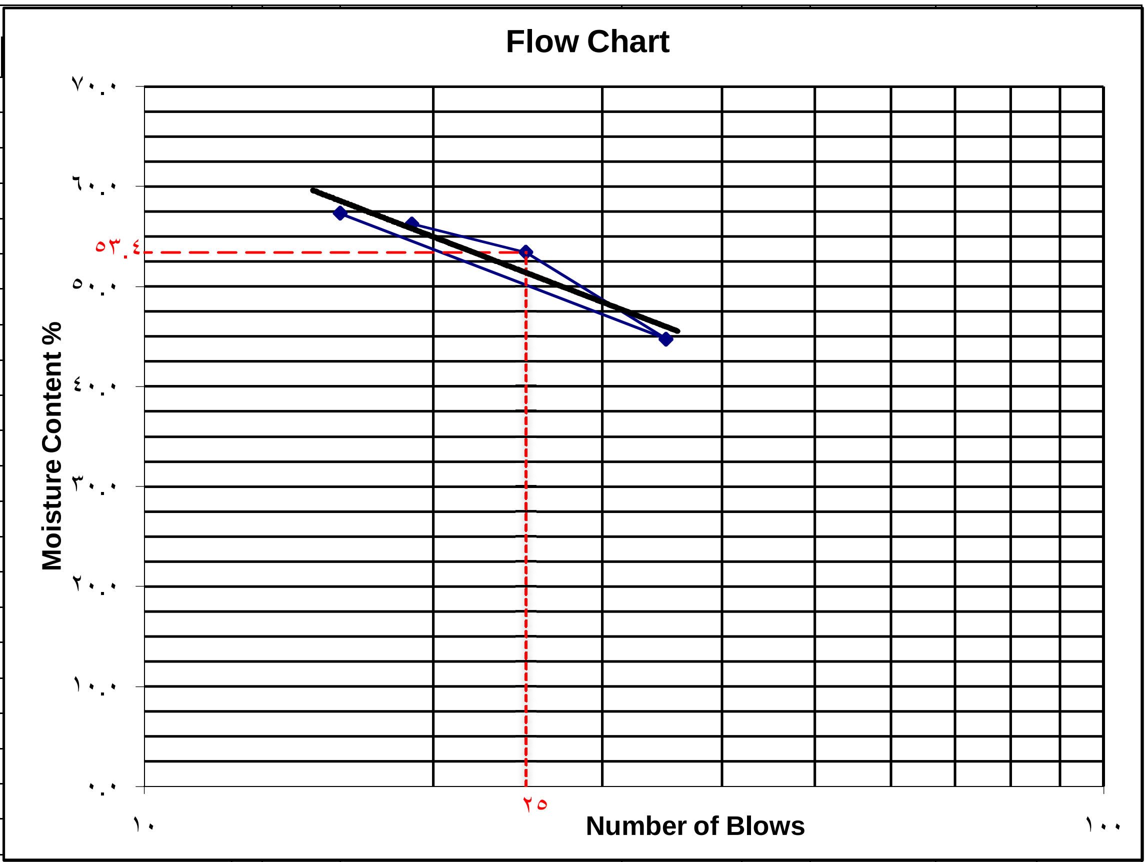
Liquid Limit %	53	Note : = pi*%Passing 200(0.075)		
Plastic Limit %	26	PI =	27	%Pass 0.075 =
Plasticity Index %	27	pp =	70	
S1B				

Liquid limit and Plastic limit S2A



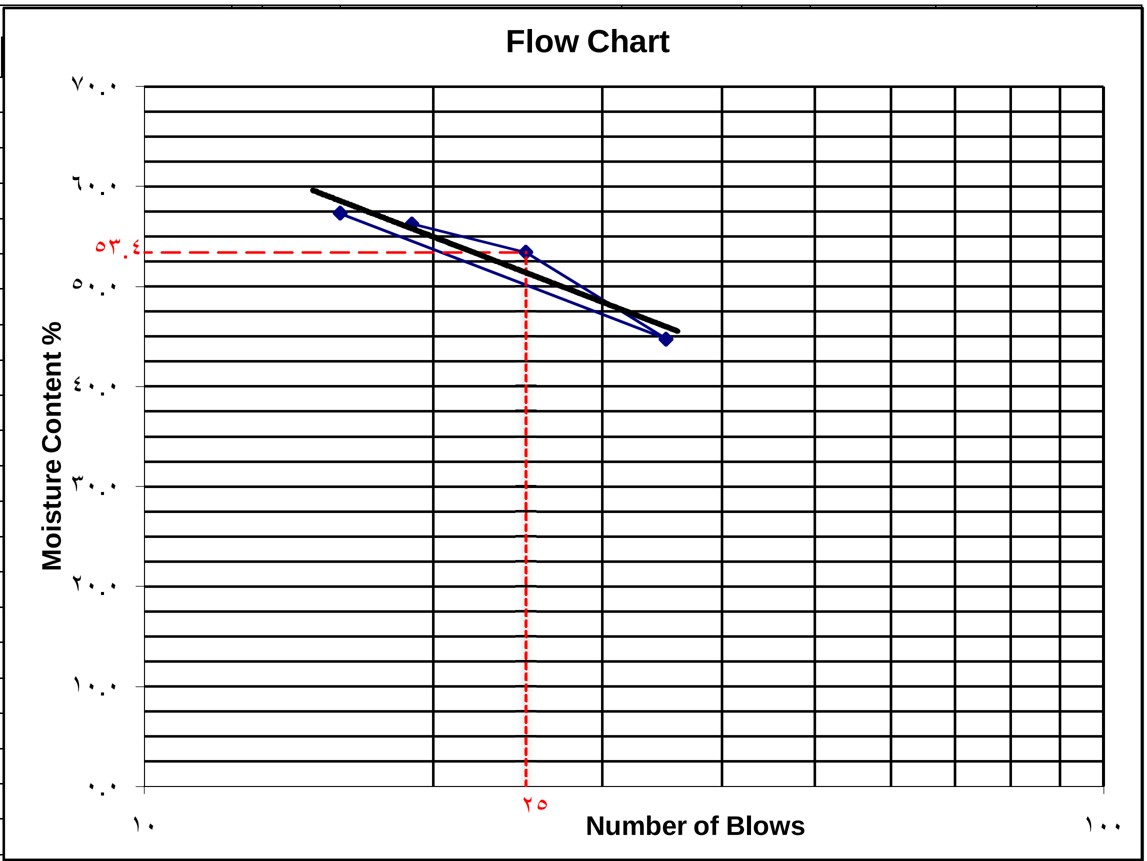
Liquid Limit %	36	Note : = pi*%Passing 200(0.075)				
Plastic Limit %	20	PI =	16	%Pass =	0.075	10
Plasticity Index %	16	pp =	70			
S2A						

liquid limit and Plastic limit S2B



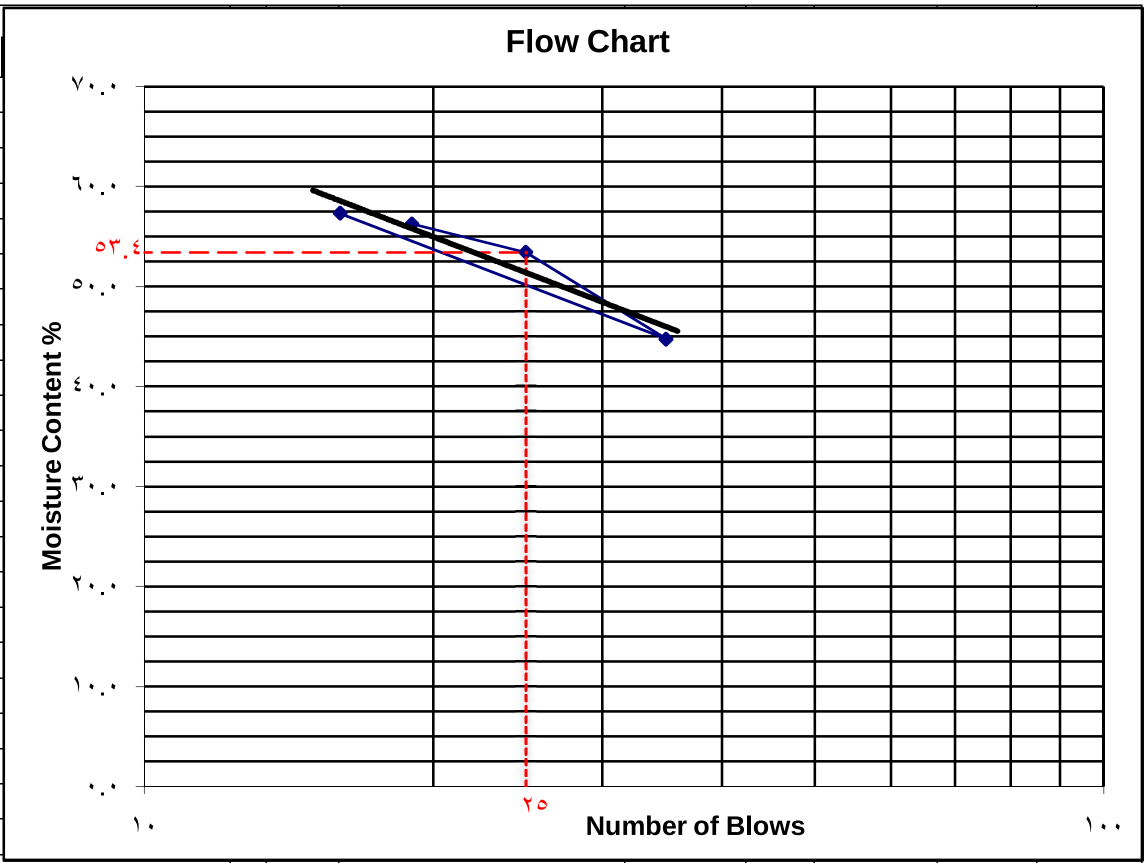
Liquid Limit %	46	Note : = pi*%Passing 200(0.075)				
Plastic Limit %	17	PI =	30	%Pass =	0.075	10
Plasticity Index %	30	pp =	70			
S2B						

liquid limit and Plastic limit S3A



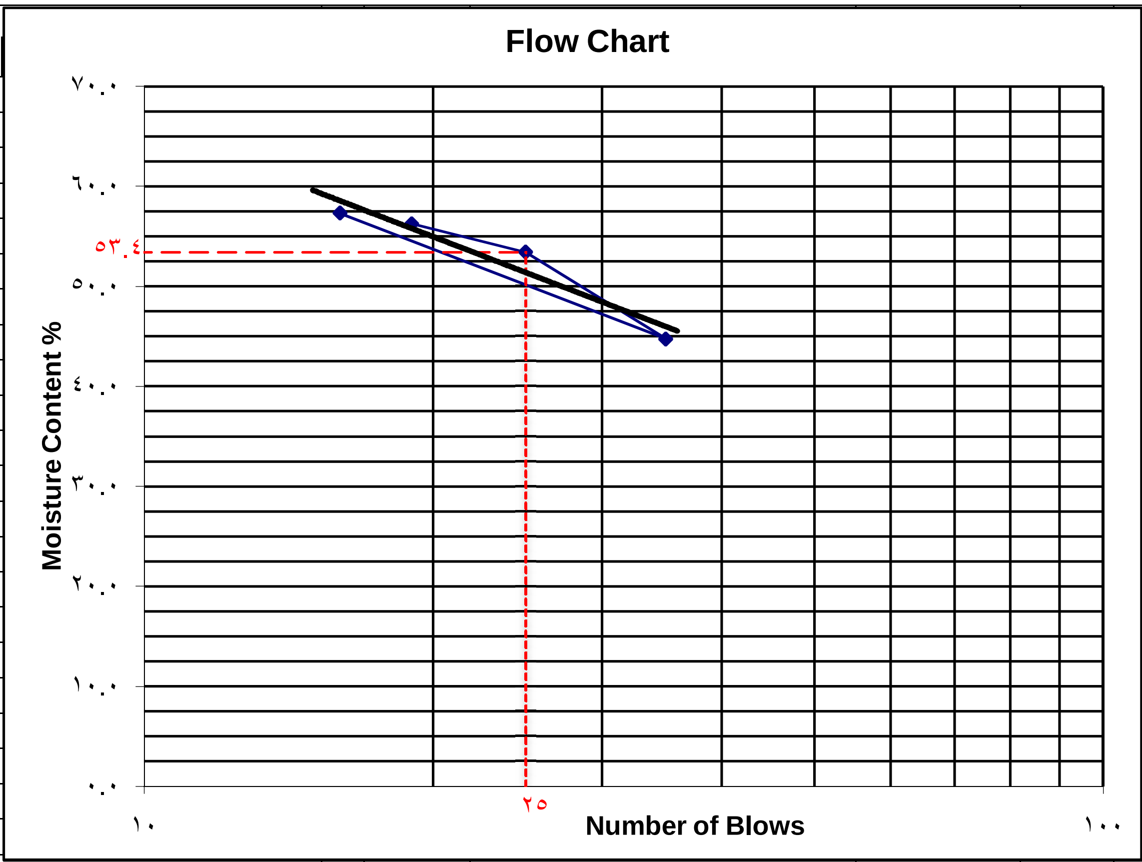
Liquid Limit %	45	Note : = pi*%Passing 200(0.075)				
Plastic Limit %	17	PI =	29	%Pass =	0.075	10
Plasticity Index %	29	pp =	70			
S3A						

liquid limit and Plastic limit S3B



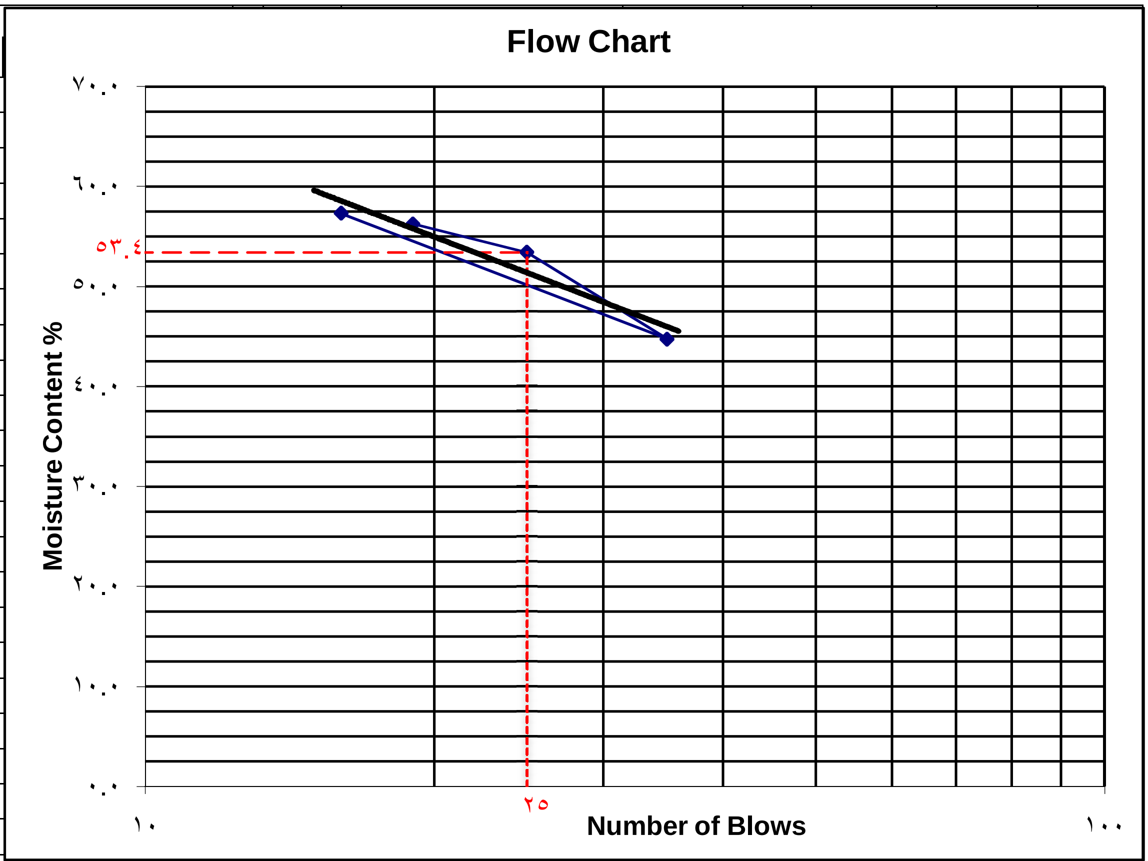
Liquid Limit %	48	Note : = pi*%Passing 200(0.075)				
Plastic Limit %	16	PI =	32	%Pass =	0.075	10
Plasticity Index %	32	pp =	70			
S3B						

liquid limit and Plastic limit S4A



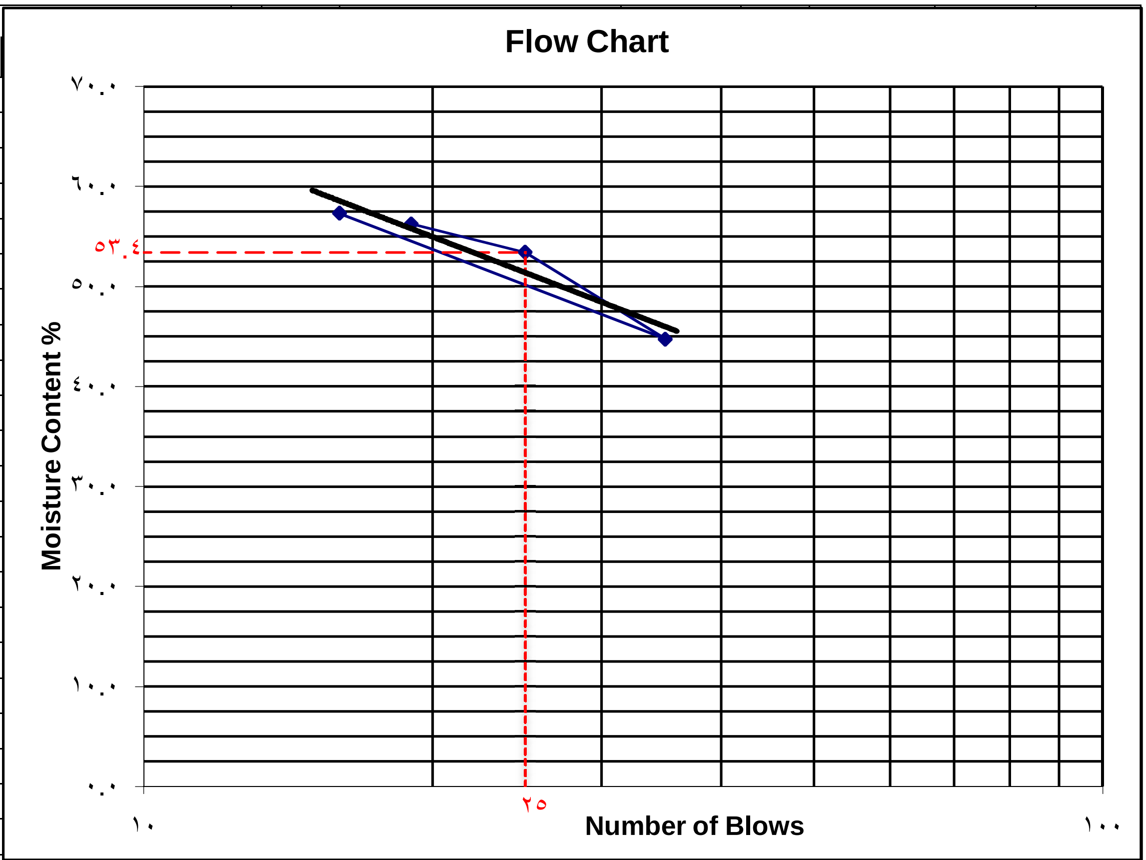
Liquid Limit %		45	Note : = pi*%Passing 200(0.075)		
Plastic Limit %		26	PI =	19	%Pass 0.075
Plasticity Index %		19	pp =	70	
S4A					

liquid limit and Plastic limit S4B



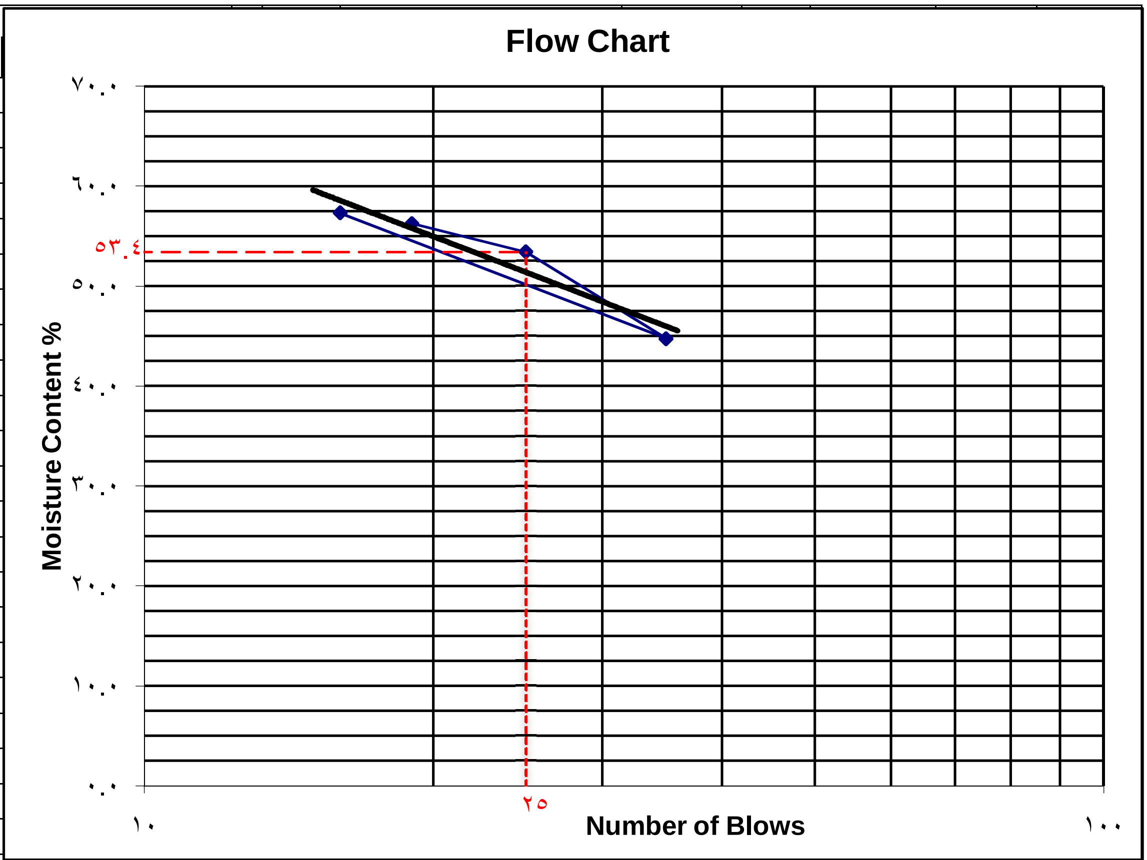
Liquid Limit %	55	Note : = pi*%Passing 200(0.075)				
Plastic Limit %	15	PI =	40	%Pass =	0.075	10
Plasticity Index %	40	pp =	70			
S4B						

liquid limit and Plastic limit S5A



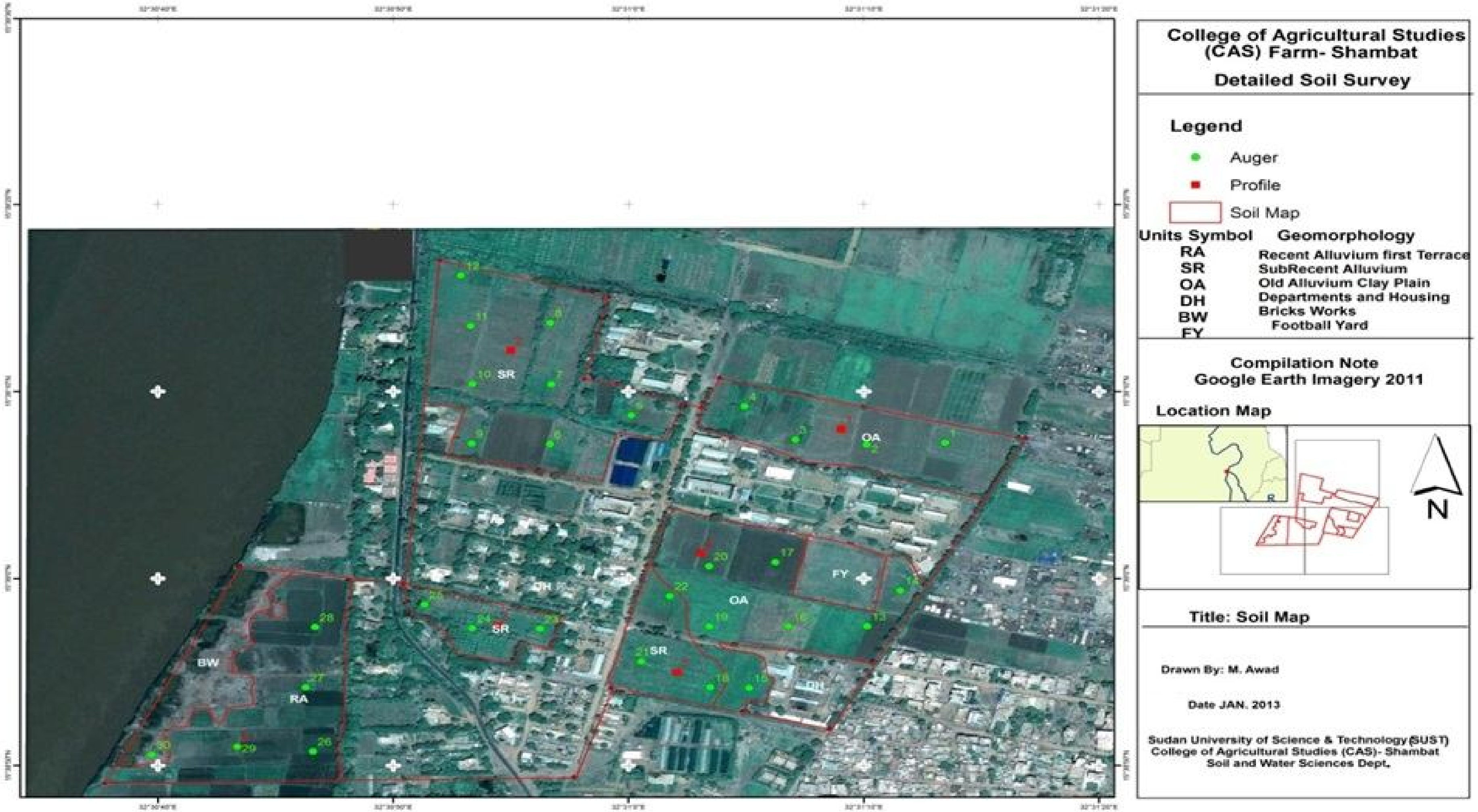
Liquid Limit %	45	Note : = pi*%Passing 200(0.075)					
Plastic Limit %	16	PI =	19	%Pass =	0.075	10
Plasticity Index %	19	pp =	70			
S5A						

liquid limit and Plastic limit S5B



Liquid Limit %	45	Note : = pi*%Passing 200(0.075)				
Plastic Limit %	16	PI =	19	%Pass =	0.075	10
Plasticity Index %	19	pp =	70			
S5B						

Appendix 4. Soil Map Units



Appendix 5 Suitability Map